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CROP PRODUCTION

Cover crops on soil quality and yield of cowpea under no-tillage in the Amazon savanna

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ABSTRACT. Conservation practices such as no-tillage are necessary to maintain, and/or improve agricultural soil quality. However, straw formation and maintenance in tropical regions is a limiting factor to adopting this system. In this sense, this research aimed to study the effect of cover crops on straw formation, soil quality indicators, and cowpea yield under no-tillage in the Amazon savanna. Two experiments were carried out in consecutive years, on a *Latossolo Amarelo*. The treatments consisted of the straw of cover crops in a single (S) and intercrop (I) system, as follows: *Urochloa brizantha* (UB$_{S}$), *Pennisetum glaucum* (PG$_{S}$), *Crotalaria juncea* (CJ$_{S}$), *Canavalia ensiformis* (CE$_{S}$), *Mucuna aterrima* (MA$_{S}$), *U. brizantha* and *C. juncea* (UBCJ$_{I}$), *U. brizantha* and *C. ensiformis* (UBCE$_{I}$), *P. glaucum* and *C. juncea* (PGCJ$_{I}$), *P. glaucum* and *C. ensiformis* (PGCE$_{I}$), and spontaneous vegetation (SV). Cowpea was cultivated after desiccation of the cover crops. Most of the straw favored soil particle aggregation, except for *C. juncea* and SV, which negatively influenced this variable. Basal soil respiration, organic carbon content, potassium, base saturation, geometric mean diameter, macroaggregates, and macroporosity at layer of 0-0.10 m were the most sensitive indicators for improving soil quality in a savanna environment. UB$_{S}$, UBCJ$_{I}$, and UBCE$_{I}$ were superior to the other treatments in improving soil quality. Almost all treatments increased cowpea yield by up to 29%, except for CJ$_{S}$ and SV.

Keywords: soil cover; conservationist system; *Vigna unguiculata*.

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Introduction

Soil quality is defined by the set of attributes that respond to soil changes as a function of agronomic management practices, which can be evaluated indirectly through the selection and evaluation of indicators sensitive to soil changes (Zornoza et al., 2015; Panico, Memoli, Esposito, Maisto, & Marco, 2018).

Generally, the most sensitive indicators to soil changes correspond to biological (basal respiration, microbial biomass, and metabolic quotient), chemical (pH, aluminum, calcium, magnesium, phosphorus, potassium, and organic matter), and physical attributes (soil density, aggregate stability, and soil penetration resistance) (Cardoso et al., 2013; Martins et al., 2019).

These indicators are important to analyze the potential of conservationist management, such as the no-tillage system, which advocates the maintenance of soil cover, crop rotation, and minimum soil disturbance. The success of this system is related to the selection of cover species adapted to each type of soil and climate. Therefore, it is necessary to study and adapt the system in each region, especially where the climate (high temperatures and humidity) makes it difficult to form and maintain straw (Teixeira et al., 2018).

Thus, the use of species that produce more than 6 t ha^{-1} of dry mass on the soil per year (Nunes et al., 2006) and are capable of recycling nutrients is essential (Bertolini et al., 2019). Among plant species with this potential, the following stand out: *Canavalia ensiformis* and *Mucuna aterrima* (Fabaceae); *Pennisetum glaucum* and *Urochloa* spp. (Poaceae) (Pereira et al., 2017; Simon et al., 2019).

Poaceae species are important to maintain the balance of the carbon/nitrogen ratio (C/N) at adequate levels for straw maintenance on the soil. In contrast, Fabaceae species provide higher amounts of nitrogen (N) to the soil. However, the release of nutrients from crop residues must occur in sync with crop demand for maximum N use (Stute & Posner, 1995). In this sense, intercropping between these families can improve the use of beneficial characteristics and minimize the undesirable ones (Bertolini et al., 2019).

Regarding to the no-tillage system, crop rotation practice allows the best use of soil nutrients since the plants have higher root dynamics in soil profile (Singh et al., 2018). In this practice, the use of species with higher economic returns to the farmer is essential, such as corn (*Zea mays* L.) (Stein & Steinmann, 2018), cowpea (*Vigna unguiculata* (L.) Walp), and common bean (*Phaseolus vulgaris* L.), crops that make up the basic diet of the population and have been gaining ground in this system in tropical countries.

In this context, human activities alter soil properties. Therefore, the most effective indicators for monitoring soil quality need to be clarified under the Amazon savanna conditions to make soil use viable, aiming at its conservation, preservation of its resilience, and the increase of crop yield without compromising its sustainability. In this context, this research aimed to study the effect of cover crops on straw formation, soil quality indicators, and cowpea yield under no-tillage in the Amazon savanna.

Material and methods

The study was carried out in the experimental area of the Agricultural Sciences Center of the Federal University of Roraima, Boa Vista, Roraima State, Brazil, on a *Latossolo Amarelo distrófico* (Typic Hapludox, Soil Taxonomy) (Anjos & Schad, 2018). The regional climate, according to the Köppen classification, is Aw, a rainy tropical climate. Monthly data on rainfall, mean temperature, and relative air humidity for the city of Boa Vista, Roraima State, Brazil, during the experiment are shown in Figure 1 (INMET, 2020).

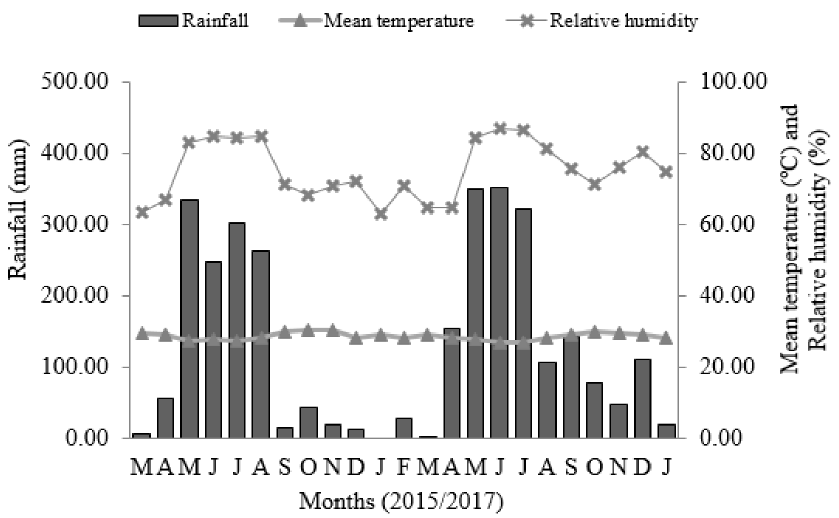

Figure 1. Accumulated monthly rainfall (mm month^{-1}), mean monthly temperature (°C), and relative air humidity (%) recorded during the experiment (2015 to 2017) in Boa Vista, Roraima State, Brazil, 2021. Source: National Institute of Meteorology – INMET, Boa Vista, Roraima State, Brazil (2021).

Area history

In 2013, soil samples were collected from the experimental area, from the 0-0.20 m layer, for chemical and physical analysis, according to Teixeira et al. (2017). The results were: pH (H_2O): 5.2; OM: 5.0 g dm^{-3}; available P: 3.0 mg dm^{-3} and K^+: 0.01 cmol$_c$ dm^{-3} (Mehlich-1); Ca^{2+}: 0.3 cmol$_c$ dm^{-3}; Mg^{2+}: 0.1 cmol$_c$ dm^{-3}; H + Al^{3+}: 2.5 cmol$_c$ dm^{-3}; Al^{3+}: 0.4 cmol$_c$ dm^{-3}; SB: 0.41 cmol$_c$ dm^{-3}; CEC: 2.91 cmol$_c$ dm^{-3}; V: 14.1%; sand: 62.1%; silt: 6.7%; and clay: 31.2%.

Lime requirement was determined based on the soil analysis results. The area was prepared conventionally (one plowing and two harrowing practices), with the incorporation of 1,200 kg ha^{-1} of dolomitic limestone with 90% total neutralizing power in the 0.20 m soil depth. After soil correction, the area was divided into fixed plots of 30 m^2 (5 × 6 m), where cover crops (*Urochloa brizantha*, *Pennisetum glaucum*, *Crotalaria juncea*, *Canavalia ensiformis*, *Mucuna aterrima*, *U. brizantha* and *C. juncea*, *U. brizantha* and *C. ensiformis*, *P. glaucum* and *C. juncea*, and *P. glaucum* and *C. ensiformis*) were grown or the spontaneous vegetation was maintained, representing 10 treatments. Fertilization was carried out in the planting row of the cover crops using 30, 60, and 50 kg ha^{-1} of nitrogen, P_2O_5, and K_2O in the form of urea, single superphosphate, and potassium chloride, respectively.

Cover crops and spontaneous vegetation were desiccated with glyphosate at a dose of 1.4 kg ha^{-1} at 70 days, before cowpea (BRS Guariba) planting. Corn of the Bandeirante variety was grown at the end of the bean cycle. The recommendation for crop fertilization was based on Uchôa et al. (2009) for cowpea and Ribeiro, Guimarães, and Alvarez (1999) for corn. The area was left fallow after this initial sequence of crop rotation and the first no-tillage crop was started in 2015.

Experiment and statistical design

Two experiments were conducted and evaluated between 2015 and 2017 in consecutive cycles, following the principles of the no-tillage system. Crop rotation involved the cover crops, cowpea (main crop), and corn. The agronomic evaluations were not performed in the corn crop, as it was cultivated to rotate with the predecessor species.

The experimental design was randomized blocks, with four replications. Ten treatments were carried out and consisted of the straw of cover crops in a single ($_S$) and intercrop ($_I$) system, as follows: UB_S – *Urochloa brizantha*; PG_S – *Pennisetum glaucum*; CJ_S – *Crotalaria juncea*; CE_S – *Canavalia ensiformis;* MA_S – *Mucuna aterrima*; $UBCJ_I$ – *U. brizantha* and *C. juncea*; $UBCE_I$ – *U. brizantha* and *C. ensiformis*; $PGCJ_I$ – *P. glaucum* and *C. juncea*; $PGCE_I$ – *P. glaucum* and *C. ensiformis*; and SV – spontaneous vegetation (predominance of *Desmodium* spp., *Digitaria* spp., and *Rottboellia exaltata*).

The experimental unit consisted of a 30-m^2 plot (5 × 6 m), where cover crops were grown with an inter-row spacing of 0.5 m. Planting density was 10 kg ha^{-1} (*Urochloa brizantha*), 20 kg ha^{-1} (*Pennisetum glaucum*), 30 kg ha^{-1} (*Crotalaria juncea*), 100 kg ha^{-1} (*Canavalia ensiformis*), and 80 kg ha^{-1} (*Mucuna aterrima*).

During the experiment, complementary irrigation was used by means of conventional sprinkler irrigation, using Fabrimar ECO A320 sprinklers, with a water depth of approximately 8 mm per day, whenever necessary.

Cover crop sowing (first cycle: April/2015 and second cycle: September/2016) was carried out manually in the experimental units at 70 days (*Urochloa brizantha*, *Mucuna aterrima*, and *Canavalia ensiformis*) and 55 days (*Pennisetum glaucum* and *Crotalaria juncea*) before cowpea planting. The desiccation of cover crops and spontaneous vegetation was performed using glyphosate (N-[phosphonomethyl]-glycine) at a dose of 1.4 kg ha^{-1}, applied using a knapsack sprayer.

At the time of desiccation, *Urochloa brizantha* and *Mucuna aterrima* were at the vegetative stage, *Pennisetum glaucum* at grain filling, and *Crotalaria juncea* and *Canavalia ensiformis* at full flowering. After desiccation, biomass samples of the treatments were collected from each experimental unit using a 0.25-m^2 hollow frame. The plant material contained in the area of the frame was oven-dried at 65°C for 72h to obtain the straw dry mass, expressed in kg ha^{-1}.

Cowpea (BRS Guariba) was sown 10 days after desiccation of the cover crops at an inter-row spacing of 0.5 m and ten seeds per linear meter. Subsequently, thinning was carried out and six plants remained per meter. Dry cowpea pods were manually harvested at 60 days after emergence (DAE) and packed in paper bags until they were manually threshed. The grains were weighed (g) and the moisture was measured (%) using a precision balance (0.01 g) and a moisture and impurity analyzer model G650, respectively. The values were transformed into kg ha^{-1} (yield estimate with moisture corrected to 13%).

Then, corn AG 1051 was sown at an inter-row spacing of 0.5 m and 3 plants per linear meter. This rotation sequence was repeated during the two cultivation cycles. The fertilization of cover crops, cowpea, and corn followed the initial fertilization.

Soil sampling

Soil samples were collected in the morning at a layer of 0-0.10 m from each experimental unit at full flowering of the cowpea crop (first and second cycles) for the evaluation of biological and chemical indicators. Four simple soil samples were collected in the inter-rows using an auger, at 10 cm away from the stem of the cowpea plants, to form a composite sample.

Disturbed and undisturbed soil samples were collected from the center of each experimental unit at 0-0.15 and 0.15-0.30 m layers at the end of the cowpea cultivation (only in the second cycle). The disturbed samples were collected in the inter-rows of the cowpea crop using a hoe, while the undisturbed samples were collected using 100-cm^3 volumetric rings. The material was transported to the laboratory and analyses were performed.

Biological indicators of soil quality

Part of the undisturbed soil samples was kept in the shade, during the collection phase, inside a styrofoam box. Then, these samples were passed through a 2-mm mesh sieve in the laboratory at 24°C, packed in plastic bags, and stored in a refrigerator (4°C). The following variables were evaluated: basal soil respiration (BSR) by the method proposed by Jenkinson and Powlson (1976) and microbial biomass carbon (MBC) according to the methodology of Vance, Brookes, and Jenkinson (1987). The metabolic quotient (qCO_2) was calculated using the values obtained from BSR and MBC by dividing the daily mean of the C-CO_2 evolved from the soil by the MBC determined in the soil.

Soil chemical properties

Part of the disturbed soil samples was air-dried and passed through 2-mm mesh sieves for further analysis of: pH (H_2O); soil organic carbon (SOC); available phosphorus (P) and potassium (K^+); exchangeable calcium (Ca^{2+}), magnesium (Mg^{2+}), and aluminum (Al^{3+}); and potential acidity (H + Al), according to Teixeira, Donagemma, Fontana, and Teixeira (2017). The sum of bases (SB) and base saturation (V) were estimated based on these properties.

Soil physical properties

The evaluations of geometric mean diameter (GMD), macroaggregates (MACROAG), microaggregates (MICROAG), and simple particles (SP) were carried out in the clods collected using the hoe, while soil density (Ds), macroporosity (MACROP), microporosity (MICROP), and total porosity (TP) were performed in the undisturbed samples collected using the volumetric rings (Edwards & Bremner, 1967; Salton, Silva, Tomazi, & Hernani, 2012).

Statistical analysis

The data obtained in each year were subjected to individual analysis of variance by the F-test ($p \leq 0.05$). The joint analysis of the data was carried out when the mean squared residual ratio was lower than 7:1. The means of the variables were grouped using the Scott-Knott test ($p \leq 0.05$). The analyses were performed using the statistical program SISVAR version 5.6 (Ferreira, 2014). A multivariate principal components analysis was applied to determine the correlation between treatments and the analyzed variables using the Infostat statistical package (Di-Rienzo et al., 2008).

Results and discussion

Biological indicators of soil quality were affected by cover crops and crop cycles. BSR was higher in the soil cultivated with UB_S, PG_S, CE_S, and $PGCE_I$, regardless of the cycle, and higher in the first cycle, regardless of the cover crop (Table 1). This result may be related to climate factors (Figure 1) during the experimental time, as the first cycle presented an imbalance relative to qCO_2 although it promoted a higher BSR value. According to Cattelan and Vidor (1990), this variable can be influenced by factors such as humidity, temperature, and soil nutrient availability.

UB_S, CJs, and the intercrop systems $UBCJ_I$, $UBCE_I$, and $PGCJ_I$ were grouped with the highest means of MBC in the first cycle, while CE_S, MA_S, $UBCE_I$, and $PGCE_I$ were the cover crops that most favored MBC in the second cycle (Table 1). Moreover, the second cycle promoted the highest MBC values, except for UB_S, CJ_S, and SV, which showed cultivation cycles similar to each other.

Table 1. Basal soil respiration (BSR), soil microbial biomass carbon (MBC), and soil metabolic quotient (qCO_2) as a function of different cover crops and crop cycles on a *Latossolo Amarelo* of the Amazon savanna, Boa Vista, Roraima State, Brazil, 2017.

CC	BSR (mg C-CO_2 kg^{-1}soil h^{-1})		*M*	MBC (mg C kg^{-1}soil)		*M*	qCO_2 (mg C-CO_2 g^{-1} MBC h^{-1})		*M*
	1st cycle	2nd cycle		1st cycle	2nd cycle		1st cycle	2nd cycle	
UB_S	3.10	2.25	2.67 a	63.74 Aa	72.96 Ab	68.35	0.05 Ab	0.03 Ba	0.04
PG_S	2.69	2.35	2.52 a	43.90 Bb	68.21 Ab	56.05	0.06 Aa	0.04 Ba	0.05
CJ_S	2.62	1.97	2.29 b	62.83 Aa	76.79 Ab	69.81	0.04 Ab	0.03 Ba	0.03
CE_S	2.84	2.08	2.46 a	41.46 Bb	89.14 Aa	65.30	0.07 Aa	0.02 Ba	0.05
MA_S	2.45	2.14	2.29 b	48.83 Bb	89.73 Aa	69.28	0.05 Ab	0.04 Ba	0.04
$UBCJ_I$	2.73	2.03	2.38 b	53.88 Ba	66.79 Ab	60.34	0.05 Ab	0.03 Ba	0.04
$UBCE_I$	2.60	2.03	2.31 b	58.22 Ba	85.72 Aa	71.97	0.05 Ab	0.02 Ba	0.04
$PGCJ_I$	2.65	2.12	2.39 b	55.87 Ba	68.87 Ab	62.37	0.05 Ab	0.03 Ba	0.04
$PGCE_I$	2.95	2.16	2.56 a	43.86 Bb	84.48 Aa	64.17	0.07 Aa	0.03 Ba	0.05
SV	2.41	1.77	2.09 b	48.65 Ab	55.89 Ab	52.27	0.05 Ab	0.03 Ba	0.04
M	2.70 A	2.09 B		52.12	75.86		0.05	0.03	

Means followed by the same uppercase letter in the row and lowercase letter in the column belong to the same cluster by the Scott-Knott test at a 5% probability. *m* = mean; CC = cover crops; $_S$ = single system; UB_S = *Urochloa brizantha*; PG_S = *Pennisetum glaucum*; CJ_S = *Crotalaria juncea*; CE_S = *Canavalia ensiformis*; MA_S = *Mucuna aterrima*; $_I$ = intercrop system; $UBCJ_I$ = *U. brizantha* and *C. juncea*; $UBCE_I$ = *U. brizantha* and *C. ensiformis*; $PGCJ_I$ = *P. glaucum* and *C. juncea*; $PGCE_I$ = *P. glaucum* and *C. ensiformis*; SV = spontaneous vegetation.

This result may be related to the low increase in dry mass that these plants promoted between crop cycles (Table 5). On the other hand, the increase in MBC is related to soil organic carbon accumulation promoted in the second crop cycle (Table 2). According to Melo, Silva, Evald, and Rocha (2017), well-managed crops quantitatively improve the soil microbial community, which contributes to the highest SOM values.

MBC is a sensitive indicator for monitoring human influences related to the soil. Studies have indicated good responses of this attribute on a dystrophic Red Latosol with *Pennisetum glaucum*, *Urochloa brizantha*, *Raphanus sativus* L., *Crambe abyssinica* Hochst, and *Mucuna aterrima* (Simon et al., 2019; Duarte et al., 2014).

The highest qCO_2 values in the first cycle were observed for UB_S, CJ_S, PG_S, $UBCJ_I$, $UBCE_I$, $PGCJ_I$, and SV. In the second cycle, qCO_2 did not differ between cover crops (Table 1). According to Saviozzi, Bufalino, Levi-Minzi, and Riffald (2002), this variable is an indicator that estimates the biological activity and substrate quality through the efficiency of the microbial biomass in using the available carbon for biosynthesis.

No effect of cover crops on soil pH was observed. However, the crop cycles influenced soil acidification, with more acidic pH in the second cycle (Table 2).

Table 2. Soil pH (H_2O) and contents of organic carbon, phosphorus, potassium, calcium, and magnesium as a function of different cover crops and crop cycles on a *Latossolo Amarelo* of the Amazon savanna, Boa Vista, Roraima State, Brazil, 2017.

CC	pH (H_2O)		*m*	Organic carbon (g kg^{-1})		*m*	Phosphorus (mg dm^{-3})		*m*
	1st cycle	2nd cycle		1st cycle	2nd cycle		1st cycle	2nd cycle	
UB_S	5.46	5.26	5.36	5.22 Ba	6.53 Aa	5.88	16.17	26.48	21.33 c
PG_S	5.48	5.35	5.41	4.06 Ba	5.42 Ab	4.74	21.67	31.14	26.40 b
CJ_S	5.27	5.11	5.19	4.64 Aa	5.57 Ab	5.10	23.00	24.89	23.94 c
CE_S	5.33	5.08	5.20	4.77 Aa	4.93 Ab	4.85	23.50	35.12	29.31 b
MA_S	5.38	5.09	5.24	4.06 Ba	5.23 Ab	4.65	15.00	18.63	16.82 c
$UBCJ_I$	5.49	5.32	5.40	4.64 Aa	4.67 Ab	4.66	18.83	25.55	22.19 c
$UBCE_I$	5.47	5.35	5.41	4.06 Ba	6.43 Aa	5.25	19.25	27.83	23.54 c
$PGCJ_I$	5.53	5.25	5.39	4.39 Aa	4.93 Ab	4.66	22.50	26.09	24.29 c
$PGCE_I$	5.49	5.26	5.37	4.83 Aa	5.60 Ab	5.21	24.00	33.09	28.55 b
SV	5.60	5.33	5.46	4.35 Aa	4.85 Ab	4.60	40.54	41.08	40.81 a
M	5.45 A	5.24 B		4.50	5.42		22.45 B	28.9 A	
CC	Potassium (mg dm^{-3})		*M*	Calcium ($cmol_c$ dm^{-3})		*m*	Magnesium ($cmol_c$ dm^{-3})		*m*
	1st cycle	2nd cycle		1st cycle	2nd cycle		1st cycle	2nd cycle	
UB_S	81.90	91.88	86.89 a	1.06	0.97	1.01 a	0.59	0.55	0.57 a
PG_S	58.40	79.44	68.92 c	1.03	0.93	0.98 a	0.54	0.52	0.53 a
CJ_S	72.80	87.50	80.15 a	1.05	0.95	1.00 a	0.60	0.56	0.58 a
CE_S	71.30	84.83	78.07 b	1.05	0.90	0.97 a	0.49	0.38	0.43 b
MA_S	58.01	69.50	63.76 c	0.98	0.92	0.95 a	0.45	0.39	0.42 b
$UBCJ_I$	80.60	86.71	83.65 a	0.95	0.88	0.92 b	0.50	0.47	0.48 b
$UBCE_I$	74.91	89.75	82.33 a	0.93	0.89	0.91 b	0.53	0.42	0.47 b
$PGCJ_I$	65.08	85.00	75.04 b	0.86	0.89	0.87 b	0.50	0.45	0.48 b
$PGCE_I$	67.51	81.67	74.59 b	0.88	0.82	0.85 b	0.51	0.44	0.48 b
SV	57.53	76.58	67.54 c	1.00	0.98	0.99 a	0.58	0.54	0.56 a
M	68.80 B	83.29 A		0.98 A	0.91 B		0.53 A	0.47 B	

Means followed by the same uppercase letter in the row and lowercase letter in the column belong to the same cluster by the Scott-Knott test at a 5% probability. *m* = mean; CC = cover crops; $_S$ = single system; UB_S = *Urochloa brizantha*; PG_S = *Pennisetum glaucum*; CJ_S = *Crotalaria juncea*; CE_S = *Canavalia ensiformis*; MA_S = *Mucuna aterrima*; $_I$ = intercrop system; $UBCJ_I$ = *U. brizantha* and *C. juncea*; $UBCE_I$ = *U. brizantha* and *C. ensiformis*; $PGCJ_I$ = *P. glaucum* and *C. juncea*; $PGCE_I$ = *P. glaucum* and *C. ensiformis*; SV = spontaneous vegetation.

This result was already expected since the crops extract soil bases. It may also be associated with nitrogen fertilization carried out in both cultivation years and the release of exudates from the roots of cover crops, as reported by Maluf, Soares, Silva, Neves, and Oliveira Silva (2015), who identified a reduction in soil pH over time due to the decomposition of plant residues, especially in soil under the influence of *Urochloa* and *Stylosanthes*.

SOC (Table 2) showed no difference between cover crops in the first cycle. The straws of UB_S and $UBCE_I$ stood out in the second cycle with the best results. An increase in carbon was observed in the second cycle for UB_S, PG_S, MA_S, and $UBCE_I$ compared to the first cycle. Evald et al. (2021) observed SOC sensitivity on soil management and its impact on soil quality.

Phosphorus (P) concentration in the soil was affected by cover crops and crop cycles, being higher when the soil was cultivated under SV, followed by PG_S, CE_S, and $PGCE_I$ (Table 2). Moreover, the content of this element was higher in the second cycle, regardless of the cover crop. Spontaneous vegetation could not immobilize mineral P, transforming it into organic P. Therefore, it remained in the form of available P, unlike the other crops, which presented higher straw and immobilized more P. This fact becomes important, as it stimulates microbial activity by increasing phosphatase activity (Fialho et al., 2020).

Thus, UB_S, CJ_S, MA_S, and the intercrops $UBCJ_I$, $UBCE_I$, and $PGCJ_I$ possibly extracted more P from the system, being retained by the straw for a longer time, thus showing low cycling and, consequently, low concentration in the soil.

An isolated effect of the analyzed factors was observed for potassium (K), in which the cover crops UB_S, CJ_S, and the intercrops $UBCJ_I$ and $UBCE_I$ were those that most contributed to the cycling of K to the soil (Table 2). The second cycle provided an increase in soil K contents. This result can be associated with the nutrient cycling performed by cover crops and the fertilization in the second cycle since K is a mobile element in the soil and is very susceptible to leaching. According to Freitas et al. (2019), the cultivation of cover crops is an important strategy to reduce K losses by leaching and erosion in the soil, as cover crops are efficient in extracting and cycling this nutrient to the soil.

Cover crops and crop cycles alone influenced the calcium (Ca) content in the soil (Table 2). Cover crops grown under simple cultivation and the spontaneous vegetation were grouped with the best results and the first cycle presented the best mean. The lower Ca content in the second cycle may have been caused by its immobilization in the soil microbial biomass, following the stoichiometric relationship between carbon and nutrients in the organic compost and the nutritional requirements of soil-decomposing microorganisms or the very need for extraction of this nutrient by the crop (Sinsabaugh et al., 2008).

As observed for Ca, magnesium (Mg) and the sum of bases (SB) also presented an isolated effect for cover crops and crop cycles. The cover crops that stood out positively for both variables were UB_S, PG_S, CJ_S, and SV, with the first cycle being superior compared to the second crop cycle (Table 3).

Table 3. Sum of base (SB), aluminum (Al), potential acidity (H + Al), and base saturation (V) as a function of different cover crops and crop cycles on a *Latossolo Amarelo* of the Amazon savanna, Boa Vista, Roraima State, Brazil, 2017.

	SB (cmol$_c$ dm^{-3})			Al (cmol$_c$ dm^{-3})			H + Al (cmol$_c$ dm^{-3})			V (%)		
CC	1st cycle	2nd cycle	*m*	1st cycle	2nd cycle	*m*	1st cycle	2nd cycle	*m*	1st cycle	2nd cycle	*m*
UB_S	1.86	1.75	1.80 a	0.04	0.10	0.07	2.2	2.7	2.4	46.5	40.1	43.3
PG_S	1.71	1.65	1.68 a	0.03	0.03	0.03	2.2	2.5	2.4	44.1	39.4	41.8
CJ_S	1.85	1.74	1.79 a	0.09	0.14	0.12	2.5	2.9	2.7	42.9	37.7	40.3
CE_S	1.71	1.49	1.60 b	0.09	0.11	0.10	2.5	2.7	2.6	41.5	35.9	38.7
MA_S	1.57	1.49	1.53 b	0.09	0.11	0.10	2.5	2.2	2.3	38.8	40.9	39.8
$UBCJ_I$	1.66	1.57	1.62 b	0.01	0.06	0.04	2.2	2.4	2.3	42.9	39.9	41.4
$UBCE_I$	1.65	1.53	1.59 b	0.03	0.07	0.05	2.2	2.5	2.3	43.4	37.8	40.6
$PGCJ_I$	1.52	1.55	1.54 b	0.01	0.09	0.05	2.2	2.6	2.4	41.3	38.6	39.9
$PGCE_I$	1.56	1.47	1.52 b	0.01	0.11	0.06	2.2	2.6	2.4	41.8	35.8	38.8
SV	1.72	1.71	1.72 a	0.00	0.08	0.04	2.1	2.8	2.5	46.1	37.3	41.7
m	1.68 A	1.60 B		0.04 B	0.09 A		2.3 B	2.6 A		42.9A	38.4B	

Means followed by the same uppercase letter in the row and lowercase letter in the column belong to the same cluster by the Scott-Knott test at a 5% probability. *m* = mean; CC = cover crops; $_S$ = single system; UB_S = *Urochloa brizantha*; PG_S = *Pennisetum glaucum*; CJ_S = *Crotalaria juncea*; CE_S = *Canavalia ensiformis*; MA_S = *Mucuna aterrima*; $_I$ = intercrop system; $UBCJ_I$ = *U. brizantha* and *C. juncea*; $UBCE_I$ = *U. brizantha* and *C. ensiformis*; $PGCJ_I$ = *P. glaucum* and *C. juncea*; $PGCE_I$ = *P. glaucum* and *C. ensiformis*; SV = spontaneous vegetation.

Aluminum (Al), potential acidity (H + Al), and base saturation showed an isolated effect for cover crops and crop cycles. These variables presented no difference between cover crops. However, the second cycle was superior to the previous cycle, except for base saturation (Table 3).

These results are similar to those obtained by Silva et al. (2017), who also observed a reduction in the contents of Ca, Mg, H + Al, SB, total CEC after two years of cultivation with cover crops in succession with the common bean 'Perola'.

Regarding soil physical properties, cover plants did not influence soil density (1.61 and 1.59 g dm^{-3}), macroporosity (26.25 and 25.76%), and total porosity (40.83 and 41.76%) in the evaluated layers, respectively. However, an isolated effect was verified for microporosity, with values of 14.57 and 16.00% for the studied layers, respectively. Likewise, Pessotto et al. (2016) observed the effect of cover crops on the microporosity in the 0-5 cm layer. However, no effect of the same plants was observed on soil density, demonstrating the impossibility of differentiating the most effective species in improving this property in the short term.

Table 4 shows a higher proportion of larger aggregate classes in the first layer for cover crops effect within layer levels when the soil was cultivated with UB_S, CJ_S, CE_S, MA_S, and the intercrops $UBCJ_I$ and $PGCJ_I$. In contrast, the second layer showed an improvement in this soil property in the cultivation of CE_S, MA_S, and the intercrops $UBCJ_I$ and $PGCE_I$. An improvement in the geometric mean diameter was observed in the 0.15-0.30 m layer compared to the other layer when the soil was cultivated with the intercrops $UBCE_I$ and $PGCE_I$.

Table 4. Geometric mean diameter, macroaggregates, microaggregates, and simple particles evaluated in two layers of a *Latossolo Amarelo* as a function of different cover crops and crop cycles in the Amazon savanna, Boa Vista, Roraima State, Brazil, 2017.

CC	Geometric mean diameter (mm)		Macroaggregates (%)		Microaggregates (%)		Simple particles (%)	
	0-0.15 m	0.15-0.30 m	0-0.15 m	0.15-0.30 m	0-0.15 m	0.15-0.30 m	0-0.15 m	0.15-0.30 m
UB_S	1.79 Aa	1.56 Ab	85.84 Ab	83.89 Ab	12.53 Aa	14.69 Aa	1.63 Aa	1.42 Aa
PG_S	1.48 Ab	1.42 Ab	82.75 Ab	79.19 Ab	15.66 Aa	18.81 Aa	1.60 Aa	2.00 Aa
CJ_S	2.14 Aa	1.04 Bb	90.57 Aa	78.43 Bb	8.09 Bb	19.69 Aa	1.34 Ba	1.88 Aa
CE_S	2.42 Aa	1.77 Ba	90.73 Aa	88.27 Aa	8.39 Ab	10.70 Ab	0.88 Aa	1.02 Aa
MA_S	2.21 Aa	2.08 Aa	89.60 Aa	89.23 Aa	9.26 Ab	9.67 Ab	1.14 Aa	1.10 Aa
$UBCJ_I$	2.49 Aa	1.81 Ba	89.83 Aa	86.36 Aa	8.99 Ab	12.29 Ab	1.17 Aa	1.35 Aa
$UBCE_I$	1.11 Bb	1.64 Ab	79.62 Bb	84.97 Aa	19.08 Aa	13.71 Bb	1.30 Aa	1.32 Aa
$PGCJ_I$	1.96 Aa	1.56 Ab	84.64 Ab	82.36 Ab	13.62 Aa	15.29 Aa	1.74 Ba	2.36 Aa
$PGCE_I$	1.48 Bb	2.20 Aa	82.10 Bb	87.90 Aa	15.65 Aa	10.12 Bb	2.25 Aa	1.98 Aa
SV	1.13 Ab	1.43 Ab	81.61 Ab	83.63 Ab	16.57 Aa	15.30 Aa	1.82 Aa	1.07 Ba

Means followed by the same uppercase letter in the row and lowercase letter in the column belong to the same cluster by the Scott-Knott test at a 5% probability. *m* = mean; CC = cover crops; $_S$ = single system; UB_S = *Urochloa brizantha*; PG_S = *Pennisetum glaucum*; CJ_S = *Crotalaria juncea*; CE_S = *Canavalia ensiformis*; MA_S = *Mucuna aterrima*; $_I$ = intercrop system; $UBCJ_I$ = *U. brizantha* and *C. juncea*; $UBCE_I$ = *U. brizantha* and *C. ensiformis*; $PGCJ_I$ = *P. glaucum* and *C. juncea*; $PGCE_I$ = *P. glaucum* and *C. ensiformis*; SV = spontaneous vegetation.

This result may be related to the root system of the cover crops. UB_S and PG_S have the ability to form a more robust and voluminous root system and CE_S has a taproot with a length longer than 20 cm, which may have favored the improvement of aggregates in the 0.15-0.30 cm. However, according to the aggregate stability method in water, the maximum aggregate stability would correspond to the GMD value equal to 5 mm. Therefore, two cultivation cycles under the no-tillage system were not enough to improve soil aggregation.

On the other hand, the use of cover crops under no-tillage system promotes, over time, an increase in organic carbon, which is responsible for soil aggregation. However, the higher amount of plant material deposited on the soil benefits soil aggregation and, consequently, decreases soil erodibility (Torres, Pereira, Assis, & Souza, 2015). Singh et al. (2018) evaluated a crop rotation system after three years of cultivation and found a higher predominance of stable macroaggregates in water (>30%) at a layer of 0–0.15 m in plots with crop residues on the soil surface.

The highest percentages of macroaggregates (Table 4) in the most superficial soil layer were observed in the soil with straw of CJ_S, CE_S, MA_S, and the intercrop $UBCJ_I$. In contrast, CE_S, MA_S, and the intercrops $UBCJ_I$, $UBCE_I$, and $PGCE_I$ were the cover crops that contributed to the highest values of this variable in the 0.15-0.30 m layer. Regarding soil layers, CJ_S provided a higher percentage of this variable in the first layer, while $UBCE_I$ and $PGCE_I$ contributed positively to macroaggregation in the second layer. In general, the geometric mean diameter is closely related to the percentage of soil aggregates, mainly macroaggregates (aggregates higher than 0.250 mm).

Thus, conservationist practices, including the no-tillage system, are essential to increase soil aggregate stability, as this system allows the maintenance of crop residues on the soil surface. According to Singh et al. (2018), the persistence of plant material on the soil favors the formation of water-stable macroaggregates in the first soil layers.

The lowest percentages of microaggregates were attributed to the first layer of the soil cultivated with CJ_S, CE_S, MA_S, and the intercrop $UBCJ_I$, as observed for the variables previously discussed. On the contrary, the cultivation of CE_S, MA_S, and the intercrops $UBCJ_I$, $UBCE_I$, and $PGCE_I$ provided the lowest percentages of this variable in the second layer (Table 4). Regarding the effect of layers within the level of cover crops, the lowest percentage of this variable was obtained in the first layer when the soil was under the influence of CJ_S. The second layer presented lower values when the soil was cultivated with the intercrops $UBCE_I$ and $PGCE_I$.

No differences were observed in the percentage of simple particles between the straws within the same studied layer. However, the comparison between layers showed that CJ_S and the intercrop $PGCJ_I$ had lower means in the first layer, whereas SV had a lower percentage of single particles in the second layer (Table 4).

An isolated effect of cover crops and crop cycles was observed on the dry mass of cover crops and cowpea yield (Table 5). UB_S, PG_S, and intercropped crops produced the highest amounts of dry mass. Legumes cultivated in a simple system were grouped with an intermediate mean, ahead of SV. Regarding the crop cycles, the second cycle stood out due to its best mean.

The cultivation on the straw of CJ_S and SV had a negative influence on crop yield. The other cover crops did not differ from each other and were grouped as a function of the highest means. Regarding crop cycles, the second cycle was superior to the previous cycle. This result may be related to the improvement of biological (MBC and qCO_2) and chemical attributes (SOC, P, and K), which provided the trend of soil restructuring and increase in the biomass production of cover crops.

Table 5. Cover plant dry mass (DM) and cowpea yield (CY) as a function of different cover crops and crop cycles on a *Latossolo Amarelo* of the Amazon savanna, Boa Vista, Roraima State, Brazil, 2017.

CC	DM (kg ha^{-1})		*Mean*	CY (kg ha^{-1})		*Mean*
	1st cycle	2nd cycle		1st cycle	2nd cycle	
			kg ha^{-1}			
UB_S	10689.73	11242.78	10966.25 a	1610.69	2102.39	1856.54 a
PG_S	9838.80	9966.00	9902.40 a	1749.45	1886.46	1817.96 a
CJ_S	8137.95	8427.35	8282.65 b	1404.30	1930.96	1667.63 b
CE_S	5440.70	8998.95	7219.83 b	1752.65	1954.07	1853.36 a
MA_S	6022.10	9608.05	7815.08 b	1713.66	1976.22	1844.94 a
$UBCJ_I$	9472.85	9922.40	9697.63 a	1904.07	2131.24	2017.66 a
$UBCE_I$	8487.15	9931.60	9209.38 a	1756.44	2161.77	1959.11 a
$PGCJ_I$	9449.15	9711.13	9580.14 a	1824.34	1860.58	1842.46 a
$PGCE_I$	7796.40	9555.25	8675.83 a	1880.59	1888.32	1884.46 a
SV	4841.45	6940.65	5891.05 c	1546.22	1581.56	1563.63 b
Mean	8017.63 B	9430.41 A		1715.01 B	1946.58 A	

Means followed by the same uppercase letter in the row and lowercase letter in the column belong to the same cluster by the Scott-Knott test at a 5% probability. CC = cover crops; $_S$ = single system; UB_S = *Urochloa brizantha*; PG_S = *Pennisetum glaucum*; CJ_S = *Crotalaria juncea*; CE_S = *Canavalia ensiformis*; MA_S = *Mucuna aterrima*; $_I$ = intercrop system; $UBCJ_I$ = *U. brizantha* and *C. juncea*; $UBCE_I$ = *U. brizantha* and *C. ensiformis*; $PGCJ_I$ = *P. glaucum* and *C. juncea*; $PGCE_I$ = *P. glaucum* and *C. ensiformis*; SV = spontaneous vegetation.

Some divergences were observed when comparing these values with other studies, such as the dry mass production of *Canavalia ensiformis* and *Crotalaria juncea*, which stood out in the conditions of northwestern Rio Grande do Sul (subtropical climate), producing means of 24.99 and 22.71 t ha^{-1}, respectively (Pereira et al., 2017). This variation of cover crops on the soil surface in different regions was expected because the no-tillage system requires adaptations depending on the region (Teixeira et al., 2018). However, according to Nunes et al. (2006), the cover crops, except for spontaneous vegetation, presented dry mass production above the ideal, which is around 6 t ha^{-1}. In this sense and considering the dry mass production of cover crops, the evaluated plants have the potential to be used as cover crops under the conditions of this study.

In general, although cowpea presented low yield on the straw of CJ_S and SV compared to the other treatments, the reached yields were higher than the national (533 kg ha^{-1}), the North Region (845 kg ha^{-1}), and Roraima means (1,151 kg ha^{-1}) (IBGE, 2021).

Principal component analysis showed that components 1 and 2 accounted for approximately 56% of the variability of the first crop cycle data (Figure 2). Thus, cowpea yield was strongly correlated with P content, pH, and qCO_2, and the cover crops associated with these variables were PG_S, SV, and the intercrops $PGCJ_I$ and $PGCE_I$.

Cover crop dry mass was more influenced by UB_S and the intercrops $UBCE_I$ and $UBCJ_I$, which form a group together with V, BSR, SOC, K, MBC, and SB. Moreover, Figure 2 shows an isolated group composed of Al and H + Al, which were correlated with CE_S and MA_S.

The second cycle (Figure 3) showed a correlation between CY and CCDM, reference variables, adjacent to BSR, V, SOC, and K, which were closely influenced by UB_S and the intercrops $UBCJ_I$ and $UBCE_I$. MA_S and the intercrop $PGCJ_I$ correlated with MBC. A positive correlation was observed between CE_S and Al. Another group can be observed in the correlation between P and H + Al, being influenced by SV and the intercrop $PGCE_I$. The pH, qCO_2, and SB were positively correlated with each other and influenced by PG_S.

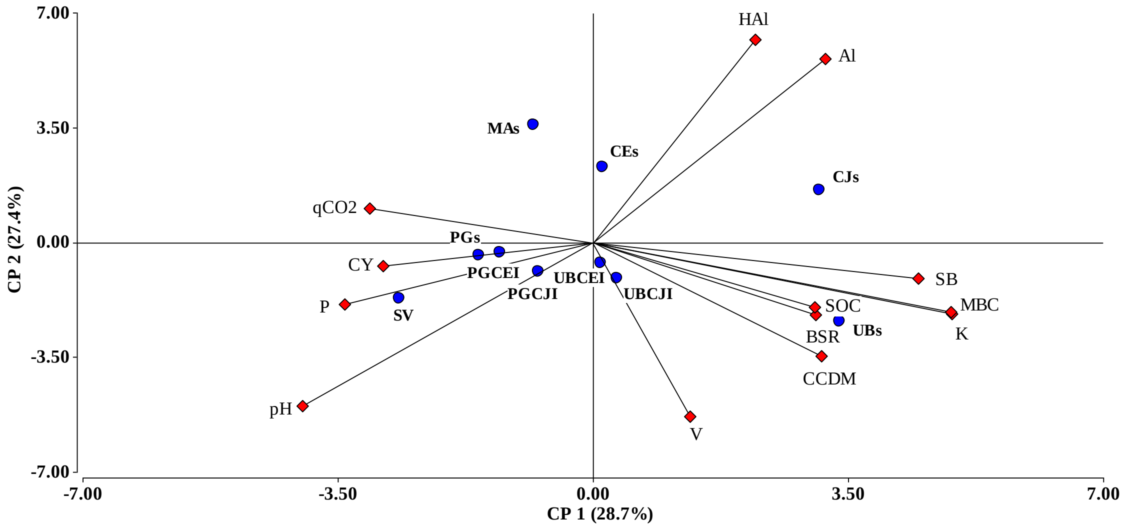

Figure 2. Principal component analysis of chemical and biological attributes of the first cropping cycle on a *Latossolo Amarelo* as a function of different cover crops in a savanna environment, Boa Vista, Roraima State, Brazil, 2017. $_S$ = single system; UB_S = *Urochloa brizantha*; PG_S = *Pennisetum glaucum*; CJ_S = *Crotalaria juncea*; CE_S = *Canavalia ensiformis*; MA_S = *Mucuna aterrima*; $_I$ = intercrop system; $UBCJ_I$ = *U. brizantha* and *C. juncea*; $UBCE_I$ = *U. brizantha* and *C. ensiformis*; $PGCJ_I$ = *P. glaucum* and *C. juncea*; $PGCE_I$ = *P. glaucum* and *C. ensiformis*; SV = spontaneous vegetation; pH = potential of hydrogen; SOC = soil organic carbon; P = phosphorus; K = potassium; Al = aluminum; H + Al = potential acidity; SB = sum of bases; V = base saturation; BSR = basal soil respiration; MBC = soil microbial biomass carbon; qCO_2 = soil metabolic quotient; CCDM = cover crop dry mass; CY = cowpea yield.

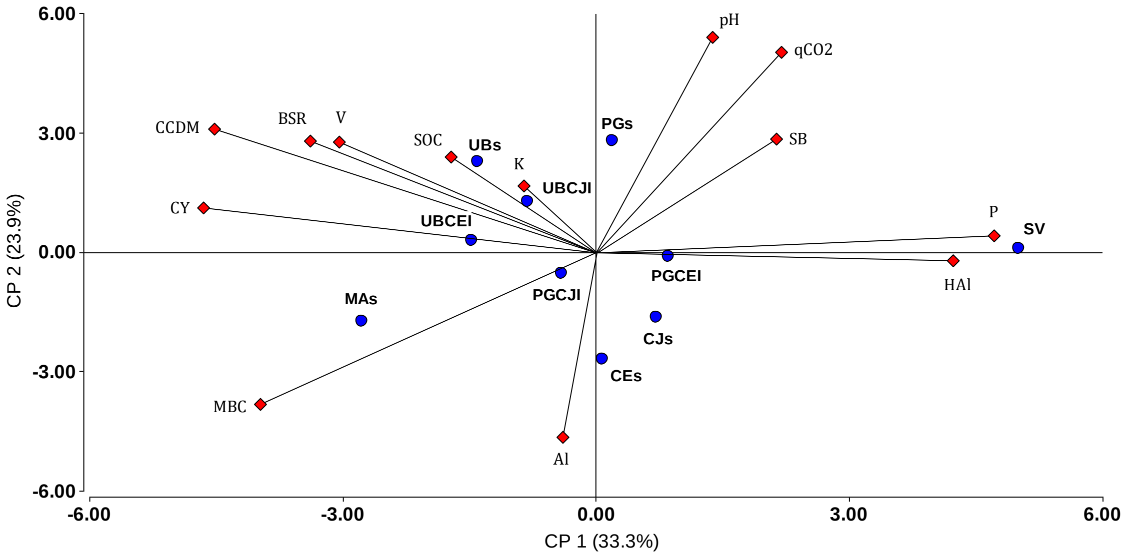

Figure 3. Principal component analysis of chemical and biological attributes of the second cropping cycle on a *Latossolo Amarelo* as a function of different cover crops in a savanna environment, Boa Vista, Roraima State, Brazil, 2017. $_S$ = single system; UB_S = *Urochloa brizantha*; PG_S = *Pennisetum glaucum*; CJ_S = *Crotalaria juncea*; CE_S = *Canavalia ensiformis*; MA_S = *Mucuna aterrima*; $_I$ = intercrop system; $UBCJ_I$ = *U. brizantha* and *C. juncea*; $UBCE_I$ = *U. brizantha* and *C. ensiformis*; $PGCJ_I$ = *P. glaucum* and *C. juncea*; $PGCE_I$ = *P. glaucum* and *C. ensiformis*; SV = spontaneous vegetation; pH = potential of hydrogen; SOC = soil organic carbon; P = phosphorus; K = potassium; Al = aluminum; H + Al = potential acidity; SB = sum of bases; V = base saturation; BSR = basal soil respiration; MBC = soil microbial biomass carbon; qCO_2 = soil metabolic quotient; CCDM = cover crop dry mass; CY = cowpea yield.

For soil physical attributes, the soil cultivated with CJ_S influenced the correlation between MICROAG(B), DS(B), MICROP(B), CCDM and CY (Figure 4). When analyzing the data, it is noticed that the values of these variables are related to the reduction in the production of dry mass of *Crotalaria juncea* in the soil and the production of cowpea. The variables DMG(A), MACROAG(A), MACROP(A) and PT(A) were positively correlated being influenced by CE_S, MA_S and the intercrop $UBCJ_I$. There is another group was formed by the correlation between DS(A), PS(A) and MICROAG(A), these variables being influenced by UB_S, PG_S and the intercrop $PGCE_I$ and $UBCE_I$. The treatment formed by VE influenced the correlation between MICROP(A), MACROP(B), PT(B) and DMG(B).

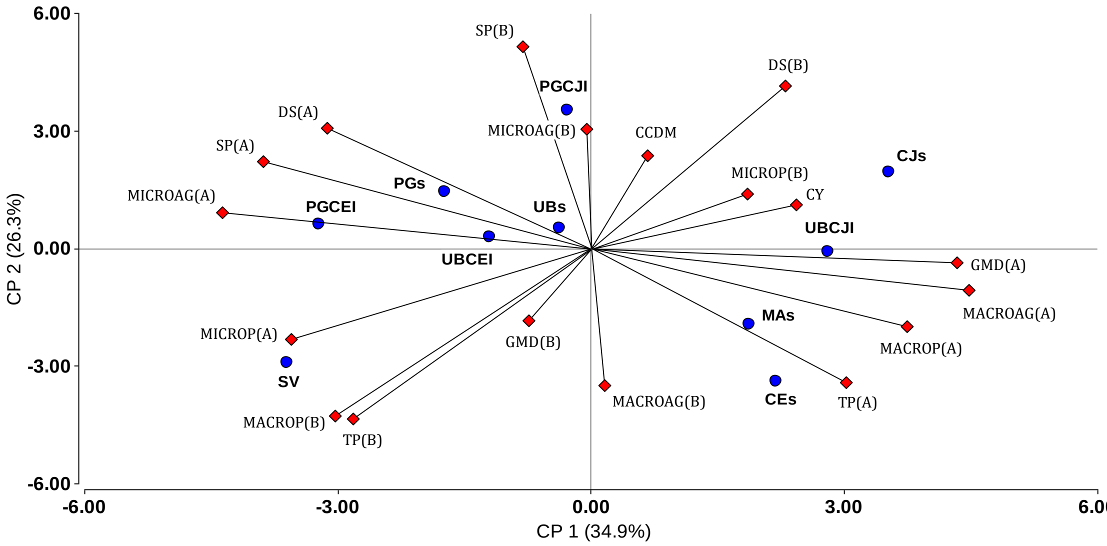

Figure 4. Principal component analysis of physical attributes of the second cropping cycle on a *Latossolo Amarelo* as a function of different cover crops in a savanna environment, Boa Vista, Roraima State, Brazil, 2017. $_S$ = single system; UB$_S$ = *Urochloa brizantha*; PG$_S$ = *Pennisetum glaucum*; CJ$_S$ = *Crotalaria juncea*; CE$_S$ = *Canavalia ensiformis*; MA$_S$ = *Mucuna aterrima*; $_I$ = intercrop system; UBCJ$_I$ = *U. brizantha* and *C. juncea*; UBCE$_I$ = *U. brizantha* and *C. ensiformis*; PGCJ$_I$ = *P. glaucum* and *C. juncea*; PGCE$_I$ = *P. glaucum* and *C. ensiformis*; SV = spontaneous vegetation; layers: A (0–0.15 m) and B (0.15–0.30 m); GMD = geometric mean diameter; MACROAG = macroaggregates; MICROAG = microaggregates; SP = simple particles; DS = soil density; MACROP = macroporosity; MICROP = microporosity; TP = total porosity; CCDM = cover crop dry mass; CY = cowpea yield.

The amount of straw formed by cover crops in the first cropping cycle presented little influence on cowpea production, which was more influenced by soil chemical and biological properties, especially P and qCO2, respectively. It may be related to the time required for system stabilization. However, the second cycle showed a positive correlation between the amount of dry mass produced by cover crops and cowpea yield.

The greater capacity to transform mineral P into organic P of the weeds in the SV area may have favored the accumulation of P in this area. Moreover, this population had little influence on soil acidification. In general, soil acidification can occur in the presence of plants of the legume family, as they release H+ during biological nitrogen fixation (Marschner, 1995).

UBS showed advantages regarding potassium cycling. For this reason, it may have favored the activity of soil microorganisms, which was verified through the improvement of BSR and MBC. Moreover, an increase in the sum of bases was observed when the soil was cultivated with *U. brizantha*, demonstrating the strong participation of potassium in this exchange complex.

CJS did not improve soil physical attributes, especially aggregation in the second layer, although it had a positive influence on some soil chemical attributes. It also presented low biomass production and low cowpea yield. Crop yield is related to the balance between soil biological, chemical, and physical attributes. However, Nouri, Lee, Yin, Tyler, and Saxton (2019) conducted a long-term study and reported that the physical attribute is closely related to the water dynamics in the soil and, consequently, to the crop yield.

The results found in the present study provide technical-scientific support regarding the use of cover crops to improve soil quality and, consequently, increase cowpea yield under experimental conditions.

Conclusion

Urochloa brizantha and the intercrops *U. brizantha* and *Crotalaria juncea,* and *U. brizantha* and *Canavalia ensiformis* stand out positively in improving soil quality. Basal soil respiration, soil organic carbon, potassium, base saturation, geometric mean diameter, macroaggregates, and macroporosity in the 0-0.10 m layer are the most sensitive indicators for improving soil quality in a savanna environment. *U. brizantha*, *Pennisetum glaucum*, *C. ensiformis*, *Mucuna aterrima*, and intercrop systems increase cowpea yield by up to 29% relative to spontaneous vegetation.

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References

Anjos, L. H. C., & Schad, P. (2018). Comparação da classificação de solos de acordo com o Sistema Brasileiro e os Sistemas Internacionais WRB e Soil Taxonomy. In K. D. Batista, J. F. Lumbreras, M.R. Coelho, V.A. Oliveira, & J. F. Vale Júnior (Eds.), *Guia de Campo da XI Reunião Brasileira de Classificação e Correlação de Solos: RCC de Roraima*. Brasília, DF: Embrapa.

Evald, A., Melo, V. F., Rocha, P. R. R., Cordeiro, A. C. C., Maia, S. D. S., & Espindola, I. D. C. (2021). Soil attributes under different water management systems of rice paddies in the Amazonian savanna of Brazil. *Revista Caatinga*, *34*(3), 640-649. DOI: https://doi.org/10.1590/1983-21252021v34n316rc

Bertolini, A., Finco, D., Nora, T. J., Omizzollo, R., Sordi, A., & Klein, C. (2019). Cobertura de solo e taxa de ciclagem de nutrientes em plantas de cobertura de verão no Oeste de Santa Catarina. *Unoesc & Ciência-ACET*, *10*(2), 83-92.

Cardoso, E., Vasconcellos, R. L. F., Bini, D., Miyauchi, M. Y. H., Santos, C. A., Alves, P. R. L., ... Nogueira, M. A. (2013). Soil health: looking for suitable indicators. What should be considered to assess the effects of use and management on soil health?. *Scientia Agricola*, *70*(4), 274-289. DOI: https://doi.org/10.1590/S0103-90162013000400009

Cattelan, A. J., & Vidor, C. (1990) Fluctuations in soil microbial biomass, activity and population due to environmental variations. *Revista Brasileira de Ciência do Solo*, *14*(2),133-142.

Di-Rienzo, J. A., Casanoves, F., Balzarini, M. G., Gonzalez, L., Tablada, M., & Robledo, C. W. (2008). *InfoStat, versión 2008*. Cordoba, AR: Grupo InfoStat; FCA; Universidad Nacional de Córdoba.

Duarte, I. B., Gallo, A. S., Gomes, M. S., Guimarães, N. F., Rocha, D. P., & Silva, R. F. (2014). Plantas de cobertura e seus efeitos na biomassa microbiana do solo. *Acta Iguazu*, *3*(2), 150-165. DOI: https://doi.org/10.48075/actaiguaz.v3i2.10625

Edwards, A., & Bremner, J. (1967). Dispersion of soil particles by sonic vibration. *Journal of Soil Science*, *18*(1), 47-63. DOI: https://doi.org/10.1111/j.1365-2389.1967.tb01487.x

Ferreira, D. F. (2014). Sisvar: a computer statistical analysis system. *Ciência e Agrotecnologia*, *35*(6), 1039-1042. DOI: https://doi.org/10.1590/S1413-70542011000600001

Fialho, C. M. T., Silva, A. A., Melo, C. A. D., Costa, M. D., Souza, M. W. R., & Reis, L. A. C. (2020). Weed Interference in soybean crop affects soil microbial activity and biomass. *Planta Daninha, 38*, 1-6. DOI: https://doi.org/10.1590/S0100-83582020380100046

Freitas, M. S. C., Souto, J. S., Gonçalves, M., Almeida, L. E. S., Salviano, A. M. & Giongo, V. (2019). *Revista Brasileira Ciência do Solo. 43*, e0170402. Decomposition and nutrient release of cover crops in mango cultivation in Brazilian semi-arid region. DOI: https://doi.org/10.1590/18069657rbcs20170402

Instituto Brasileiro de Geografia e Estatística [IBGE]. (2021) *Produção agrícola municipal*. Retrieved on Aug. 5, 2021 from https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/9117-producao-agricola-municipal-culturas-temporarias-e-permanentes.html?edicao=29008&t=destaques

Instituto Nacional de Meteorologia [INMET]. (2020). *Banco de dados meteológicos para ensino e pesquisa***.** Retrieved on Feb. 6, 2020 from http://www.inemet.gov.br/portal/index.php?r= bdmep

Jenkinson, D. S., & Powlson, D. S. (1976). The effects of biocidal treatments on metabolismo in soil-V: A method for measuring soil biomass. *Soil Biology & Biochemistry*, *8*(3), 209-213. DOI: https://doi.org/10.1016/0038-0717(76)90005-5

Maluf, H. J. G. M., Soares, E. M. B., Silva, I. R., Neves, J. C. L., & Oliveira Silva, M. F. (2015). Disponibilidade e recuperação de nutrientes de resíduos culturais em solo com diferentes texturas. *Revista Brasileira de Ciência do Solo*, *39*(6), 1690-1702. DOI: https://doi.org/10.1590/01000683rbcs20140658

Marschner, H. (1995). *Mineral nutrition of higher plants*. London, UK: Elsevier.

Martins, L. N. B., Santiago, F. L. D. A., Montecchia, M. S., Correa, O. S., Saggin Junior, O. J., Souza, E. D. D., ... Carneiro, M. A. C. (2019). Biochemical and biological properties of soil from Murundus Wetlands converted into agricultural systems. *Revista Brasileira de Ciência do Solo*, *43*, 1-13. DOI: https://doi.org/10.1590/18069657rbcs20180183

Melo, V. F., Silva, D. T., Evald, A., & Rocha, P. R. R. (2017). Qualidade química e biológica do solo em diferentes sistemas de uso em ambiente de savana. *Revista Agro@mbiente on-line*, *11*(2), 101-110. DOI: https://doi.org/10.18227/1982-8470ragro.v11i2.3850

Nouri, A., Lee, J., Yin, X., Tyler, D. D., & Saxton, A. M. (2019). Thirty-four years of no-tillage and cover crops improve soil quality and increase cotton yield in Alfisols, southeastern USA. *Geoderma*, *337*, 998-1008. DOI: https://doi.org/10.1016/j.geoderma.2018.10.016

Nunes, U. R., Andrade Junior, V. C., Silva, E. B., Santos, N. F., Costa, H. A. O., & Ferreira, C. A. (2006). Produção de palhada de plantas de cobertura e rendimento do feijão em plantio direto. *Pesquisa Agropecuária Brasileira*, *41*(6), 943-948. DOI: https://doi.org/10.1590/S0100-204X2006000600007

Panico, S. C., Memoli, V., Esposito, F., Maisto, G., & Marco, A. (2018) Plant cover and management practices as drivers of soil quality. *Applied Soil Ecology, 129*, 34-42. DOI: https://doi.org/10.1016/j.apsoil.2018.05.001

Pereira, A. P., Schoffel, A., Koefender, J., Camera, J. N., Golle, D. P., & Horn, R. C. (2017). Ciclagem de nutrientes por plantas de cobertura de verão. *Revista de Ciências Agrárias*, *40*(4), 120-129. DOI: https://doi.org/10.19084/RCA17065

Pessotto, P. P, Silva, V. R., Ortigara, C., Koppe, E., Strojaki, T., & Santi, A. L. (2006). Influência de diferentes plantas de cobertura nas propriedades físicas de um Latossolo Vermelho. *Revista Agrarian*, *9*(34), 348-356.

Ribeiro, A. C., Guimarães, P. T. G., & Alvarez, V. H. (1999). *Recomendações para o uso de corretivos e fertilizantes em Minas Gerais - 5ª Aproximação*. Viçosa, MG: Comissão de Fertilidade do Solo do Estado de Minas Gerais.

Salton, J. C., Silva, W. M., Tomazi, M., & Hernani, L. C. (2012). *Determinação da agregação do solo - Metodologia em uso na Embrapa Agropecuária Oeste*. Dourados, MS: Embrapa Agropecuária Oeste. (Embrapa Agropecuária Oeste-Comunicado Técnico, INFOTECA-E).

Saviozzi, A., Bufalino, P., Levi-Minzi, R., & Riffald, R. (2002). Biochemical activities in a degraded soil restored by two amendments: A laboratory study. *Biology and Fertility of Soils*, *35*, 96-101. DOI: https://doi.org/10.1007/s00374-002-0445-9

Silva, M. P., Arf, O., Sá, M. E., Abrantes, F. L., Berti, C. L. F., & Souza, L. C. D. (2017). Plantas de cobertura e qualidade química e física de Latossolo Vermelho distrófico sob plantio direto. *Revista Brasileira de Ciências Agrárias, 12*(1), 60-67, DOI: https://doi.org/10.5039/agraria.v12i1a5424

Simon, C. A, Lima, S. F., Cordeiro, M. S., Secco, V. A., Nacata, G., Silva, A. M. M., ... Brasil, M. S. (2019). Cover crops as modifying agents of microbiological soil attribute. *Australian Journal of Crop Science*, *13*(10), 1578-1585. DOI: https://doi.org/10.21475/ajcs.19.13.10.p1723

Singh, G., Bhattacharyya, R., Das, T. K., Sharma, A. R., Ghosh, A., Das, S., & Jha, P. (2018). Crop rotation and residue management effects on soil enzyme activities, glomalin and aggregate stability under zero tillage in the Indo-Gangetic Plains. *Soil & Tillage Research*, *184*, 291-300. DOI: https://doi.org/10.1016/j.still.2018.08.006

Sinsabaugh, R. L., Lauber, C. L., Weintraub, M. N., Ahmed, B., Allison S. D., Crenshaw, C., ... Zeglin, L. H. (2008). Stoichiometry of soil enzyme activity at global scale. *Ecology Letters*, *11*(11), 1252-1264. DOI: https://doi.org/10.1111/j.1461-0248.2008.01245.x

Stein, S., & Steinmann, H. H. (2018). Identifying crop rotation practice by the typification of crop sequence patterns for arable farming systems - A case study from Central Europe. *European Journal of Agronomy*, *92*, 30-40. DOI: https://doi.org/10.1016/j.eja.2017.09.010

Stute, J. K., & Posner, J. L (1995). Synchrony between legume nitrogen release and corn demand in the Upper Midwest. *Agronomy Journal*, *87*(6), 1063-1069. DOI: https://doi.org/10.2134/agronj1995.00021962008700060006x

Teixeira, P. C., Donagemma, G. K., Fontana, A., & Teixeira, W. G. (2017). *Manual de métodos de análise de solo*. Brasília, DF: Embrapa.

Teixeira, E. I., Ruiter, J., Ausseil, A. G., Daigneault, A., Johnstone, P., Holmes, A., ... Ewert, F. (2018). Adapting crop rotations to climate change in regional impact modelling assessments. *Science of the Total Environment*, *616-617*, 785-795. DOI: https://doi.org/10.1016/j.scitotenv.2017.10.247

Torres, J. L. R., Pereira, M. G., Assis, R. L., & Souza, Z. M. (2015). Atributos físicos de um Latossolo Vermelho cultivado com plantas de cobertura, em semeadura direta. *Revista Brasileira de Ciência do Solo*, *39*(2), 428-437. DOI: https://doi.org/10.1590/01000683rbcs20140597

Uchôa, S. C. P., Alves, J. M. A., Cravo, M. S., Silva, A. J., Melo, V. F., Ferreira, G.B., & Ferreira, M. M. M (2009). Fertilidade do solo (1. ed.). In J. E. Zilli, A. A. Vilarinho, & J. M. A. Alves (Eds.), *A cultura do feijão-caupi na Amazônia Brasileira* (p. 131-183). Boa Vista, RR: Embrapa Roraima.

Vance, E. D., Brookes, P. C., & Jenkinson, D. S. (1987). An extraction method for measuring soil microbial biomass-C. *Soil Biology & Biochemistry*, *19*(6), 703-707. DOI: https://doi.org/10.1016/0038-0717(87)90052-6

Zornoza, R., Acosta, J. A., Bastida, F., Domínguez, S. G., Toledo, D. M. & Faz, A. (2015). Identification of sensitive indicators to assess the interrelationship between soil quality, management practices and human health. *Soil, 1*(1), 173-185. DOI: https://doi.org/10.5194/soil-1-173-2015