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Cover Crops as Affecting Soil Chemical and Physical Properties and Development of Upland Rice and Soybean Cultivated in Rotation

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Abstract: Cover crops can provide changes in soil chemical and physical properties, which could allow a sustainable development of soybean and upland rice rotation in Brazilian Cerrado. The objective of this study was to determine the effects of cover crops (cultivated in the offseason) in the soybean-upland rice rotation (cultivated in the summer season) on the soil chemical and physical properties, yield components and grain yield of the cash crops. The experimental design was a randomized block design in factorial scheme 4 × 2 with six replications. Treatments were composed by four cover crops: fallow, millet (*Pennisetum glaucum*) + *Crotalaria ochroleuca*, millet + pigeon pea (*Cajanus cajans*), and millet + pigeon pea + *Urochola ruziziensis* in the offseason with one or two cycles of cover crops, with rice (*Oryza sativa*) or soybean (*Glycine max*) in the summer season. Cover crops alone provided no changes in soil chemical properties. However, the rotation cover crops / cash crops / cover crops / cash crops reduced pH, Al and H + Al and increased Ca, Mg, K and Fe contents in the soil. The cover crops millet + pigeon pea and millet + pigeon pea + *U. ruziziensis* improved soil physical properties in relation to fallow, especially in the 0–0.10 m soil layer. In spite of the improvement of the soil physical properties after two years of rotation with cover crops and cash crops, the soil physical quality was still below the recommended level, showing values of macroporosity, *S* index and soil aeration capacity lower than 0.10 m^3/m^3, 0.035 and 0.34, respectively. Upland rice production was higher under mixtures of cover crops than under fallow, mainly because of soil physical changes done by these mixtures of cover crops. Soybean grain yield was similar under all cover crops tested, but was higher after the rotation cover crops / upland rice / cover crops than after only one cycle of cover crops.

Key words: crop rotation; no-tillage system; sustainable agriculture; tropical agriculture; rice; soybean

Upland rice cultivation has been increasing worldwide because water availability for irrigation has been decreasing, mainly because of rapid growth in industry and urban centers. Therefore, the development of technologies that increase upland rice yields under aerobic conditions, thereby saving water, would be an effective strategy to improve global rice grain production and avoid water shortage (Nascente et al, 2013a). The use of technologies such as no-tillage system (NTS), using cover crops and crop rotation, may represent a viable alternative to reduce the impact on intensive land use and could promote the improvement of chemical and physical soil properties (Carneiro et al, 2008; Silva et al, 2011; Pacheco et al, 2013; Nascente et al, 2014, 2015, 2016). With the use of cover crops, which is a conservation practice, plant species are grown and straw maintained on the soil surface in order to ensure or increase the productive capacity of the soil (Boer et al, 2007; Carvalho et al, 2011; Nascente et al, 2013a). Thus, when these plants are incorporated into the production system, they will act as soil conditioners (Moreti et al, 2007; Nascente et al, 2015).

In the Cerrado region of Brasil, the soybean and

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corn succession (CONAB, 2017) prevails. However, the continued use of the same cash crops can bring phytosanitary problems for these crops, and therefore, it is not a sustainable practice. The use of cover crops and other cash crops options in succession, such as rice, can provide significant benefits for the agriculture in this region, such as reduction in the infestation of insects, diseases and weeds.

NTS is consolidated as conservationist technology among farmers in the Cerrado region (Carvalho et al, 2004; Pacheco et al, 2013). Its effectiveness is related, among other factors, to the amount and quality of crop residues, which has great importance for Cerrado sustainability (Pires et al, 2008). Thus, the species of cover crops used should have high biomass production capacity, and straw must have impact on the soil surface and ability to promote significant nutrient cycling (Crusciol et al, 2005, 2015; Nascente et al, 2013a). In this case, species of cover crops would provide benefits such as greater conservation of soil moisture, protection against soil erosion, significant increases in soil fertility and collaborate on integrated management of pests, diseases and weeds (Fageria et al, 2005). Legumes species can also influence the water storage capacity of the soil and reduce the loss of carbon and nitrogen in intensified systems (Drinkwater et al, 1998). Besides, the interaction of the cover crops with the physical attributes of the soil is related to the intrinsic characteristics of each species, the management of the cultural residues and the edaphoclimatic conditions of each region (Sousa Neto et al, 2008). Therefore, the effects of cover crops on the physical properties of the soils should be evaluated when cover crops are used alone and in mixture. However, there are few studies on effects of cover crops alone and in mixture, on soil properties in the Cerrado region.

Millet (*Pennisetum glaucum*) is a cover crop option, due to high biomass production, fast straw degradation, which releases nutrients to the soil that can be used for the following crop (Nascente et al, 2013a, 2014, 2015). Perennial forages such as *Urochloa*, for large biomass production and greater persistence in soil, are other options (Crusciol et al, 2015). In addition, there is pigeon pea legume (*Cajanus cajans*) and sunn hemp (*Crotalaria* spp.) which besides the production of biomass, can fix atmospheric nitrogen (Torres et al, 2008). Nascente et al (2016) reported that the use of millet as cover crop alone or intercropped with *U. ruziziensis* or *C. spectabilis* is a management practice option that provides high rice grain yield.

However, despite the options of cover crops species and the benefits provided, the majority of farmers in the Cerrado region do not use species of cover crops in their agricultural areas, and even less in species mixtures. Studies to identify techniques for cover crops intercropping that promote beneficial changes in chemical and physical attributes in the soil, which provides increase in crop yields to be included in the soybean / rice rotation in the Cerrado region, may favor the expansion of the NTS in the tropical region as well as the adoption of this technology. Therefore, the objective of this work was to determine the effects of the use of cover crops (cultivated in the offseason) in the soybean / upland rice rotation (cultivated in the summer season) on the chemical and physical properties of the soil, and yield components and grain yield of the cash crops.

MATERIALS AND METHODS

Site description

The experiments were conducted at Capivara Farm of the Embrapa Rice and Beans Unit, which is located in Santo Antônio de Goiás, GO, Brazil at 16º28'00" S and 49º17'00" W and 823 m of elevation. The average annual rainfall was between 1 500 and 1 700 mm, and the average annual temperature was 22.7 ºC, ranging annually from 14.2 ºC to 34.8 ºC. During the period of this study, the temperature and the amount of rainfall data were recorded (Supplemental Fig. 1).

The soil was classified as a clayey loam (kaolinitic, thermic Typic Haplorthox) acidic soil (Embrapa, 2006). Prior to the study in 2015, chemical and physical analyses were performed in a depth range of 0–0.20 m for the initial characterization of the area (Table 1). Chemical and physical analyses were performed according to the methodology proposed by Donagema et al (2011). The experimental area had been cultivated in a crop-livestock integration using a no-tillage system for seven consecutive years, followed by a crop rotation program of soybean (summer), rice (summer) and irrigated common bean (winter), corn + *Urochloa* (summer), and two years of grazing pasture.

Experimental design and treatments

The experimental design was a randomized block design in factorial scheme 4 × 2 with six replications, during two summer seasons. Treatments were composed by four cover crops: fallow, millet (*Pennisetum*

Table 1. Chemical soil attributes in 2015.

Soil attribute	Value
Layer (cm)	0–20
pH	5.4
Soil organic matter (g/kg)	27.0
K (mmol/L)	3.8
P (mg/L)	7.7
Ca (mmol/L)	32
Mg (mmol/L)	14
Al (mmol/L)	0.0
H + Al (mmol/L)	37
Cu (mg/L)	2.0
Zn (mg/L)	4.4
Fe (mg/L)	32
Mn (mg/L)	26
Cation exchange capacity (mmol/L)	86.8
Base saturation (%)	57.4
Sand (g/kg)	140
Silt (g/kg)	440
Clay (g/kg)	420

glaucum) + *Crotalaria ochroleuca*, millet + pigeon pea (*Cajanus cajans*), and millet + pigeon pea + *Urochola ruziziensis* in the offseason with one or two cycles of cover crops. In the first summer season, half of the trial was cultivated with rice and half with soybean in independent plots. In the second summer season, we inverted, place that was with rice now was cultivated with soybean and vice-versa (Table 2). The plots had the dimension of 12 m × 14 m. The usable area of the plot was composed of the eight 12-meter-long central rows of rice or soybean. A corridor 2 m in width was left between the plots.

Cover crops management

The cover crops were sown on March, 2015 and on March, 2016 (Table 2). A seeding rate of 20, 20, 20 and 10 kg/hm^2 pure live seeds was applied for millet, *C. ochroleuca*, pigeon pea and *U. ruziziensis*, respectively. All species were sown in 45 cm spacing. Sowing was carried out with a seeder fertilizer at the depth of 5 cm and without the use of fertilizers. The cover crop plants were not irrigated. Cover crops were desiccated with a glyphosate application (1.8 kg/hm^2 acid equivalent) on 29th October, 2015 and 26th October, 2016. Fifteen days after, cover crops were managed with a straw crushing-shredding device (Triton®), leaving the straw on the ground.

Soybean management

The sowing of soybean cultivar BRSGO 6959 RR was performed mechanically on 6th November, 2015 and 11th November, 2016, using a no-till seeder (Semeato, Personale Drill 13, Passo Fundo, Brazil) with a row spacing of 0.45 m and a density of 18 pure live seeds per mater. The soybean seeds were inoculated with *Bradyrhizobium japonicum*. Seedling emergence occurred at 6 and 5 d after sowing in 2015/2016 and 2016/2017, respectively. The base fertilization, to be applied in the sowing furrows, was calculated according to the soil chemical characteristics and the recommendations of Sousa and Lobato (2003). Therefore, the amount of fertilizer put at sowing time was 90 kg/hm^2 P_2O_5, as triple superphosphate, and 48 kg/hm^2 K_2O, as potassium chloride, in both years. Cultural practices were performed according to standard recommendations for a soybean crop to keep the area free from weeds, diseases and insects.

Rice crop management

The sowing of rice cultivar from a mutant line 07SEQCL441 CL, which was derived from a *Primavera* variety and was resistant to the *Imazapyr* + *Imazapic* herbicide, was performed mechanically on 1st December, 2015 and 17th November, 2016 using no-till seeder (Semeato, model Personale Drill 13, Passo Fundo, RS, Brazil) with a row spacing of 0.35 m and a density of 80 pure live seeds per meter. Seedling emergence occurred at 5 d after sowing in

Table 2. Cover crops and cash crops cultivated during the trials.

2015	2015/2016	2016	2016/2017
Cover crop	Cash crop	Cover crop	Cash crop
M + C	Upland rice	M+ C	Soybean
M + P	Upland rice	M + P	Soybean
M + P + U	Upland rice	M + P + U	Soybean
Fallow	Upland rice	Fallow	Soybean
M + C	Soybean	M + C	Upland rice
M + P	Soybean	M + P	Upland rice
M + P + U	Soybean	M + P + U	Upland rice
Fallow	Soybean	Fallow	Upland rice

Cover crop (CC)	Biomass (t/hm^2)
M + C	12.7 b
M + P	12.4 b
M + P + U	14.9 a
Fallow	8.3 c
Crop rotation (CR)	
CC/cash crop (2015/2016)	9.7 b
CC/cash crop/CC/cash crop (2016/2017)	18.1 a$^{\#}$
ANOVA (*F* probability)	
Cover crop (CC)	< 0.001
Crop rotation (CR)	< 0.001
CC × CR	0.2083

M, Millet; C, Crotalaria; P, Pigeon pea (*Cajanus cajans*); U, *Urochloa ruziziensis*.

[#] This value represents the sum of biomass production in 2015/2016 (9.7 t/hm^2) with 2016/2017 (8.4 t/hm^2).

Means followed by the same letter in columns do not differ by the Turkey test for $P < 0.05$.

both seasons. The base fertilization, to be applied in the sowing furrows, was calculated according to the soil chemical characteristics and the recommendations of Sousa and Lobato (2003). Therefore, sowing fertilization was 15 kg/hm^2 N as urea, 90 kg/hm^2 P_2O_5 as triple superphosphate, and 45 kg/hm^2 K_2O as potassium chloride in both years. Nitrogen topdressing fertilization with 60 kg/hm^2 N (as urea) was done 40 d after the rice emergence. Cultural practices were performed according to standard recommendations for a rice crop to keep the area free from weeds, diseases and insects.

Soil chemical measurements

Soil chemical characteristics (pH, SOM, P, H + Al, Al, K, Ca and Mg) were determined for the 0–0.05, 0.06–0.10 and 0.11–0.20 m layers according to Donagema et al (2011). Soil samples were taken on March both in 2016 and 2017. Eight subsamples were collected for each composite sample in each plot. The soil pH was determined in a 0.01 mol/L $CaCl_2$ suspension (1:2.5 soil/solution). Exchangeable Ca, Mg and Al were extracted with neutral 1 mol/L KCl in a 1:10 soil/solution ratio and determined by titration with a 0.025 mol/L NaOH solution. Phosphorus and exchangeable K were extracted with a Mehlich 1 extracting solution (0.05 mol/L HCl in 0.0125 mol/L H_2SO_4). The extracts were colorimetrically analyzed for P, and flame photometry was used to analyze K. Soil organic matter was determined by the method of Walkley and Black (1934).

Soil physical measurements

Soil samples with disturbed and undisturbed structure were collected in all treatments in June 2015 (initial sample) and in May 2017 (final analysis), in the 0–0.10 and 0.11–0.20 m layers, with nine replicates.

The soil samples with disturbed structure were used to determine the soil particle density (PD) by the volumetric flask method. The undisturbed samples, collected in cylinders 0.05 m in diameter and 0.05 m in height, were used to determine soil water retention curve and soil bulk density (BD). The total porosity (TP) was calculated by the equation: $TP = (1 - BD / PD)$. Microporosity (Mip) was determined by the water content retained at 6 kPa tension, and macroporosity (Map) was obtained by the difference between TP and Mip (Donagema et al, 2011). The soil water retention curves were determined using the centrifugal method (Freitas Júnior and Silva, 1984) and they were adjusted by means of nonlinear regression using the mathematical model proposed by van Genuchten (1980), given by:

$$\theta = (\theta_{\mathrm{sat}} - \theta_{\mathrm{res}}) [1 + (\alpha h)^n]^{-m} + \theta_{\mathrm{res}} \qquad (1)$$

where θ, θ_{sat} and θ_{res} are the soil water contents corresponding to the tension h, saturation and residual moisture, respectively; h is the matrix water tension of the soil in kPa, n and m ($m = 1 - 1 / n$) are dimensionless empirical fitting parameters and α is a parameter expressed in kPa^{-1}.

Based on the parameters obtained, the S index, tangent to the soil water retention curve at the inflection point, was determined according to the equation (Dexter, 2004):

$$S = -n (\theta_{\mathrm{sat}} - \theta_{\mathrm{res}})(1 + 1 / m)^{-(1 + m)} \qquad (2)$$

Soil air capacity (SAC) was calculated according to the relation (Reynolds et al, 2002):

$$SAC = (TP - FC) / TP \qquad (3)$$

in which FC is the field capacity, considered equal to the soil water content at 8 kPa.

Available water capacity (AWC) was calculated by the difference between the FC and the water content at 1 500 kPa, considered the permanent wilting point (PWP), multiplied by the thickness of the considered layer.

Soybean yield measurements

Soybean was harvested on 25th February, 2016 and on 13th February, 2017 in the usable area, using a mechanical harvester. The soybean grains were weighed, and the yields were adjusted to a moisture content of 13% and converted to kg/hm^2. Agronomic characteristics, including number of pods per plant and number of seeds per pod, were evaluated for 10 randomly chosen plants per plot, along with the 100-grain weight (calculated from eight random samples per plot, adjusted to a moisture content of 13%).

Rice yield measurements

Rice was harvested on 14th March, 2016 and on 22nd March, 2017 in the usable area, using a mechanical harvester. Plots were evaluated for the number of panicles per plant, which was determined by counting the number of panicles within 1.0 m of one of the rows in the useful area of each plot. The number of grains per panicle and 1000-grain weight (water content adjusted to 13%) were randomly evaluated from each plot. Grain yield was determined by weighing the harvested grain of each plot.

Statistical analysis

For statistical analysis, the SAS Statistical Software, SAS Institute, Cary, NC, USA (SAS, 1999) was used. Data were subjected to an analysis of variance, and when the *F* test proved significant, the data were compared by a Tukey's test. Pearson's correlation analysis was also performed among the physical properties.

RESULTS

The mix millet + pigeon pea + *Urochloa* produced the highest biomass and differed from the others (Table 2). Fallow produced the lowest biomass and differed from the others. When comparing the biomass of different cover crop rotations, two cycles of cover crops produced more biomass and differed from the only one cycle of cover crops (Table 2).

There was no interaction between cover crops and growing seasons for the soil nutrients evaluated (Table 3). Cover crops and the fallow provided no significant changes in the pH, Ca, Mg, Al, H + Al, P, K, SOM, Cu, Fe, Mn and Zn content in the soil at layers 0–0.05 m, 0.06–0.10 m and 0.11–0.20 m (Table 3). However, growing seasons significantly affected chemical soil properties. At layer 0–0.05 m, pH, Ca, Mg, K and Fe contents were higher in the soil under two cycles of cover crops than soil under one cycle of cover crops (Table 3). In the same layer (0–0.05 m), Al, H + Al, Cu, Mn and Zn contents were higher under soil with one cycle of cover crops than under soil with two cycles of cover crops. Phosphorus and soil organic matter (SOM) contents were similar in both years (one or two cycles of cover crops).

In the depth of 0.06–0.10 m, pH, Ca, Mg, K and Fe contents were higher under two cycles of cover crops than under one cycle (Table 3). On the other hand, H +

Table 3. Soil chemical properties (0–0.05, 0.06–0.10 and 0.11–0.20 m in depth) at cash crop harvesting as affected by crop rotations (March 2016 and March 2017).

Treatment		pH			Ca (mmol/L)			Mg (mmol/L)			Al (mmol/L)		
		0–0.05	0.06–0.10	0.11–0.20	0–0.05	0.06–0.10	0.11–0.20	0–0.05	0.06–0.10	0.11–0.20	0–0.05	0.06–0.10	0.11–0.20
CC	M + C	5.37 a	5.13 a	5.08 a	28.92 a	19.70 a	20.49 a	12.93 a	8.15 a	7.58 a	0.67 a	1.25 a	1.08 a
	M + P	5.34 a	5.12 a	5.12 a	28.31 a	20.32 a	18.63 a	13.86 a	7.76 a	6.75 a	0.75 a	1.25 a	1.08 a
	M + P + U	5.30 a	5.13 a	5.08 a	26.92 a	18.80 a	18.16 a	12.65 a	8.21 a	7.20 a	0.92 a	1.08 a	1.08 a
	Fallow	5.29 a	5.17 a	5.13 a	27.63 a	20.85 a	21.24 a	11.54 a	7.84 a	7.51 a	0.75 a	1.17 a	1.08 a
CR	2016	5.10 b	4.89 b	4.82 b	19.79 b	15.41 b	13.26 b	11.46 b	7.57 b	5.45 b	0.92 a	1.25 a	1.25 a
	2017	5.54 a	5.39 a	5.38 a	36.10 a	24.42 a	26.00 a	13.53 a	8.41 a	9.08 a	0.63 b	1.13 a	0.92 b
ANOVA	CC	0.9080	0.9706	0.8910	0.8427	0.6618	0.2028	0.8095	0.9441	0.7225	0.7329	0.9020	0.9909
	CR	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.0464	0.0187	< 0.001	0.0439	0.4978	0.0442
	CC × CR	0.8826	0.9763	0.9440	0.9484	0.8880	0.8778	0.7653	0.7697	0.9344	0.8617	0.9841	0.8044

Treatment		H + Al (mmol/L)			P (mg/L)			K (mg/L)			SOM (g/kg)		
		0–0.05	0.06–0.10	0.11–0.20	0–0.05	0.06–0.10	0.11–0.20	0–0.05	0.06–0.10	0.11–0.20	0–0.05	0.06–0.10	0.11–0.20
CC	M + C	31.33 a	30.83 a	29.00 a	20.15 a	25.62 a	29.68 a	127.50 a	94.75 a	88.17 a	36.72 a	30.14 a	28.30 a
	M + P	31.25 a	30.92 a	28.33 a	30.54 a	26.46 a	25.93 a	118.17 a	87.83 a	73.25 a	36.56 a	30.83 a	28.06 a
	M + P + U	29.50 a	30.75 a	28.75 a	23.75 a	30.36 a	27.36 a	114.67 a	83.58 a	73.42 a	37.36 a	30.53 a	28.68 a
	Fallow	38.42 a	30.25 a	28.58 a	28.59 a	30.27 a	36.26 a	120.42 a	85.67 a	83.17 a	35.32 a	30.83 a	27.83 a
CR	2016	41.04 a	36.00 a	33.29 a	26.70 a	24.60 a	47.61 a	104.08 b	76.67 b	64.79 b	35.93 a	31.08 a	27.29 a
	2017	19.21 b	25.38 b	24.04 b	24.82 a	31.76 a	12.01 b	136.29 a	99.25 a	94.21 a	37.05 a	30.08 a	29.14 a
ANOVA	CC	0.5206	0.9741	0.9707	0.1974	0.7736	0.4464	0.9692	0.8592	0.5735	0.5129	0.9127	0.9278
	CR	< 0.001	< 0.001	< 0.001	0.6116	0.0879	< 0.001	0.0460	0.0247	0.0024	0.2552	0.2043	0.0546
	CC × CR	0.3400	0.9578	0.9277	0.1564	0.6906	0.8636	0.9581	0.5255	0.9099	0.6703	0.6379	0.7942

Treatment		Cu (mg/L)			Fe (mg/L)			Mn (mg/L)			Zn (mg/L)		
		0–0.05	0.06–0.10	0.11–0.20	0–0.05	0.06–0.10	0.11–0.20	0–0.05	0.06–0.10	0.11–0.20	0–0.05	0.06–0.10	0.11–0.20
CC	M + C	2.28 a	3.44 a	3.40 a	29.80 a	25.93 a	26.38 a	52.20 a	52.44 a	48.94 a	9.63 a	8.34 a	6.89 a
	M + P	2.55 a	3.66 a	3.52 a	28.34 a	27.22 a	26.15 a	55.08 a	52.85 a	49.22 a	10.88 a	8.87 a	7.09 a
	M + P + U	2.44 a	3.61 a	3.49 a	27.84 a	25.92 a	23.71 a	51.56 a	45.30 a	43.53 a	11.74 a	7.82 a	6.49 a
	Fallow	2.52 a	3.29 a	3.22 a	29.48 a	26.00 a	24.09 a	51.25 a	48.17 a	46.79 a	11.26 a	9.88 a	7.54 a
CR	2016	2.72 a	4.64 a	4.66 a	6.87 b	9.65 b	9.15 b	63.16 a	70.43 a	62.03 a	13.08 a	12.54 a	9.19 a
	2017	2.17 b	2.36 b	2.15 b	50.87 a	42.89 a	41.02 a	41.88 b	28.95 b	32.21 b	8.68 b	4.91 b	4.81 b
ANOVA	CC	0.6257	0.1235	0.3198	0.8056	0.8074	0.1235	0.7912	0.3283	0.6723	0.5129	0.3036	0.6405
	CR	0.0016	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.0001	< 0.001	< 0.001
	CC × CR	0.3429	0.6396	0.9358	0.6278	0.9549	0.2149	0.2112	0.3219	0.8839	0.8468	0.4202	0.6017

M, Millet; C, Crotalaria; P, Pigeon pea (*Cajanus cajans*); U, *Urochloa ruziziensis*; CC, Cover crop; CR, Crop rotation; SOM, Soil organic matter; ANOVA, Analysis of variance.

Means followed by the same letter in columns do not differ by the Turkey test for $P < 0.05$.

Table 4. Soil physical characters as affected by cover crops, sampling times and soil layers.

Treatment		BD (t/m^3)		TP		Mip		Map		*S* index		SAC		AWC (mm)	
		L1	L2	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2
CC	M + C	1.40 ab	1.47	0.47 b	0.45	0.39	0.39 b	0.079 ab	0.056 a	0.023 ab	0.020	0.18 ab	0.14 a	7.50	7.41
	M + P	1.39 b	1.46	0.48 a	0.45	0.40	0.40 b	0.082 a	0.056 a	0.024 ab	0.020	0.19 a	0.14 a	7.50	7.35
	M + P + U	1.38 b	1.45	0.48 a	0.46	0.40	0.40 b	0.083 a	0.056 a	0.025 a	0.020	0.19 a	0.14 a	7.60	7.20
	Fallow	1.42 a	1.47	0.47 b	0.45	0.40	0.41 a	0.064 b	0.040 b	0.021 b	0.019	0.15 b	0.10 b	7.40	7.45
CR	2016	1.43 a	1.49 a	0.47 b	0.44 b	0.41 a	0.40 a	0.060 b	0.039 b	0.021 b	0.019 a	0.14 b	0.10 b	7.81 a	7.85 a
	2017	1.37 b	1.43 b	0.48 a	0.46 a	0.39 b	0.39 b	0.095 a	0.065 a	0.024 a	0.029 a	0.21 a	0.15 a	7.18 b	6.86 b
ANOVA	CC	0.050	0.720	0.004	0.779	0.187	0.008	0.048	0.043	0.049	0.785	0.049	0.041	0.873	0.825
	Y	< 0.001	< 0.001	< 0.001	0.0001	< 0.001	0.024	< 0.001	< 0.001	0.001	0.4914	< 0.001	< 0.001	< 0.001	< 0.001
	CC × Y	0.052	0.799	0.129	0.570	0.078	0.102	0.077	0.638	0.330	0.469	0.056	0.656	0.250	0.101

M, Millet; C, Crotalaria; P, Pigeon pea (*Cajanus cajans*); U, *Urochloa ruziziensis*; CC, Cover crop; CR, Crop rotation; BD, Bulk density; TP, Total porosity; Mip, Microporosity; Map, Macroporosity; SAC, Soil air capacity; AWC, Available water capacity; L1, 0–0.10 cm; L2, 0.11–0.20 cm.

Means followed by the same letter in columns do not differ by Turkey test for $P < 0.05$.

Al, Cu, Mn and Zn contents were higher under one cycle of cover crops than under two cycles. Al, P and SOM contents had similar values in both growing seasons (one or two cycles of cover crops).

Regarding the layer 0.11–0.20 m, pH, Ca, Mg, K and Fe contents were higher under two cycles of cover crops than under one cycle (Table 3). The contents of Al, H + Al, P, Cu, Mn and Zn were higher under one cycle of cover crops than under two cycles. SOM had similar values in both growing seasons (one or two cycles of cover crops).

There was no interaction between cover crops and sample year for the soil physical properties evaluated (Table 4). After two years (two cycles of cover crops), the cover crops, including fallow, promoted improvement in soil physical properties in the two layers studied. Bulk density, microporosity and available water capacity decreased, and total porosity, macroporosity, *S* index (only in 0–0.10 m layer) and soil air capacity increased.

In the 0–0.10 m layer, the cover crops, with the exception of millet + crotalaria, provided improvements in soil physical properties compared with fallow (Table 4). They promoted reduction in bulk density and increases in total porosity, macroporosity, *S* index and soil air capacity. In this layer, the microporosity and the available water capacity were not affected by the cover crops. In the 0.11–0.20 m layer, all cover crops promoted increases in macroporosity and soil air capacity and a reduction in microporosity compared with fallow. As the S index and soil air capacity were highly related to soil pore arrangement, they presented a positive correlation with macroporosity and total porosity, and showed a negative correlation with bulk density (Table 5).

There was no interaction between cover crops and previous crop for yield components and grain yield of upland rice and soybean (Table 6). The number of rice pods per plant was higher under the cover crop millet + crotalaria (187 panicles per plant) and differed from fallow (145 panicles per plant). Number of grains per panicle was higher in the cover crops millet + pigeon pea (124 grains per panicle) and differed from fallow (97 grains per panicle). There was no difference presented by the cover crops for 1000-grain weight. Grain yield was higher under millet + crotalaria (2 580 kg/hm^2) and millet + pigeon pea (2 740 kg/hm^2), and differed from fallow (1 981 kg/hm^2).

Regarding growing season (one or two cycles of cover crops), number of pods per plant was higher for two cycles of cover crops (186) in 2016/2017 than one cycle of cover crops (164) in 2015/2016. On the other hand, number of grains per panicle was higher for one cycle of cover crops (119) in 2015/2016 than for two cycles of cover crops (99) in 2016/2017. Grain yield and 1000-grain weight were similar in both growing seasons (one and two cycles of cover crops).

There was no difference among number of pods per plant, number of grains per panicle, 1000-grain weight and grain yield of soybean under the cover crops evaluated (Table 6). In the comparison of growing

Table 5. Correlation coefficient (*r*) among soil physical properties.

Trait	BD	TP	Mip	Map	S	SAC	AWC
BD		**-0.99***	**0.20**	**-0.89***	**-0.93***	**-0.85***	**-0.41**
TP	-0.92*		**-0.10**	**0.84***	**0.90***	**0.80***	**0.40**
Mip	0.06	0.15		**-0.62***	**-0.46**	**-0.66***	**-0.32**
Map	-0.87*	0.83*	-0.43		**0.96***	**0.99***	**0.49**
S	-0.81*	0.79*	-0.32	0.90*		**0.92***	**0.55**
SAC	-0.87*	0.81*	-0.45	0.99*	0.88*		**0.48**
AWC	0.21	-0.08	0.11	-0.13	-0.16	-0.12	

BD, Bulk density; TP, Total porosity; Mip, Microporosity; Map, Macroporosity; SAC, Soil air capacity; AWC, Available water capacity.

Values followed by an asterisk are significant at 1% probability. Values in regular and in bold are data for 2015 and 2017, respectively.

Table 6. Yield and nutrition traits in rice and soybean.

Treatment		NPP		NGP		TGW (g)		GY (kg/hm^2)		N (g/kg)		P (g/kg)	
		Rice	Soybean	Rice	Soybean	Rice	Soybean	Rice	Soybean	Rice	Soybean	Rice	Soybean
CC	M + C	187 a	72 a	116 ab	2.55 a	25.22 a	15.68 a	2 580 a	3 440 a	15.5 a	55.86 ab	3.02 a	5.32 a
	M + P	169 ab	78 a	124 a	2.57 a	25.08 a	15.68 a	2 740 a	3 310 a	16.3 a	56.83 a	2.98 a	5.44 a
	M + P + U	199 a	76 a	100 b	2.52 a	26.50 a	15.91 a	2 362 ab	3 538 a	16.8 a	55.30 ab	3.20 a	5.41 a
	Fallow	145 b	74 a	97 b	2.53 a	24.18 a	15.47 a	1 981 b	3 297 a	16.7 a	54.72 b	2.90 a	5.18 a
CR	2016	164 b	76 a	119 a	2.52 a	25.42 a	15.36 b	2 522 a	3 252 b	18.1 a	58.3 a	3.32 a	5.92 a
	2017	186 a	75 a	99 b	2.56 a	25.08 a	16.01 a	2 301 a	3 541 a	14.6 b	53.1 b	2.74 b	4.75 b
ANOVA	CC	0.0421	0.4695	0.0450	0.7881	0.3730	0.5353	0.0159	0.6599	0.5130	0.0173	0.3924	0.2932
	Y	0.0218	0.5761	0.0201	0.2683	0.7119	0.0074	0.1767	0.0434	0.0002	<0.001	0.0003	<0.001
	CC × Y	0.7667	0.6116	0.0613	0.4787	0.8953	0.3951	0.3795	0.1899	0.4917	0.1063	0.8534	0.3224

Treatment		K (g/kg)		Ca (g/kg)		Mg (g/kg)		Cu (mg/kg)		Fe (mg/kg)		Mn (mg/kg)		Zn (mg/kg)	
		Rice	Soybean	Rice	Soybean	Rice	Soybean	Rice	Soybean	Rice	Soybean	Rice	Soybean	Rice	Soybean
CC	M + C	2.46 a	12.20 a	0.34 a	2.45 a	1.36 a	2.62 b	4.9 a	11.1 bc	33 a	77 a	31 a	22 a	32 a	40 a
	M + P	2.44 a	12.90 a	0.33 a	2.52 a	1.36 a	2.74 a	5.1 a	11.5 ab	39 a	84 a	39 a	23 a	33 a	40 a
	M + P + U	2.50 a	12.80 a	0.34 a	2.49 a	1.41 a	2.75 a	5.0 a	12.0 a	34 a	81 a	34 a	23 a	34 a	40 a
	Fallow	2.44 a	13.05 a	0.33 a	2.52 a	1.33 a	2.72 a	4.4 a	10.6 c	34 a	81 a	29 a	22 a	31 a	38 a
CR	2016	2.61 a	7.98 b	0.37 a	2.34 b	1.48 a	2.87 a	4.8 a	10.9 b	45 a	79 a	38 a	21 b	33 a	41 a
	2017	2.29 b	17.49 a	0.29 b	2.65 a	1.25 b	2.53 b	4.9 a	11.7 a	25 b	82 a	28 b	23 a	32 a	38 b
ANOVA	CC	0.9462	0.6634	0.8895	0.5922	0.7513	0.0332	0.5219	0.0327	0.7881	0.4918	0.4452	0.6383	0.4684	0.7127
	Y	0.0017	< 0.001	< 0.001	< 0.001	0.0006	< 0.001	0.6535	0.0149	0.0003	0.4498	0.0415	0.0047	0.5356	0.0079
	CC × Y	0.4140	0.0955	0.7600	0.1132	0.7021	0.5705	0.7540	0.0599	0.7329	0.7714	0.3090	0.5321	0.0512	0.7450

M, Millet; C, Crotalaria; P, Pigeon pea (*Cajanus cajans*); U, *Urochloa ruziziensis*; CC, Cover crop; CR, Crop rotation; NPP, Number of panicles per plant; NGP, Number of grains per panicle; TGW, 1000-grain weight; GY, Grain yield.

Means followed by the same letter in columns do not differ by Turkey test for $P < 0.05$.

seasons (one or two cycles of cover crops), 1000-grain weight and grain yield were higher in 2016/2017 (two cycles of cover crops) than in 2015/2016 (one cycle of cover crops). On the other hand, number of pods per plant and number of grains per panicle were similar in both growing seasons (one and two cycles of cover crops).

DISCUSSION

The different mix of cover crops was unable to provide different results in the chemical attributes of the soil. Moreti et al (2007) reported that cover crops could significantly affect the soil chemical attributes. However, in our trial, these effects were similar among the mixtures used in all the layers evaluated (0–0.05, 0.06–0.10 and 0.11–0.20 m). On the other hand, the system cover crops / cash crops / cover crops / cash crops was more efficient to change soil chemical properties than the system cover crops / cash crops. This could be because two cycles of cover crops produced more biomass. Pacheco et al (2011) and Nascente et al (2013a) reported that cover crops can produce high biomass, and during the period of straw degradation, after chemical desiccation (herbicide application), they can release nutrients to the soil. In this sense, two cycles of cover crops reduced pH, Al and H + Al contents and increased Ca, Mg, K and Fe contents. According to Pacheco et al (2011), cover crops can significantly change the soil chemical attributes. Crusciol et al (2015) added that cover crops have great potential for the absorption and accumulation of K^+, which is returned to the ground after their desiccation. However, there is no increase in the SOM in the crop rotations used. The use of cover crops in no-tillage systems, due to keeping straw on the soil surface without plowing, normally provides for increases in the soil's organic matter through the years (Nascente et al, 2013a; Crusciol et al, 2015). However, only two growing seasons using cover crops was not able to significantly improve SOM when compared with one season using cover crops. Nascente et al (2013b, 2014) also reported similar values in the levels of SOM when different cover crops were used in the no-tillage system. The magnitude of SOM increase after using a NTS is dependent on soil type, species and biomass input of cover crops and regional climate (Santos et al, 2011). Short-term changes in total SOM due to the soil management practices are often small and difficult to assess (Zotarelli et al, 2007).

The improvement in soil physical properties due to cover crops, especially under millet + pigeon pea and millet + pigeon pea + *Urochloa*, is due to the beneficial influence of grasses on the structure and stability of soil aggregates, as demonstrated by several researchers (Tisdall and Oades, 1979; Silva and

Mielniczuk, 1997; Rilling et al, 2002), and is attributed to the high root density, which promotes the aggregation of the particles by the constant soil water uptake, periodic renewal of the root system and the uniform distribution of soil exudates, which stimulate microbial activity, whose byproducts act in the formation and stabilization of aggregates (Silva and Mielniczuk, 1997). Corroborating this information, Silva et al (1998) and Nascente et al (2013b) found that *Urochloa ruziziensis* improves soil aggregation.

In turn, Campos et al (1999) and Wohlenberg et al (2004) verified that the sequence of crops with the succession of grasses with legumes is the one that favors the greater soil aggregation. The former authors attributes this performance to the root system of the grass and to the rate of legume decomposition, creating favorable environment for the aggregation by the roots action, soil cover, supply of organic material and conservation of moisture favorable to the action of the microorganisms.

In general, soil physical conditions favorable to plant growth have been associated with a minimum air porosity of 0.10 m^3/m^3 (Dexter, 1988; Xu et al, 1992), below which the diffusion of oxygen becomes limiting to the functioning of the roots. In the two layers, all values of macroporosity were lower than the limit of 0.10 m^3/m^3, signaling some degree of compaction. The highest values of macroporosity, in absolute values, were verified in the soil where pigeon pea was included as cover crop. Andrade et al (2009) found that pigeon pea contributes to increased macroporosity in surface layer of a soil grown with common bean.

Considering S of 0.035 as a limit between good structural soil and soil with a tendency to become degraded and S no more than 0.020 as indicative of totally physically degraded soils (Dexter, 2004), it is verified that only in the 0–0.10 m layer, the cover crops provided values greater than 0.020. Andrade et al (2009) verified that corn intercropped with *Urochloa*, crotalaria and pigeon pea increases the S index in the 0–0.10 m layer of a soil cultivated with common bean.

In addition, in the two layers, all values of soil air capacity were below 0.34, which is considered the value that reflects good soil physical quality (Reynolds et al, 2002). The decrease in the available water capacity in the two soil layers, after two years (Table 4), probably occurred due to changes in bulk density and microporosity, although it did not correlate significantly with these soil physical properties (Table 5). The available water capacity depends on PWP and FC. According to Reynolds et al (2002), the soil water content in PWP is determined primarily by its clay content, which is not greatly affected by soil management. FC, in turn, is defined by a complex interaction of clay content, bulk density and soil organic matter, and changes in these factors are often compensated, albeit partially, in their impact on the value of FC, being responsible for the inconsistency of results.

Upland rice had the lowest grain yield under fallow, which produced the lowest biomass. The biomass of cover plants has significant influence on soil structure and water and air flows (Cunha et al, 2011). The soil under fallow showed higher soil bulk density and lower total porosity, macroporosity and soil air capacity. According to Guimarães and Moreira (2001), upland rice development is decreased with increasing soil bulk density. Guimarães et al (2011) added that increasing soil bulk density can reduce root development with significant effect on grain yield.

Regarding soybean yield, it was observed that the mixture of cover crops did not affect its grain yield. In the same way, Nascente and Crusciol (2012) reported that species of cover crops (millet, *Panicum maximum*, *Urochloa ruziziensis*, *Urochloa brizantha* and fallow) do not affect soybean yield. Ricce et al (2011) added that cover crops when correctly managed do not impair soybean emergence and development, even with large biomass. Besides, two cycles of cover crops provided better development of soybean plants and allowed increases in grain yield.

Our results showed that using cover crops at offseason in agricultural systems that involves soybean and upland rice at summer season in rotation for two growing seasons was interesting once it improved soil fertility, such as increasing Ca, Mg, K and Fe contents in the soil and reducing pH, Al and H + Al contents, reduced soil bulk density, improved total porosity of soil and increased soybean grain yield. Besides, to be environmental friendly, the use of cover crops allows reducing soil erosion and it is better than fallow, because using continuous fallowing in the NTS in rotation with cash crops increases the number of weeds in agricultural areas (Castro et al, 2011; Nascente et al, 2013a).

CONCLUSIONS

Cover crops alone provided no changes in soil chemical properties. However, the rotation cover crops / cash crops / cover crops / cash crops reduced pH, Al and H + Al and increased Ca, Mg, K and Fe contents in the soil. The cover crops millet + pigeon pea and millet + pigeon pea + *Urochloa* improved soil physical properties in relation to fallow, especially in the 0–0.10 m soil layer. In spite of the improvement of the soil physical properties after two years of rotation with cover crops and cash crops, the soil physical quality is still below the recommended level, according to the values of macroporosity, *S* index and soil aeration capacity. Upland rice production was higher under mixtures of cover crops than under fallow, mainly because of soil physical changes affected by these mixtures of cover crops. Soybean grain yield was similar for all cover crops tested, but was higher after the rotation cover crops / upland rice / cover crops than after only one cycle of cover crops.

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SUPPLEMENTAL DATA

The following material is available in the online version of this article at http://www.sciencedirect.com/science/journal/16726308; http://www.ricescience.org.

Supplemental Fig. 1. Temperature and the amount of rainfall data during the period of this study.

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