Expl Agric. (2017), volume 53 (2), pp. 242–254 © *Cambridge University Press 2016*
doi:10.1017/S001447971600034X

ORGANIC MATTER PRODUCTION AND CHEMICAL COMPOSITION OF COVER CROPS FERTILIZED WITH NPK

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(*Accepted 12 May 2016*; *First published online 20 June 2016*)

SUMMARY

The crop rotation is a practice to protect and improve the soil properties and an alternative to improve the quality of crop residues is the application of fertilizers at the planting of cover crops. Thus, we evaluated the effect of fertilization with nitrogen, phosphorus and potassium (NPK) on organic matter production and chemical composition of cover crops succeeding the corn crop. The treatments consisted of the cultivation of *Avena sativa* L., *Lupinus albus* L., *Pennisetum glaucum* L., *Raphanus sativus* L. and *Sorghum bicolor* L. with (200 kg ha^{-1} of NPK [08-28-16] applied by broadcast seeding) and without fertilization at planting. Organic matter production by all cover crops, as well as concentrations of neutral detergent fibre (NDF) in shoots and roots of *A. sativa* L. and *R. sativus* L. were higher when they were fertilized. *L. albus* L. showed higher NDF and acid detergent fibre (ADF) contents than the other cover crops, with and without fertilization. Nitrogen concentration increased, but the carbon/nitrogen ratio (C/N) in the shoots of *L. albus* L., *R. sativus* L. and *S. bicolor* L. decreased when fertilization was applied. The use of N by the *A. sativa* L. and *P. glaucum* L. and of P and K by *S. bicolor* L. was 16, 54, 82 and 20% more efficient, respectively, when fertilization was applied. The *A. sativa* L., *P. glaucum* L. and *R. sativus* L. showed higher NDF/N, ADF/N and hemicellulose/N ratios in the fertilized treatment. Although the results obtained in this study are highly satisfactory, more research should be conducted to evaluate the decomposition of crop residues from cover crops fertilized with NPK, and the effects of this strategy on corn crops in succession.

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INTRODUCTION

The growing global concern over the environment stimulates the adoption of conservationist management systems, and the use of cover crops in the succession of vegetable crops is an interesting practice to preserve the soil quality without preventing high yields in crops of economic interest, such as corn (Chivenge *et al.*, 2011; Nyamangara *et al.*, 2014). To this end, factors like the organic matter production and chemical composition of cover crops should be taken into account for the succession of vegetable crops, as they influence the release and cycling of nutrients (Koné *et al.*, 2008). In this regard, the concentrations of C, N and P, cell wall components (hemicellulose, cellulose and lignin) and their interrelationships have been evaluated in studies of cover crops because they are the most important regulators of decomposition of crop residues (Matos *et al.*, 2011; Mendonça and Stott, 2003).

High concentrations of nutrients (especially N and P), C/N ratios below 25:1, and low lignin contents in crop residues promote their decomposition and lead to faster release of nutrients, which fosters their direct nutritional effect as green fertilizers (Mafongoya *et al.*, 1997; Rosolem and Calonego, 2013). On the other hand, low-quality crop residues have an indirect nutritional effect because they modify the physical, chemical and biological properties of the soil (Tian and Kang, 1998). The fast decomposition of crop residues may be undesirable for the succession of vegetable crops in regions where winters are dry, like the Brazilian Southeast, where production and maintenance of crop residues are more difficult (Silva *et al.*, 2010). Therefore, it is essential to better know the chemical composition of cover crops for each region (Tian and Kang, 1998).

The organic matter production and chemical composition of cover crops vary according to species, region, climate and management (Thönnissen *et al.*, 2000). Therefore, fertilizing cover crops can be an alternative to increase organic matter production (crop residues) in regions with dry winters aiming to optimize the cultivation of corn in succession and generate more profit to producers (Foloni and Rosolem, 2008). However, little information exists on the chemical composition of cover crops as a function of application of NPK fertilizers in tropical regions with dry winters. Thus, our objective was to evaluate the effect of NPK fertilization on the organic matter production and chemical composition of legumes (white lupine), brassicas (forage radish) and grasses (oat, millet and forage sorghum) utilized as cover crops in succession to the corn crop established in an Oxisol soil in Southeast Brazil.

MATERIAL AND METHODS

Location and soil-climatic conditions

The field experiment was carried out in Alfenas-MG, Brazil (21º25'S and 45º56'W; altitude of 888 m). The climate of the region is classified as tropical humid and dry (rainy in the summers and dry in the winters), according to the Köppen classification (Köppen and Geiger, 1928), with an average annual precipitation of 1,590 mm. The climatic conditions recorded during the study are shown in Figure 1. The soil of the studied area was classified as an Oxisol (EMBRAPA, 1999), with the following chemical properties (Silva, 1999) in the top 0–20 cm layer: pH in $H_2O = 6.4$; P-Mehlich = 19

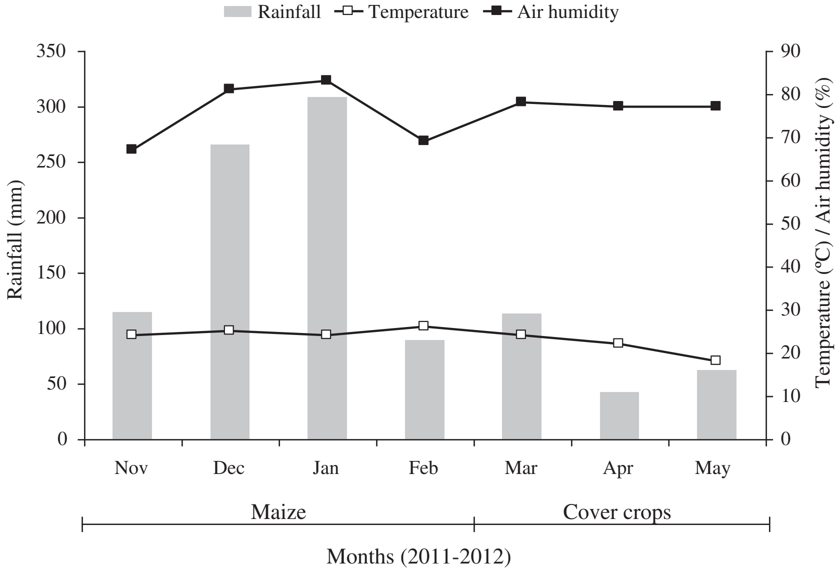

Figure 1. Monthly average accumulated precipitation, temperature and relative humidity of 3 the air from November 2011 to May 2012 in the city of Alfenas, Southeast Brazil.

mg dm^{-3}; K^{+} = 252 mg dm^{-3}; Ca^{2+} = 4.9 $cmol_c$ dm^{-3}; Mg^{2+} = 0.8 $cmol_c$ dm^{-3}; Al^{3+} = 0.0 $cmol_c$ dm^{-3}; H+Al = 1.9 $cmol_c$ dm^{-3}; sum of bases (SB) = 6.4 $cmol_c$ dm^{-3}; CEC = 8.3 $cmol_c$ dm^{-3}; base saturation (V%) = 77; aluminum saturation (m%) = 0; organic matter (OM) = 35 g kg^{-1} and remaining P= 15 mg L^{-1}. The organic matter content was considered medium, and the phosphorus and potassium contents were considered very high, according to the Soil Fertility Committee of Minas Gerais (*Comissão de Fertilidade do Solo do Estado de Minas Gerais*, CFSEMG, 1999).

Plant material and growth conditions

Before the implementation of the experiment, the area was planted with corn hybrid P30F53, which received 450 kg ha^{-1} of NPK (08-33-12) at planting, and had a fresh matter yield of 50 t ha^{-1} after 110 days of cultivation. After the corn was ensiled, the area was tilled manually to incorporate residues from the corn crop; to eliminate the *Brachiaria decumbens* Stapf. plants that occupied the corn interrows; for the seeding (±3 cm of depth) of cover crops (described below); and to incorporate the fertilizer into some treatments. The experiment was implemented according to the treatments, which consisted of the cultivation of five cover crops: oat (*Avena sativa* L. cv. IAC 7), white lupin (*Lupinus albus* L. cv. common), millet (*Pennisetum glaucum* L. cv. BN-2), forage radish (*Raphanus sativus* L. cv. IPR-116) and forage sorghum (*Sorghum bicolor* L. cv. AG 2002), using 80, 75, 30, 10 and 20 kg ha^{-1} of seeds at planting, respectively. The cover crops were cultivated with (200 kg ha^{-1} of NPK [08-28-16], applied during manual tilling) and without fertilization at planting, composing the 5 × 2 factorial arrangement.

The fertilization dose used at the planting (200 kg ha^{-1} of NPK) of cover crops was half of the amount recommended for the cultivation of corn in succession to cover crops (Raij *et al.*, 1996), since fertilized cover crops are expected to provide another part of nutrients (Silva *et al.*, 2008a). A randomized-blocks experimental design with three replicates was adopted. Experimental plots had an area of 15 m^2 (5 × 3 m). No treatments or irrigation were applied during the growth of the cover crops. The cover crops were harvested 5 cm above the soil surface (86 days after seeding), when the plants were in the following phenological stages: *A. sativa* L. (booting stage), *L. albus* L. (vegetative stage), *P. glaucum* (pre-flowering stage), *R. sativus* L. (vegetative stage), and *S. bicolor* L. (EC2 stage). After being harvested, the material was sent for analysis.

Evaluations of mass production and chemical composition

Fresh matter production was determined as the average of four subsamples harvested in each plot using a metal frame with an area of 0.25 m^2 (0.5 × 0.5 m) thrown over the pasture, at random. The dry matter (DM) production was obtained after drying the plant material in a forced-air oven at 60 ºC for 72 h. Subsequently, the organic matter production results were extrapolated to 1 ha. The roots (0–20 cm depth) of the cover crops (chemical composition of the cell wall) were also evaluated after 10 plants were collected in each plot, using a mattock. After collection, the soil adhered to the roots was removed with running water and sieves to prevent losses of material. Next, the samples of root were placed in a forced-air oven at 60 ºC for 72 h. Later, the dry plant material (shoots and roots) was ground in a Wiley mill and transferred to the laboratory for analyses.

The DM contents were determined according to the method described by Association of Official Analytical Chemists (AOAC, 1990), while neutral detergent fibre (NDF, hemicellulose + cellulose + lignin) and acid detergent fibre (ADF, cellulose + lignin) concentrations were obtained by the methods described by Goering and Van Soest (1970). The hemicellulose contents were obtained as the difference between NDF and ADF. To determine the concentration of N, the plant material was subjected to sulfuric acid digestion, followed by distillation and titration and to determine the concentrations of P and K, the material was subjected to nitric-perchloric digestion. The concentration of K was determined by using a flame photometer, and P, by colorimetry (Malavolta *et al.*, 1989). The accumulation of nutrients was obtained as the product between DM production and the concentration of the respective nutrient, and the nutrient use efficiency was calculated as the division between the DM production and the accumulation of the respective nutrient. Next, the results of accumulation and nutrient use efficiency were extrapolated to 1 ha.

Statistical analyses

The obtained results were subjected to analysis of variance, with means compared by Tukey's test ($p \leq 0.05$) on SAS (Statistical Analyses System, 2008) software. Subsequently, Pearson's correlation studies were carried out among organic matter production, DM content, cell wall components and concentrations of N, P and K in the cover crops to determine the effect of fertilization.

RESULTS

Organic matter production and composition of the cell wall

The organic matter production from the shoots and the concentrations of DM (only shoots), NDF, ADF and hemicellulose from the shoots and roots were changed significantly ($p \leq 0.05$) by the treatments (Table 1). The production of fresh matter by all cover crops was higher when there was fertilization with 200 kg ha^{-1} NPK (08-33-12) at planting as compared with the crops without fertilization; *L. albus* L. plants had the largest fresh matter of all plants. However, the DM content of *A. sativa* L., *P. glaucum* L., and *R. sativus* L. without fertilization was higher than that of the fertilized plants. Regarding the cell wall components, fertilization provided a 9% higher NDF content in the shoots of *A. sativa* L.; 22% more hemicellulose in *P. glaucum* L.; and 48, 36 and 377% higher NDF, ADF and hemicellulose contents, respectively, in the *R. sativus* L. plants as compared with the treatment without fertilization. In the roots, the NDF and ADF contents of *A. sativa* L., *R. sativus* L. and *S. bicolor* L. fertilized at planting was greater than that of the unfertilized plants, but the NDF of *L. albus* L. and *P. glaucum* L. was 7 and 12% higher in fertilized plants than in unfertilized plants, respectively. *L. albus* L. showed higher NDF and ADF contents than the other cover crops with and without fertilization (Table 1).

Concentrations, accumulations and use efficiency of N, P and K

Concentrations, accumulation and nutrient use efficiency of N, P and K in the shoots of the cover crops were changed significantly ($p \leq 0.05$) by the treatments (Table 2). When fertilization was applied, shoot N concentration of *R. sativus* L. and *S. bicolor* L. increased by 33 and 135%, respectively, as compared to unfertilized plants. Interestingly, shoot N concentration in unfertilized plants of *A. sativa* and *P. glaucum* was 16 and 54% higher than in fertilized plants, respectively. *S. bicolor* L. plants showed the highest concentration of N and the lowest concentration of P and K as compared with the rest of the cover crops when fertilization was applied. In general, the highest accumulations of N, P and K by the cover crops were found when there was fertilization at planting. The *L. albus* L. plants showed the greatest accumulation of N, whereas the greatest accumulations of P were found in *A. sativa* L., *L. albus* L. and *R. sativus* L., and the greatest accumulation of K was observed in *A. sativa* L. and *L. albus* L. The use of N by *A. sativa* L. and *P. glaucum* L. and of P and K by *S. bicolor* L. was 16, 54, 82 and 20% more efficient, respectively, when fertilization was applied, as compared with the crops without fertilization. However, the use of N by *L. albus* L., *R. sativus* L. and *S. bicolor* L. and the use of K by *A. sativa* L., *P. glaucum* L. and *R. sativus* L. were more efficient in unfertilized plants (Table 2).

Table 1. Mass production from the shoots and chemical composition of the cell wall (shoots and roots) of the cover crops cultivated with and without NPK fertilization after the ensilage of corn.

	FMP (t ha^{-1})		DMP (t ha^{-1})		DM (%)	
Plants	+NPK	-NPK	+NPK	-NPK	+NPK	-NPK
A. sativa	25.94 ± 1.38 Ab	9.12 ± 0.29 Bb	6.33 ± 0.08 Aa	2.87 ± 0.07 Bbc	24.1 ± 1.1 Ba	31.5 ± 0.9 Aa
L. albus	45.00 ± 3.52 Aa	27.86 ± 0.78 Ba	7.08 ± 0.29 Aa	4.83 ± 0.24 Ba	15.8 ± 0.5 Ab	17.4 ± 1.2 Abc
P. glaucum	33.69 ± 1.24 Aab	17.72 ± 2.22 Bab	4.84 ± 0.17 Ab	3.34 ± 0.17 Bb	14.3 ± 0.2 Bb	19.2 ± 1.4 Ab
R. sativus	32.85 ± 0.80 Aab	13.29 ± 0.26 Bb	4.18 ± 0.06 Abc	2.54 ± 0.12 Bc	12.7 ± 0.3 Bb	19.1 ± 1.3 Ab
S. bicolor	27.19 ± 0.59 Ab	19.11 ± 3.12 Bab	3.58 ± 0.10 Ac	2.54 ± 0.24 Bc	13.2 ± 0.6 Ab	13.6 ± 1.0 Ac
$LSD_{0.05}$	13.23		0.79		4.60	
	NDF shoots (%)		ADF shoots (%)		Hemicellulose shoots (%)	
Plants	+NPK	-NPK	+NPK	-NPK	+NPK	-NPK
A. sativa	60.0 ± 0.6 Aa	55.1 ± 1.0 Bbc	41.5 ± 1.7 Ab	38.2 ± 0.8 Aa	18.4 ± 1.1 Aa	16.8 ± 1.7 Aa
L. albus	48.4 ± 1.0 Ab	50.0 ± 0.6 Ac	38.8 ± 1.7 Ab	40.2 ± 1.2 Aa	9.5 ± 0.7 Ab	9.8 ± 0.7 Ab
P. glaucum	59.8 ± 0.5 Aa	57.9 ± 2.8 Aab	40.2 ± 0.8 Ab	41.9 ± 1.9 Aa	19.5 ± 1.3 Aa	16.0 ± 0.9 Ba
R. sativus	63.2 ± 1.5 Aa	42.6 ± 0.8 Bd	56.2 ± 0.8 Aa	41.2 ± 0.9 Ba	7.0 ± 0.7 Ab	1.4 ± 0.4 Bc
S. bicolor	59.4 ± 0.8 Aa	62.0 ± 1.5 Aa	40.3 ± 0.9 Ab	43.1 ± 2.0 Aa	19.0 ± 0.3 Aa	18.9 ± 1.0 Aa
$LSD_{0.05}$	5.17		5.15		4.17	
	NDF roots (%)		ADF roots (%)		Hemicellulose roots (%)	
Plants	+NPK	-NPK	+NPK	-NPK	+NPK	-NPK
A. sativa	49.6 ± 0.9 Ad	46.9 ± 0.8 Bd	42.5 ± 2.2 Ab	36.3 ± 1.8 Bc	7.0 ± 2.4 Ab	10.6 ± 2.2 Aab
L. albus	80.2 ± 1.3 Ba	85.7 ± 1.8 Aa	67.1 ± 0.6 Aa	67.1 ± 1.8 Aa	13.0 ± 0.8 Ab	18.5 ± 2.7 Aa
P. glaucum	58.1 ± 2.7 Bc	65.1 ± 0.4 Ab	43.9 ± 2.9 Ab	49.2 ± 0.1 Ab	14.2 ± 0.4 Ab	15.8 ± 0.5 Aab
R. sativus	74.1 ± 1.1 Ab	59.0 ± 0.1 Bc	61.3 ± 0.5 Aa	51.3 ± 2.9 Bb	12.8 ± 1.4 Ab	7.6 ± 2.9 Ab
S. bicolor	69.7 ± 0.3 Ab	54.1 ± 1.5 Bc	45.5 ± 1.1 Ab	35.1 ± 1.9 Bc	24.2 ± 1.4 Aa	18.9 ± 3.5 Aa
$LSD_{0.05}$	5.55		7.99		8.85	

Means ± standard error of the mean (SEM) followed by different uppercase letters in the row and different lowercase letters in the column differ by Tukey's test ($p \leq 0.05$). FMP – fresh matter production; DMP – dry matter production; DM – dry matter; NDF – neutral detergent fibre; ADF – acid detergent fibre; LSD – least significant difference.

Table 2. Concentration, accumulation and nutrient use efficiency of N, P and K by the shoots of the cover crops cultivated with and without NPK fertilization after the ensilage of corn.

	N		P		K	
	Concentration (g kg^{-1} of DM)					
Plants	+NPK	-NPK	+NPK	-NPK	+NPK	-NPK
A. sativa	18.07 ± 0.77 Bcd	20.94 ± 0.27 Ab	2.56 ± 0.26 Ab	2.15 ± 0.09 Bb	32.50 ± 0.87 Aa	24.66 ± 0.67 Bab
L. albus	25.21 ± 0.40 Ab	22.03 ± 0.61 Aab	2.33 ± 0.07 Ab	2.30 ± 0.15 Ab	26.33 ± 1.20 Abc	24.00 ± 1.00 Aab
P. glaucum	15.98 ± 0.99 Bd	24.62 ± 1.50 Aa	2.06 ± 0.09 Ab	1.85 ± 0.03 Ab	27.33 ± 1.33 Ab	22.20 ± 0.61 Bab
R. sativus	21.04 ± 0.77 Ac	15.85 ± 0.41 Bc	3.84 ± 0.03 Aa	3.68 ± 0.15 Aa	25.00 ± 0.58 Abc	21.18 ± 0.61 Bb
S. bicolor	35.91 ± 0.46 Aa	15.29 ± 0.78 Bcd	1.21 ± 0.07 Bc	2.20 ± 0.06 Ab	22.33 ± 1.86 Bc	26.66 ± 1.45 Aa
LSD$_{0.05}$	3.40		0.50		4.93	
	Accumulation (kg ha^{-1})					
Plants	+NPK	-NPK	+NPK	-NPK	+NPK	-NPK
A. sativa	114.40 ± 3.30 Ab	60.25 ± 2.06 Bb	16.29 ± 1.76 Aa	6.17 ± 0.09 Bbc	206.09 ± 7.57 Aa	70.85 ± 0.93 Bb
L. albus	178.45 ± 7.24 Aa	58.22 ± 5.33 Bbc	16.54 ± 1.04 Aa	11.19 ± 1.26 Ba	186.90 ± 14.94 Aa	115.70 ± 3.19 Ba
P. glaucum	77.35 ± 4.83 Ac	82.23 ± 4.83 Aa	9.98 ± 0.08 Ab	6.19 ± 0.29 Bbc	132.32 ± 7.23 Ab	74.55 ± 5.79 Bb
R. sativus	88.15 ± 4.11 Ac	40.37 ± 3.00 Bcd	16.08 ± 0.28 Aa	9.32 ± 0.18 Bab	104.71 ± 3.47 Abc	53.72 ± 2.01 Bb
S. bicolor	128.79 ± 4.08 Ab	38.55 ± 2.49 Bd	4.35 ± 0.13 Ac	5.60 ± 0.61 Ac	79.72 ± 4.33 Ac	68.50 ± 9.98 Ab
LSD$_{0.05}$	19.39		3.52		32.24	
	Nutrient use efficiency (kg DM kg nutrient^{-1})					
Plants	+NPK	-NPK	+NPK	-NPK	+NPK	-NPK
A. sativa	55.54 ± 2.34 Aab	47.75 ± 0.62 Bc	398.04 ± 41.78 Ab	466.63 ± 18.84 Aa	30.81 ± 0.82 Bc	40.60 ± 1.07 Aab
L. albus	39.68 ± 0.62 Bc	83.94 ± 5.10 Aa	429.29 ± 12.63 Ab	438.89 ± 30.93 Aa	38.14 ± 1.80 Aabc	41.80 ± 1.67 Aab
P. glaucum	63.04 ± 4.00 Aa	40.90 ± 2.48 Bc	485.68 ± 21.26 Ab	540.80 ± 8.44 Aa	36.75 ± 1.71 Bbc	45.11 ± 1.27 Aab
R. sativus	47.65 ± 1.78 Bbc	63.17 ± 1.63 Ab	260.45 ± 2.06 Ac	272.40 ± 11.26 Ab	40.04 ± 0.93 Bab	47.27 ± 1.39 Aa
S. bicolor	27.85 ± 0.36 Bd	65.73 ± 3.26 Ab	827.72 ± 48.68 Aa	454.54 ± 12.50 Ba	45.36 ± 3.52 Aa	37.73 ± 2.10 Bb
LSD$_{0.05}$	11.02		106.19		8.01	

Means ± standard error of the mean (SEM) followed by different uppercase letters in the row and different lowercase letters in the column differ by Tukey's test ($p \leq 0.05$). N – nitrogen; P – phosphorus; K – potassium; LSD – least significant difference.

Pearsons' correlations

The N and the DM contents of the *A. sativa* L. plants with and without fertilization at planting were positively correlated, but the concentration of P in unfertilized plants was negatively correlated with the hemicellulose content, and K was also negatively correlated with NDF (Table S1 in Supplementary Material available online at http://dx.doi.org/10.1017/S001447971600034X). Conversely, the concentrations of K and NDF in the unfertilized plants of *L. albus* L. were positively correlated, but there was a negative correlation between P and NDF, and between N and ADF. The *P. glaucum* L. plants fertilized at planting displayed a positive correlation between the concentrations of N and NDF, as well as between the K and ADF. However, there was a negative correlation between the concentration of K and the DM and hemicellulose contents. When fertilization was not applied at planting, the concentration of K and the hemicellulose content of *P. glaucum* L. were positively correlated. Fresh matter production by *R. sativus* L. showed a positive correlation with the concentration of P, with and without fertilization at planting. The concentration of K in the *R. sativus* L. plants that were fertilized was negatively correlated with the cell wall components. The concentrations of P and K in *S. bicolor* L. displayed a negative correlation with the hemicellulose content when there was fertilization at planting. When the plant was not fertilized, the concentrations of N and P were positively correlated with the hemicellulose and NDF contents, respectively (Table S1 in Supplementary Material).

Interrelationships between parameters that regulate the decomposition of cover crops

The C/N, C/P, C/K, N/P, N/K, P/K, NDF/N, ADF/N and hemicellulose/N ratios in the shoots of the cover crops were changed significantly ($p \leq 0.05$) by the treatments (Table 3). The C/N ratio of the *L. albus* L., *R. sativus* L. and *S. bicolor* L. plants that received fertilization was 14, 33 and 136% lower than that of the unfertilized plants, respectively, although the N/P and N/K ratios were higher when fertilization was applied. On the other hand, N/P and N/K ratios of *A. sativa* L. and *P. glaucum* L. decreased with fertilization. The lowest C/K ratios of the *A. sativa* L., *P. glaucum* L. and *R. sativus* L. plants occurred when fertilization was applied at planting, but this treatment resulted in higher NDF/N, ADF/N and hemicellulose/N in the same plants. Unfertilized *L. albus* L. and *S. bicolor* L. plants, however, showed higher NDF/N, ADF/N and hemicellulose/N than fertilized plants. *P. glaucum* L. showed the highest C/N and NDF/N ratios of all plants when fertilization was applied, but without it, *L. albus* L. had the highest NDF/N ratio. The P/K ratio of *R. sativus* L. and *S. bicolor* L. reduced when there was fertilization at planting as compared with the treatment without fertilization. Fertilization provided a higher C/P ratio in the shoots of *S. bicolor* L. as compared with the unfertilized treatment (Table 3).

DISCUSSION

The supply of fertilizers is essential to increase organic matter production by plants due to the required amount and physiological functions performed by the nutrients (Marschner, 1995). This fact was demonstrated in this study, in which the production

Table 3. Ratios between nutrients and cell wall components of the cover crops cultivated with and without NPK fertilization after the ensilage of corn.

	C/N*		C/P*		C/K*	
Plants	+NPK	-NPK	+NPK	-NPK	+NPK	-NPK
A. sativa	24.99 ± 1.05 Aab	21.49 ± 0.28 Bb	179.12 ± 18.80 Ab	209.98 ± 8.47 Aa	13.87 ± 0.37 Bc	18.27 ± 0.48 Aab
L. albus	17.85 ± 0.28 Bc	20.42 ± 1.17 Ab	193.18 ± 5.68 Ab	197.50 ± 13.91 Aa	17.16 ± 0.81 Aabc	18.81 ± 0.75 Aab
P. glaucum	28.37 ± 1.80 Aa	18.41 ± 1.11 Bb	218.56 ± 9.56 Ab	243.36 ± 3.79 Aa	16.54 ± 0.76 Bbc	20.30 ± 0.57 Aab
R. sativus	21.44 ± 0.79 Bbc	28.43 ± 0.73 Aa	117.20 ± 0.92 Ac	122.57 ± 5.06 Ab	18.02 ± 0.41 Bab	21.27 ± 0.62 Aa
S. bicolor	12.53 ± 0.16 Bd	29.58 ± 1.46 Aa	372.47 ± 21.90 Aa	204.55 ± 5.62 Ba	20.41 ± 1.58 Aa	16.98 ± 0.94 Bb
LSD$_{0.05}$	4.96		47.78		3.60	

Plants	N/P		N/K		P/K	
	+NPK	-NPK	+NPK	-NPK	+NPK	-NPK
A. sativa	7.24 ± 1.03 Bc	9.77 ± 0.47 Ab	0.56 ± 0.03 Bc	0.85 ± 0.03 Aab	0.080 ± 0.009 Abc	0.086 ± 0.002 Ab
L. albus	10.81 ± 0.24 Ab	5.23 ± 0.21 Bc	0.96 ± 0.06 Ab	0.50 ± 0.05 Bc	0.090 ± 0.006 Ab	0.096 ± 0.010 Ab
P. glaucum	7.75 ± 0.53 Bbc	13.33 ± 0.96 Aa	0.59 ± 0.06 Bc	1.11 ± 0.08 Aa	0.073 ± 0.004 Abc	0.083 ± 0.003 Ab
R. sativus	5.48 ± 0.16 Ac	4.32 ± 0.29 Ac	0.84 ± 0.04 Abc	0.75 ± 0.04 Abc	0.153 ± 0.005 Ba	0.173 ± 0.004 Aa
S. bicolor	29.72 ± 1.76 Aa	6.94 ± 0.34 Bbc	1.63 ± 0.12 Aa	0.59 ± 0.06 Bbc	0.056 ± 0.002 Bc	0.083 ± 0.004 Ab
LSD$_{0.05}$	3.42		0.28		0.02	

	NDF/N		ADF/N		Hem/N	
Plants	+NPK	-NPK	+NPK	-NPK	+NPK	-NPK
A. sativa	33.36 ± 1.44 Aab	26.34 ± 0.29 Bb	23.09 ± 1.43 Aa	18.29 ± 0.48 Bc	10.26 ± 0.75 Ab	8.05 ± 0.77 Bb
L. albus	19.23 ± 0.53 Bc	42.07 ± 3.09 Aa	15.44 ± 0.78 Bb	33.88 ± 3.14 Aa	3.79 ± 0.27 Bcd	8.18 ± 0.25 Ab
P. glaucum	37.66 ± 2.04 Aa	23.75 ± 2.23 Bb	25.41 ± 2.11 Aa	17.18 ± 1.60 Bc	12.24 ± 0.29 Aa	6.57 ± 0.64 Bb
R. sativus	30.12 ± 1.10 Ab	26.95 ± 0.61 Ab	26.79 ± 0.97 Aa	26.03 ± 0.85 Ab	3.33 ± 0.28 Ad	0.91 ± 0.23 Bc
S. bicolor	16.55 ± 0.43 Bc	40.79 ± 2.17 Aa	11.25 ± 0.37 Bb	28.40 ± 2.27 Aab	5.30 ± 0.14 Bc	12.38 ± 0.17 Aa
LSD$_{0.05}$	7.04		6.78		1.92	

*Concentration of carbon estimated at 450 g kg^{-1} dry matter. C – carbon; N – nitrogen; P – phosphorus; K – potassium; NDF – neutral detergent fibre; ADF – acid detergent fibre; Hem – hemicellulose; LSD – least significant difference.

Means ± standard error of the mean (SEM) followed by different uppercase letters in the row and different lowercase letters in the column differ by Tukey's test ($p \leq 0.05$).

of mass (Table 1) of all cover crops increased with NPK fertilization, even with the high fertility of Oxisol. The obtained results are similar to those described by Tian and Kang (1998). With the increase in organic matter production, more nutrients were extracted by the plants (Table 2), which may provide greater cycling of nutrients (crop residues) and better use of chemical fertilizers by the successive crop as a result of the increased soil biological activity (Arf *et al.*, 1999). However, the concentration of nutrients in the biomass does not necessarily increase with the use of fertilizers, as there may be some imbalance between the nutrients in the soil solution, resulting in lower uptake of an element over another, or greater production of mass, resulting in a dilution of the concentration of that nutrient (Marschner, 1995). For instance, the concentrations of N in *A. sativa* L. and *P. glaucum* L. and the concentrations of P and K in *S. bicolor* L. were higher without fertilization (Table 2), which changed the composition of the cell wall of cover crops differently among the treatments (Table 1).

Although the molecules of hemicellulose, cellulose and lignin do not have N, P and K in their structure, these nutrients affect directly and indirectly the expression of enzymes acting in their synthesis (Gille *et al.*, 2011; Quang *et al.*, 2012). Fertilization with NPK increased the hemicellulose content of *P. glaucum* L. plants and the hemicellulose + cellulose + lignin (NDF) content of *R. sativus* L. and *A. sativa* L. plants (Table 1). The increase in the concentrations of hemicellulose over lignin is interesting in the utilization of cover crops, since the former is more easily degraded by the soil microorganisms than lignin (Espíndola *et al.*, 2006). This allows the nutrients, especially N, to be released faster, which may provide a reduction in nitrogen fertilization in planting the successive crop (Silva *et al.*, 2008a). In the roots, the cellulose + lignin (ADF) of *A. sativa* L., *R. sativus* L., and *S. bicolor* L. increased with the supply of NPK at planting (Table 1). The increase in these cell wall fractions in the roots may contribute to increasing the water infiltration and porosity of the soil, since the decomposition of the roots by the soil microorganisms will be slower because of the mechanical protection of lignin on cellulose, enabling the formation of channels throughout the soil profile (Rosolem *et al.*, 2002).

Based on the results obtained in this study, it is clear that the effect of fertilization with NPK on the cell wall contents of cover crops still needs to be further studied, given that when the correlation between the levels of K and hemicellulose in *P. glaucum* L. was analysed, we observed that it was negative when NPK was supplied, and positive without fertilization (Table S1 in Supplementary Material). Just like the hemicellulose, cellulose and lignin contents, the interrelationship of between fractions and the concentrations of C, N, P and K modify the chemical composition of the plant residues and their decomposition rate (Lima *et al.*, 2012). The C/N ratios of *L. albus* L., *R. sativus* L. and *S. bicolor* L. decreased when NPK was supplied at planting (Table 3). Lower C/N ratios provide a rapid decomposition of the crop residues in tropical regions, but, in the winter, decomposition is slower due to the lower temperatures and availability of water, which is beneficial for the release of nutrients to take place at the beginning of the cultivation of corn in succession (Gonçalves and Ceretta, 1999). This fact suggests that the successive crop in summer should be planted shortly after the cultivation of cover crops to increase the use of nutrients released in the plant decomposition process (Arf *et al.*, 1999). The

N/P and N/K ratios of *A. sativa* L. and *P. glaucum* L. were lower when NPK was applied (Table 3), suggesting that these plants utilize large amounts of absorbed N for mass production (Table 1), since the concentration of N in the leaf tissue reduced and its use efficiency by the plant increased with fertilization (Table 2) (Masclaux-Daubresse *et al.*, 2010).

Other ratios such as NDF/N, ADF/N and hemicellulose/N are important to indicate the variability of mineralization or immobilization of N in the soil (Lima *et al.*, 2012). Thus, it was observed that the NDF/N, ADF/N and hemicellulose/N ratios of the *A. sativa* L. and *P. glaucum* L. plants increased when fertilization was applied (Table 3). This occurs as a result of the increased mass production (fibrous components) and dilution of the N absorbed and incorporated into the plant. This fact is undesirable, as mentioned by Cobo and Barrios (2002), who reported negative correlations between NDF, ADF and lignin concentrations and the C/N and lignin/N ratios of cover crops with N available in the soil that led to lower uptake of N by the rice crop two to eight weeks after planting. In this regard, the use of cover plants with higher NDF/N, ADF/N and hemicellulose/N ratios would be indicated for successive crops that have a higher demand for N, P and K after the first month of growth (Carvalho *et al.*, 2008; Francisco *et al.*, 2007). Usually, legume species are more largely utilized for green fertilization/rotation of crops as they have lower C/N, NDF/N, ADF/N and hemicellulose/N ratios and lower contents of fibrous components; however, based on the results obtained in this study, we noted that the grass species also have potential to be used in regions with dry winters, especially when fertilized with NPK at planting (Lima *et al.*, 2012; Tian and Kang, 1998).

In addition to improving the chemical composition of cover crops and, indirectly, the physical, chemical and biological soil properties, the supply of NPK can be utilized to anticipate the fertilization of the succeeding crop (Foloni and Rosolem, 2008; Francisco *et al.*, 2007; Tian and Kang, 1998). These strategies allow a faster decomposition of the crop residues and release of nutrients, which benefits the corn crop in succession and results in good yields and profit (Chivenge *et al.*, 2011; Silva *et al.*, 2007, 2008b, 2008c). Although the results obtained in this study are highly satisfactory, further research should be conducted to evaluate the decomposition of residues from cover crops (legumes, brassicas and grasses) fertilized with NPK in regions with dry winters. Additionally, more studies are necessary on decomposition rates in the field and the subsequent corn crop before specific recommendations can be made about fertilization and the choice of the cover crop.

SUPPLEMENTARY MATERIALS

For supplementary material for this article, please visit http://dx.doi.org/10.1017/S001447971600034X.

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