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Cover Crops and Nitrogen Fertilization Effects on Nitrogen Soil Fractions under Corn Cultivation in a No-Tillage System

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ABSTRACT: The use of cover crops has recently increased and represents an essential practice for the sustainability of no-tillage systems in the *Cerrado* region. However, there is little information on the effects of nitrogen fertilization and cover crop use on nitrogen soil fractions. This study assessed changes in the N forms in soil cropped to cover crops prior to corn growing. The experiment consisted of a randomized complete block design arranged in split-plots with three replications. Cover crops were tested in the plots, and the N topdressing fertilization was assessed in the subplots. The following cover species were planted in succession to corn for eight years: *Urochloa ruziziensis*, *Canavalia brasiliensis* M. ex Benth, *Cajanus cajan* (L.) Millsp, and *Sorghum bicolor* (L.) Moench. After corn harvesting, the soil was sampled at depths of 0.00-0.10 and 0.10-0.20 m. The cover crops showed different effects at different soil depths. The soil cultivated with *U. ruziziensis* showed higher contents of total-N and particulate-N than the soil cultivated with *C. cajan*. Particulate-N was the most sensitive to changes in the soil management among the fractions of N assessed. The soil under N topdressing showed a lower content of available-N in the 0.10-0.20 m layer, which may be caused by the season in which the sampling was conducted or the greater uptake of the available-N by corn.

Keywords: soil management, plant nutrition, fertilization and nutrition of annual crops.

INTRODUCTION

Corn is the most important food crop in the world, with an average production of more than 950 million tons in 2014 (USDA, 2015). The area planted in corn in Brazil is 15.76 million hectares with an average yield of 4.84 Mg ha^{-1} (Conab, 2013). During the winter, prior to corn planting, cover crops can be used to protect the soil and absorb nutrients from deeper soil layers to be released to soil after crop residue decomposition (Duda et al., 2003; Ziech et al., 2015).

Nitrogen is the nutrient with the highest demand by crops, and 40-60 % of the N absorbed by crops comes from nitrogen fertilization with synthetic fertilizers applied to the soil, a practice that accounts for 20 % of the production cost (Zagonel et al., 2002).

Nitrogen availability depends on the content of the directly available N represented by inorganic N forms as well as organic and mineralizable forms during its cycle (Camargo et al., 1997; Lorensini et al., 2014). Approximately 98 % of total soil N occurs in organic forms, and a significant portion of N is not readily available to plants (Urquiaga and Zapata, 2000). However, some N-fractions can be mineralized and become available to plants as nitrate and ammonium (D´Andrea et al., 2004), such as available-N and particulate-N and their mineralizable forms. The availability of these N forms depends on their location and content in the soil profile and on the soil tillage regime adopted (D'Andrea et al., 2004).

Among the various N fractions of different chemical compositions in the soil, amino sugars and amino acids are part of the soil available-N fractions and can be an important source of N for use by crops (Curtin and McCallun, 2004). However, it is difficult to predict the contribution of N mineralization during the crop cycle; the availability of this nutrient depends on a number of factors including, its mineral forms (nitrate and ammonium) and rapidly mineralized organic forms, which are functions of biotic and abiotic factors, as well as the total N content and the soil C/N ratio, soil moisture and temperature (Knoepp and Vose, 2007; Ferreira et al., 2014).

Particulate-N fraction (>53 μm) is one of the most sensitive to changes in soil, and this compartment plays an important role in nutrient cycling, being considered a labile N fraction in the soil (Conceição et al., 2005; Luce et al., 2014). After microbial mineralization, this fraction is an important source of mineral N in agricultural soils (Luce et al., 2014). Furthermore, this fraction is related to the formation and stabilization of soil aggregates (Six et al., 2002).

In soil cultivated with corn without cover crops, the mineral N content rapidly decreases after nitrogen fertilization due to various factors, such as crop absorption, leaching (Ros et al., 2003) and incorporation by microbial biomass (Coser et al., 2007; Kuzyakov and Xu, 2013). The use of cover crops may minimize the rapid soil N decrease at the beginning of the growing season. In addition, lack of soil disturbance, due to such factors as no-tillage systems, helps to minimize organic matter loss and increase soil C and N stocks (Diekow et al., 2005) over the years. No-tillage makes it possible to use cover crops that alter nutrient cycling and the processes of mineralization and immobilization in the soil, which depend on the C/N ratio of its crop residue and lignin, cellulose and hemicellulose content (Carvalho et al., 2012; Ferreira et al., 2014).

Given the complex dynamics of N in the soil and the increased use of cover crops with different chemical compositions in production systems, studies of the effects of these plants in different soil N fractions are needed. However, few studies have been performed in areas under a no-tillage system in the Brazilian *Cerrado* region.

The hypothesis of this study is that cover crop species with different chemical compositions (N, lignin, cellulose, hemicellulose, C/N ratio, lignin/N ratio) influence the soil organic N availability and the concentrations of soil nitrate and ammonium. This study aimed to assess cover crops and N topdressing effects on N soil fractions in plots cultivated with corn in a no-tillage system in the Brazilian *Cerrado* region.

MATERIALS AND METHODS

Location and characteristics of the experimental area

The experiment was carried out at Embrapa Cerrados in Planaltina, DF (15° 35’ 30” S and 47° 42’ 00” W), in the central western region of Brazil. It was conducted on a succession of corn and cover crops grown on the same plots since 2005. The climate, according to Köppen’s classification system, is Aw (rainy tropical), with dry winters and rainy summers. Moreover, a striking feature of the local climate in the *Cerrado* region is a short dry period in the rainy season, called *veranico*. Data on the precipitation and air temperature during the implementation of the experiment are shown in figure 1.

Before the experiment, the area had been used for soybean/corn rotation from 1999 to 2004. The soil was classified as *Latossolo Vermelho Distrófico*, in according to the Brazilian Soil Classification (Santos et al., 2013), a clayey Oxisol, in Soil Taxonomy. The soil chemical characteristics at the start of the experiment were as follows: pH(H_2O) 6.0; organic matter 21.7 g kg^{-1}; $P_{Mehlich-1}$ 0.9 mg kg^{-1}; Al^{3+} 0.1 $cmol_c$ kg^{-1}; Ca^{2+}+Mg^{2+} 2.9 $cmol_c$ kg^{-1}; K^+ 0.1 $cmol_c$ kg^{-1}. The mineralogical composition of the diagnostic horizon of the studied soil was kaolinite (320 g kg^{-1}), gibbsite (496 g kg^{-1}), hematite (142 g kg^{-1}) and goethite (42 g kg^{-1}), as described by Reatto et al. (2009).

Crop management and experimental design

Corn was sown in November 2005 under a no-tillage system over the following cover crop residues cultivated in the offseason of the same year: *Urochloa ruziziensis* Germain and Evrard (Poaceae), *Canavalia brasiliensis* Mart. ex Benth (Fabaceae), *Cajanus cajan* (L.) Millsp (Fabaceae) and *Sorghum bicolor* (L.) Moench (Poaceae). The density of *C. cajan*, *S. bicolor* and *U. ruziziensis* was 20 plants m^{-1}, and 10 plants m^{-1} for *C. brasiliensis*. A spacing of 0.5 m between planting rows was used for all species, as recommended by Carvalho and Amabile (2006). The chemical composition of the cover crops is described in table 1, according to Carvalho et al. (2012).

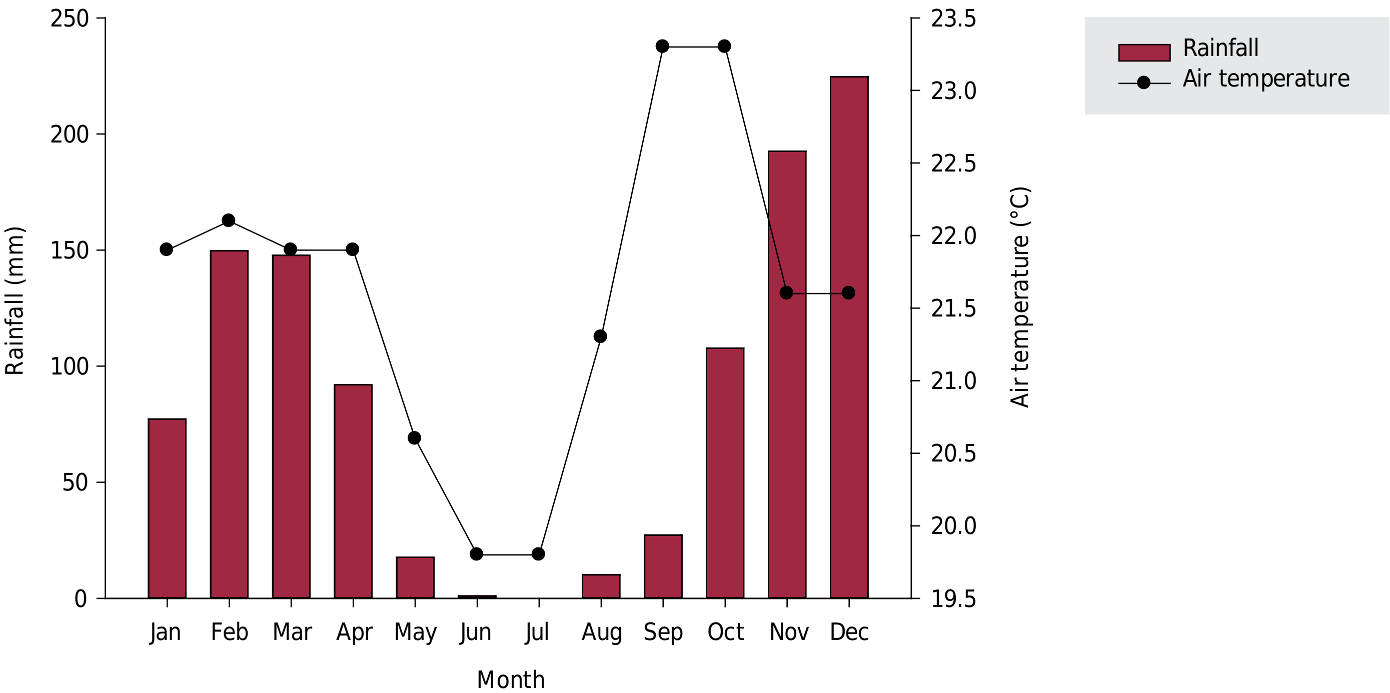

Figure 1. Mean temperature and rainfall during the experimental period.

Table 1. Carbon/Nitrogen ratio, hemicellulose, cellulose and lignin concentrations, and Lignin/Nitrogen ratio the aerial parts of cover plants

Cover Crop	C/N	Hemicellulose	Celullose	Lignin	Lignin/N
			g kg^{-1}		
Cajanus cajan	10.8	160.6	105.8	59.5	2.97
Canavalia brasiliensis	9.6	196.9	124.3	38.1	1.08
Sorghum bicolor	38.9	284.4	184.2	20.3	1.75
Urochloa ruziziensis	8.3	319.3	105.7	17.5	0.81

Values are means concentrations of flowering and maturity (Carvalho et al., 2012).

A randomized complete block design was arranged in split-plots with three replications. The plots were represented by the cover crops, and N topdressing fertilization on the corn crop (with and without N topdressing) was assessed in the subplots.

The corn crop was fertilized with 20 kg ha^{-1} of N, 150 kg ha^{-1} of P_2O_5 and 80 kg ha^{-1} of K_2O, which were applied at sowing. The N topdressing treatments were fertilized with two more applications of N performed with urea (75 kg ha^{-1} N) at the V4 and V6 corn growth stages.

Soil sampling and analysis

After the corn harvest in April 2013, soil samples were collected from the 0.0-0.10 and 0.10-0.20 m layers, forming one composite sample of each five subsamples. Portions of the samples were transported in an insulated box and stored at 4 °C for the determination of nitrate and ammonium. The remaining samples were air dried and passed through a 2 mm sieve (air-dried soil; ADS) to measure the available-N fractions.

Soil nitrate and ammonium determinations were carried out by extraction with potassium chloride. Total soil N was determined by the Kjeldahl method (Bremner and Mulvaney, 1982).

Available N in the soil was determined using extraction with Na_3PO_4 solution/borax buffer pH 11.2 + NO_3^- (Gianello and Bremner, 1986). In this method, 2 g of each sample were transferred to a micro-distiller and 25 mL of a buffer solution pH 11.2 (200 g $Na_3PO_4.12H_2O$ + 50 g Borax in 2000 mL of distilled water), 0.2 g MgO, 0.1 g Devarda's alloy and 10 drops of dimethicone were added to reduce excessive foaming in the presence of the alloy. The distillate was transferred to a 50 mL volumetric flask containing 10 mL of 0.05 mol L^{-1} HCl. The calculations were made using a calibration curve obtained by distillation of the N standard solutions containing 0, 10, 25, 50, 75 and 95 μg mL^{-1} of N. The N extracted was quantified by a colorimetric spectrophotometer UV/VIS at 440 nm, according to Gianelo and Bremner (1986).

Nitrogen granulometric fractionation was conducted according to Cambardella and Elliott (1992) with modifications proposed by Bayer et al. (2004) and Bongiovanni and Lobartini (2006). In this procedure, 20 g of ADS was weighed and placed in a 500 mL flask containing 70 mL of sodium hexamethaphosphate (5 g L^{-1}) and stirred for 15 h on a horizontal shaker at 130 rpm. After this period, the suspension was passed through a 53 μm sieve and washed with water jets. The material retained on the sieve was dried at 45°C and ground for analysis of the N content, according to Bremner and Mulvaney (1982). This fraction (>53 μm) corresponds to particulate-N. Mineral-associated N (MAN) was calculated as the difference between total soil N and particulate N.

Statistical analysis

The data were subjected to analysis of variance and the means compared by Tukey's test ($p<0.05$) using Statistical Analysis System (SAS) software.

Component analysis was used to identify the parameters of plant material quality, or the groups of these parameters, that best explain the presence of the different N fractions in soil due to the use of cover crops in a no-tillage system. Principal component analysis (PCA) was used for the distinction of the species studied, considering all the attributes together (C/N ratio, hemicellulose, cellulose, lignin, lignin/N, total-N, particulate-N, MAN, particulate-N/total-N, available-N, NO_3^-, NH_4^+, available-N/total-N). These analyses were carried out using the program XLSTAT 2011 (Addinsoft, 2011).

RESULTS AND DISCUSSION

Nitrogen soil fractions

Significant differences for the total soil N (total-N), particulate-N, mineral-associated N and the particulate-N/total-N ratio were observed in the 0.00-0.10 m layer for the different cover crops ($p<0.05$). There was no other effect of the N topdressing that was applied to the corn plants besides the interaction of cover crops × N fertilization. In the 0.10-0.20 m soil layer, there was no effect related to the cover crops, N fertilization or the interaction of these factors on the analyzed soil N fractions (Table 2).

The cover crops had similar results for the total-N in the leguminous plants (*C. cajan* and *C. brasiliense*) and in the grasses (*S. bicolor* and *U. ruziziensis*), but a higher total-N content in the soil was observed with the use of *U. ruziziensis* compared to the soil planted with *C. cajan* (Table 2). This shows the ability of *U. ruziziensis* to store N in the 0.00-0.10 m layer, especially when compared to *C. cajan*, a leguminous plant with the ability to fix atmospheric N.

Use of leguminous plants, in general, as cover crops in no-tillage systems increases the stock of total soil N (Amado et al., 2001; Conceição et al., 2005; Weber and Mielniczuk 2009), which is predominantly due to the incorporation of this element by biological N

Table 2. Total N (TN), particulate (Part-N)and mineral-associated N (MAN) and particulate N/total N (Part-N/TN) ratio, available nitrogen (Avail-N), ammonium, nitrate and available-N/total-N (Avail-N/TN) ratio in the soil under different cover crops, with and without nitrogen topdressing on corn in the 0.00-0.10 and 0.10-0.20 m layers

Cover crop	TN	Part-N	MAN	Part-N/TN	Avail-N	NO_3^-	NH_4^+	Avail-N/TN
	g kg^{-1}			%	mg kg^{-1}			%
0.00-0.10 m								
Cajanus cajan	1.39 b	0.36 b	1.03 a	25.92 b	25.77 a	5.85 a	3.56 b	1.86 a
Canavalia brasiliensis	1.49 ab	0.45 ab	1.03 a	30.64 b	44.77 a	4.85 a	3.17 b	2.59 a
Sorghum bicolor	1.40 ab	0.58 a	0.81 b	41.84 a	38.98 a	5.50 a	3.97 b	2.26 a
Urochloa ruziziensis	1.52 a	0.54 a	0.98 a	35.67 ab	32.33 a	4.40 a	13.38 a	2.12 a
N management								
Without N	1.43 a	0.49 a	0.94 a	34.15 a	31.59 a	5.07 a	11.38 a	2.19 a
With N	1.46 a	0.48 a	0.98 a	32.88 a	32.65 a	5.23 a	12.24 a	2.23 a
0.10-0.20 m								
Cajanus cajan	1.33 a	0.35 a	0.98 a	26.30 a	32.90 b	3.81 a	10.81 a	2.49 b
Canavalia brasiliensis	1.49 a	0.38 a	1.10 a	25.73 a	67.12 a	2.59 a	11.55 a	4.51 a
Sorghum bicolor	1.35 a	0.45 a	0.89 a	33.66 a	38.42 b	3,14 a	14.00 a	2.85 ab
Urochloa ruziziensis	1.43 a	0.46 a	0.97 a	32.18 a	38.41 b	5.16 a	18.01 a	2.68 b
N management								
Without N	1.37 a	0.40 a	0.98 a	28.77 a	52.65 a	3.19 a	16.32 a	3.78 a
With N	1.42 a	0.42 a	1.00 a	30.17 a	35.65 b	4.16 a	13.59 a	2.48 b

Means followed by the same letter in each column are not significantly different by Tukey's test ($p<0.05$).

fixation (BNF). However, the current study showed that, in addition to legumes, some species of grasses, such as *U. ruziziensis*, also promote an increase in total N. Although *C. cajan* is a legume that fixes significant amounts of N, its higher content of lignin and a higher lignin/N ratio (Table 1) compared to *U. ruziziensis* resulted in low N availability in the soil.

The two grass species (*U. ruziziensis* and *S. bicolor*) resulted in higher values of particulate-N (>53 μm) ($p<0.05$) in the soil than *C. cajan*, indicating that the chemical composition of the cover crop must have also influenced the levels of the more labile fraction of N in the soil. Additionally, the effect of the grasses on the particulate-N can be explained by the large input of organic matter in the rhizosphere of these species (*U. ruziziensis* and *S. bicolor*), which ensures greater aggregation in the topsoil (Garcia and Rosolem, 2010); this fraction is associated with the formation and stability of soil aggregates (Six et al., 2002). Moreover, particulate-N was the largest pool of labile organic N in soils under no-tillage and may represent a fraction of the soil organic N that is decomposed early in the growing season, thereby furnishing plant-available N to crops when N requirements are greatest (Luce et al., 2013).

Higher concentrations of particulate-N in the soil cultivated with *U. ruziziensis* than in the soil cultivated with *C. cajan* is due to the chemical composition of these cover crops, mainly the lignin content, which is 28 % lower in *U. ruziziensis* than in *C. cajan* (Table 1). Lignin is a component of plant tissue that decomposes slowly. Thus, although *C. cajan* is a N-fixing legume, it is possible that part of the N is more slowly absorbed by plant roots due to the lower rate of crop residue decomposition due to the high lignin and the greater lignin/N ratio (Carvalho et al., 2012). Although particulate-N is a reservoir of N that has a strong correlation with soil available-N (Luce et al., 2013), particulate-N is influenced by the chemical composition of the cover crops (Six et al., 2001). The residue quality measured as the (lignin + soluble polyphenol)-to-N ratio appeared to be well correlated with the N release pattern for four different prunings of high quality Leucaena (Vanlauwe and Sanginga, 2004). Only a small portion of the N-rich compounds derived from lignin, such as ammonoxidized lignin, is utilized for agricultural production in a short period because of its greater resistance to decomposition (De la Rosa et al., 2013). Although pasture and eucalyptus plantation particulate organic matter (POM) had similar C/N ratios, the net N mineralization was two-fold greater in the pasture POM than in the plantation POM, suggesting that biochemical characteristics other than the C/N ratio were a major influence on the net N mineralization rates (Mendham et al., 2004).

Soil cultivated with *S. bicolor* differed from all the other species ($p<0.01$) in mineral-associated N, resulting in a lower content of this fraction in the soil. This soil N compartment is considered less sensitive to management practices than particulate-N (Conceição et al., 2005).

The particulate-N/total N ratio was higher in the area cultivated with *S. bicolor* (41.84 %) compared to *C. cajan* and *C. brasiliensis* in the 0.00-0.10 m layer, with values of 25.92 and 30.64 %, respectively. These values are similar to those obtained by Conceição et al. (2005), ranging from 23 to 28 % with ryegrass and mucuna cover crops, respectively, in association with the corn crop. Additionally, Winck et al. (2014) obtained a particulate-N/total N ratio from 29 to 32 % at the soil superficial layer with several crop rotations in a no-tillage system.

In the 0.10-0.20 m layer, there was no effect of the cover crops with respect to the total-N, particulate-N, or mineral-associated N, indicating that, despite the addition of crop residues with different chemical compositions to the soil, their effects occurred only in the soil surface layer. Nitrogen fertilization altered N stocks in the 0.00-0.20 m layer in long-term experiments (22 years) (Weber and Mielniczuk, 2009). Nevertheless, this effect is smaller than that observed with the use of legumes. A lower C/N ratio favors mineralization of N in soil (Silva et al., 2008), and legumes have a higher decomposition rate than grasses (Torres et al., 2005). However, the lignin content, lignin/N ratio and polyphenol concentrations also influence the soil N mineralization (Carvalho et al., 2012).

Nitrogen added by symbiotic fixation is more efficient than N added by fertilizers in the promotion of soil C accumulation, and particulate fractions tend to accumulate if the soil is not turned, maintaining the soil organic matter labile fractions (Souza et al., 2009). The importance of N from the mineralization of cover crop residues in accumulating soil C was also observed by Sisti et al. (2004) in a long-term experiment with crop rotation compared to conventional tillage. Thus, cover crops could provide an additional source of N to the soil in addition to synthetic N fertilization, especially in low C emission agriculture systems.

The annual application of N to the corn crop did not change the total soil N content, particulate-N and mineral associated fractions in the two soil layers studied.

The use of cover crops influenced the amounts of ammonium ($p<0.01$) but did not impact the levels of available N and nitrate in the 0.00-0.10 m layer. Similarly, there was no effect of the topdressing-N and fertilization × cover crop interaction (Table 2). As soil collection was carried out at the end of the crop cycle (maturation stage of corn), most mineral N had possibly been absorbed by the crop or leached into the deeper layers of the soil profile, especially nitrate that is more mobile in soil. The ammonium content in the soil in this layer (0.00-0.10 m) cultivated with *U. ruziziensis* was 3.4 to 4.2 times higher than in the soil where other cover crops were planted (Table 2), indicating a high rate of nitrogen mineralization of its residues. Our data showed that *U. ruziziensis* has higher concentrations of compounds with high mineralization rates, which might provide more available nutrients for plants.

In the 0.10-0.20 m layer, there was an effect of the cover crops and topdressing-N for available-N ($p<0.01$). Moreover, there was also interaction between topdressing-N and the cover crops on the nitrate ammonium levels in the soil (Table 3).

In the 0.10-0.20 m layer, *C. brasiliensis* showed the highest available-N ($p<0.05$). This can be explained by its high biomass production, the efficiency of the BNF resulting in high incorporation of N in soil and accelerated crop residue decomposition with consequent higher nutrient mineralization (Carvalho et al., 2008;2012).

The amounts of total-N and particulate-N in the soil cultivated with *U. ruziziensis* grass were similar to those of the leguminous plant *C. brasiliensis* (Table 2) in the soil surface layer (0.00-0.10 m). In the 0.10-0.20 m layer, there was no significant difference in the total-N and particulate-N content between these cover crops. However, in the 0.10-0.20 m layer, under *U. ruziziensis* the available-N was 57 % lower than in the same layer under *C. brasiliensis*, showing the greater capacity of this legume to incorporate nutrients into subsurface soil layers (Table 2).

The chemical composition of the two species (*U. ruziziensis* and *C. brasiliensis*) that had a high rate of decomposition and high N concentration promotes nutrient recycling from crop residues and higher N input to the soil (Carvalho et al., 2012). The soil depths where these positive effects occur may vary as a result of the action of the plant root systems of cover crops.

The amounts of available-N and nitrate were similar between the cover crops and the topdressing-N treatments in the 0.00-0.10 m layer. In this layer, the concentration of ammonium in the soil cultivated with *U. ruziziensis* was 3.4 to 4.2 times higher than for the other cover crops, demonstrating the occurrence of N mineralization in deeper

Table 3. Interaction between cover crops and nitrogen topdressing in the ammonium content in the 0.10-0.20 m layer

Cover crop	With N topdressing	Without N topdressing
	mg kg^{-1}	
Cajanus cajan	10.81 aA	13.27 aA
Canavalia brasiliensis	11.55 aB	23.57 aA
Sorghum bicolor	14.00 aA	15.40 abA
Urochloa ruziziensis	18.01 aA	13.05 bA

Means followed by the same lowercase letter in each column and capital letter in each row are not significantly different by Tukey's test ($p<0.05$).

soil layers even at the end of the plant cycle. Moreover, part of the mineral N can be incorporated into microbial biomass (Coser et al., 2007); in this case, cover crops or topdressing-N had no effect on the available-N/total-N ratio in the 0.00-0.10 m layer.

The lowest N release in the soil by *C. cajan* may be due to its high content of recalcitrant C compounds, such as lignin (Carvalho et al., 2012). Although the rate of decomposition of *C. cajan* was 65 % and that of sorghum was 80 % in the 150 days after crop residues were applied to the soil (Kliemann et al., 2006), the present study did not show greater availability of N in the soil. It should be noted that *C. cajan* has a high BNF capacity, but N release in the soil via microbial decomposition may be subject to the lignin and lignin/N ratios in the crop residues (Table 1).

The available-N/total-N ratio under *U. ruziziensis* was lower than under *C. brasiliensis*, indicating that although the amount of total-N in this grass is similar to the other cover crops (Table 3), the available-N/total-N ratio was 1.57 times smaller than with *C. brasiliensis*, possibly promoting low N availability in the soil.

In the 0.10-0.20 m layer, the topdressing-N showed lower available-N than the treatment without topdressing-N ($p<0.01$), demonstrating that N application accelerated the mineralization of the cover crop residues in this layer and/or the occurrence of percolation of the available N to deeper soil layers. Adding N to the soil accelerates plant residue mineralization, mostly in the nitrate form (Vasconcellos et al., 2001), which can promote N leaching in the soil profile.

The available-N/total-N ratio was affected by cover crops and topdressing-N of the corn crop ($p<0.01$). *C. brasiliensis* showed a higher available-N/total-N ratio than *C. cajan* and *U. ruziziensis*. In the treatment with topdressing-N, the available-N/total-N ratio was lower in the 0.10-0.20 m layer.

In this same layer, there was a significant interaction between cover crops and topdressing-N for ammonium levels ($p<0.01$) in the soil (Table 3). After corn harvesting, there was a lower amount of ammonium in the treatment with topdressing-N only in the soil cultivated with *C. brasiliensis*. Because this leguminous plant has a low C/N ratio and low lignin contents (Table 1), N application likely contributed to the faster mineralization of plant residues added to the soil, reducing the levels of ammonium, possibly due to the higher nitrification rate in the deeper soil layer. However, in the treatments without topdressing-N, the soil cultivated with *U. ruziziensis* had lower levels of ammonium than the soil cultivated with legumes ($p<0.01$), regardless of their chemical composition. In the treatments with topdressing-N, there were no differences among the cover crops.

The data obtained for nitrate and ammonium in the soil are within the range normally obtained by other studies performed under similar conditions. Values between 6.7 and 9.41 mg of NH_4^+ + NO_3^- in soil cultivated with corn at the end of the cycle crop were obtained by Ros et al. (2003). Similarly, Ceretta et al. (2002) observed approximately 10 mg kg^{-1} of nitrate and ammonium in the 0.00-0.15 m layer, before planting the crop. Therefore, it can be inferred that the legumes showed different behaviors in the two soil layers in relation to the available-N soil fractions. Despite the similar values of total-N and particulate-N in the 0.00-0.10 m layer (Table 2), in the 0.10-0.20 m layer, *C. brasiliensis* promoted higher available-N and available-N/total-N ratio (Table 2). On the other hand, in the 0.00-0.10 m layer with *U. ruziziensis,* the total-N and mineral-associated N contents were similar to the values observed in the 0.00-0.10 m layer with *C. brasiliensis*, with a higher amount of ammonium in the soil. In the 0.10-0.20 m layer, a lower content of available-N and lower ratio between the available-N and total-N in the soil were observed.

Principal components analysis for nitrogen soil fractions

Two principal components were generated (PC 1 and PC 2) as tools for the distinction of species, considering all the attributes together (C/N ratio, hemicellulose, cellulose, lignin, lignin/N, total-N, particulate-N, MAN, particulate-N/total-N, available-N, NO_3^-, NH_4^+, available-N/total-N), for 0.00-0.10 m (Figure 2) and 0.10-0.20 m (Figure 3). Similar patterns were observed in both soil layers. The distribution of the selected variables showed a cumulative variance of 83.08 and 79.76 % for the sum of principal components PC1 and PC2 in the 0.00-0.10 and 0.10-0.20 m layers, respectively. The PC1 axis separated legumes from grasses in both layers. *U. ruziziensis* was associated with total-N, N-NH_4^+ and particulate-N at both depths and its hemicellulose content. The presence of lignin was the feature that most distinguished *C. cajan* from the other species.

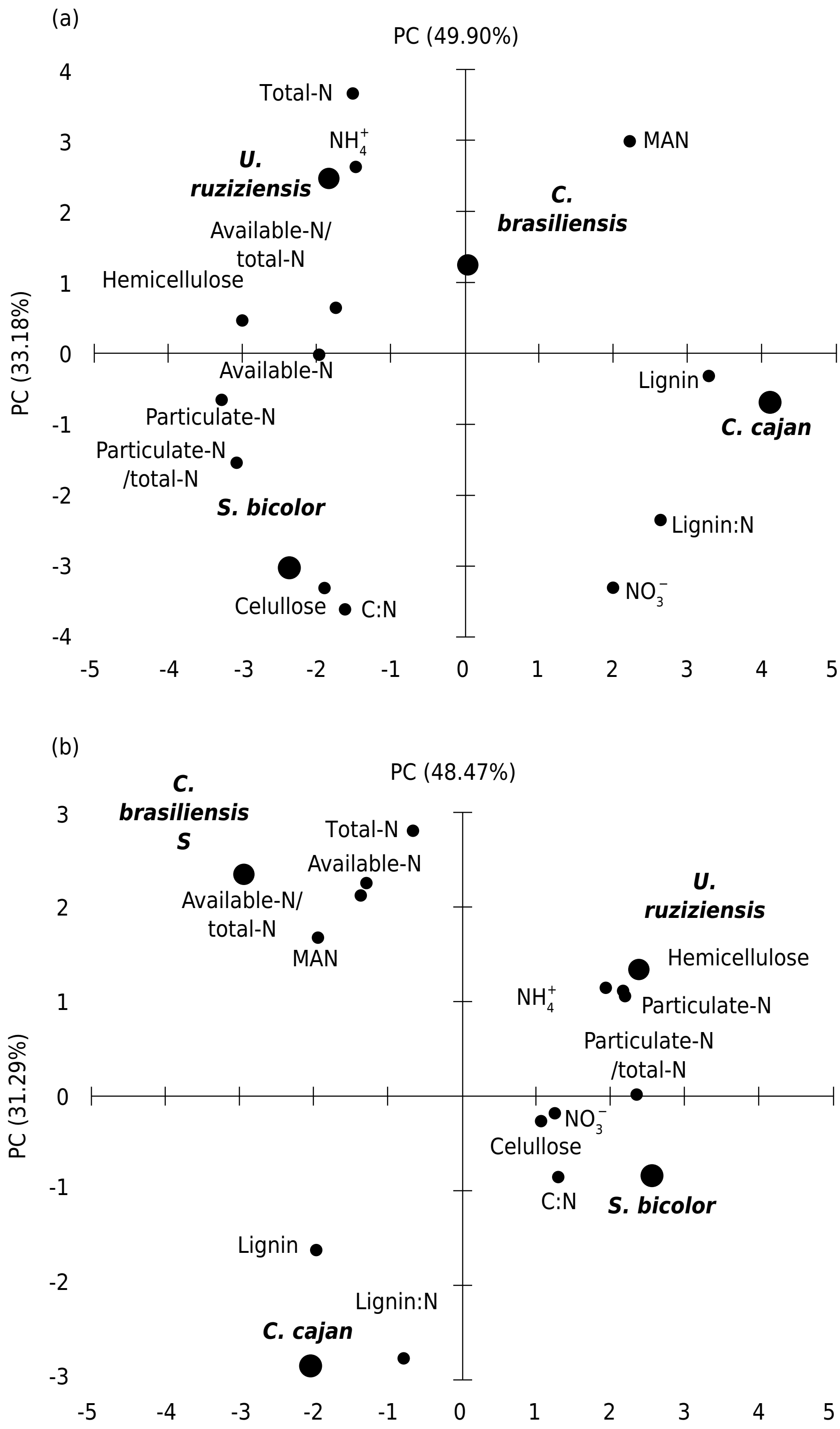

Figure 2. Ordination diagram based on principal component analysis of the studied variables, 0.00-0.10 m (a) and 0.10-0.20 m (b).

CONCLUSIONS

The studied cover crop species showed, in general, different abilities to accumulate nitrogen fractions in the soil as a result of their chemical characteristics.

The C/N ratio was the main characteristic that differentiated the abilities of cover crops to accumulate N in the soil; *C. brasiliensis* and *U. ruziziensis* with the lowest C/N ratios promoted the greatest soil available-N (0.10-0.20 m) and NH_4^+ (0.00-0.10 m) levels, respectively.

Of all the nitrogen soil fractions assessed, particulate-N was the most sensitive to changes in the type of soil management.

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