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Research Article

Contribution of corn intercropped with *Brachiaria* species to nutrient cycling[1]

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ABSTRACT

The corn biomass and nutrient dynamics may be altered when it is intercropped with *Brachiaria* (syn. *Urochloa* spp.). The present study aimed to investigate the dynamics of biomass, nitrogen (N), phosphorus (P) and potassium (K) for farming systems that produce corn intercropped with *Brachiaria* species. Field experiments were performed during the season and off-season, in a split-plot design. The main plots were composed of *Brachiaria* species (*B. brizantha*, *B. ruziziensis* and *B.* Convert) intercropped with corn, in addition to corn monocropping. The subplots consisted of three forage sampling periods, ranging from 0 to 60 days after the corn harvest. The intercropping arrangements did not affect the corn grain yield, nutrient accumulation and partitioning, relatively to the corn monocropping. After the grain harvest, *B. brizantha* achieved the greater biomass accumulation rate in both the season (69 kg ha^{-1} day^{-1}) and off-season (17 kg ha^{-1} day^{-1}). The nutrient accumulation ranged widely between the *Brachiaria* species and planting seasons: 0.2-1.2 kg ha^{-1} day^{-1} for N; 0.01-0.07 kg ha^{-1} day^{-1} for P; and 0.13-0.8 kg ha^{-1} day^{-1} for K. However, the greatest nutrient accumulation was found for *B. brizantha*, followed by *B. ruziziensis* and then *B.* Convert. In the short-term, corn intercropped with *Brachiaria* in the season showed the largest effect on the nutrient cycling and biomass yield. The intercropping between corn and *B. brizantha* in the season was the best way to enhance the biomass yield and the N, P and K cycling.

KEYWORDS: *Zea mays* L., *Urochloa* spp., nutrient balance, forage plants.

RESUMO

Contribuição de milho consorciado com espécies de *Brachiaria* na ciclagem de nutrientes

A dinâmica de biomassa e nutrientes do milho pode ser alterada quando consorciado com *Brachiaria* (syn. *Urochloa* spp.). Objetivou-se investigar a dinâmica de biomassa, nitrogênio (N), fósforo (P) e potássio (K) para sistemas de produção de milho consorciado com espécies de *Brachiaria*. Campos experimentais foram conduzidos durante a safra e safrinha, em esquema de parcelas subdivididas. As parcelas principais foram compostas por espécies de braquiária (*B. brizantha*, *B. ruziziensis*, e *B.* Convert) consorciadas com milho, além de monocultivo de milho. As subparcelas consistiram de períodos de amostragem da forragem, variando de 0 a 60 dias após a colheita do milho. O consórcio não afetou a produtividade de grãos, acúmulo e partição de nutrientes no milho. Após a colheita de grãos, *B. brizantha* obteve a maior taxa de acúmulo de biomassa na safra (69 kg ha^{-1} dia^{-1}) e safrinha (17 kg ha^{-1} dia^{-1}). O acúmulo de nutrientes variou amplamente entre as espécies de *Brachiaria* e estação de cultivo: 0.2-1.2 kg ha^{-1} dia^{-1} para N; 0.01-0.07 kg ha^{-1} dia^{-1} para P; e 0.13-0.8 kg ha^{-1} dia^{-1} para K. Contudo, o maior acúmulo de nutrientes foi registrado para *B. brizantha*, seguida de *B. ruziziensis* e *B.* Convert. A curto prazo, o milho consorciado com *Brachiaria* na safra obteve maior efeito sobre a ciclagem de nutrientes e produção de biomassa. O consórcio entre milho e *B. brizantha* na safra foi a melhor opção para aumentar a produção de biomassa e a ciclagem de N, P e K.

PALAVRAS CHAVE: *Zea mays* L., *Urochloa* spp., balanço de nutrientes, plantas forrageiras.

INTRODUCTION

Cover crops have been included in crop rotation to meet challenges such as the deterioration of soil physical traits and nutrient losses. Overall, cover crops contribute to the recovery and cycling of nutrients, reduce the risk of soil erosion and assist in controlling pests, diseases and nematodes (Leandro & Asmus 2015, Ren et al. 2019, Tanaka et al. 2019).

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Under the tropical and subtropical conditions of Brazil, intercropping corn and perennial grasses of the *Brachiaria* genus is an excellent alternative for establishing *Brachiaria* as a cover crop (Pariz et al. 2016, Almeida et al. 2017a). To investigate the competition between corn and *Brachiaria* species, studies have assessed the nutrient balance in the intercropping period, in relation to the plating period, plant density and corn maturity ratings (Borghi et al. 2013, Ceccon et al. 2013, Crusciol et al. 2013). Nonetheless, little attention has been given to the nutrient accumulation and partitioning after the corn harvesting, especially among *Brachiaria* species.

Some researchers have reported that the biomass and nutrient accumulation in the monocropping of *Brachiaria* species are affected by agricultural practices, such as the establishment method and forage planting period (Cruz et al. 2008, Pariz et al. 2010). However, the biomass and nutrient accumulation among *Brachiaria* species intercropped with corn remain poorly understood. Besides the effects of corn on the *Brachiaria* growth in the intercropping period, the biomass and nutrient accumulation could also be regulated by the planting season.

Most of the areas cultivated with corn, in Brazil, have been planted using intensive cropping systems in the off-season, often following the early cycle soybean [*Glycine max* (L.) Merr.] harvest. In short, later plantings of corn and *Brachiaria* expose the crop to a lower availability of rainfall, solar radiation and time available for forage vegetation after the corn harvesting.

The soil nutrient availability, biomass accumulation and growing period have been known to affect the cover crops nutrient cycling (Fageria et al. 2005, Lorin et al. 2016). A better understanding of the amount of nutrients accumulated by *Brachiaria* species is important for determining the benefits of nutrient cycling and soil fertility. Following this perspective, this study aimed to evaluate the accumulation and partitioning of biomass nitrogen (N), phosphorus (P) and potassium (K) in corn and *Brachiaria* species intercropped both in the season and off-season, as well as to verify the potential of nutrient cycling after the corn harvesting, given that intercropping benefits are closely associated with biomass and nutrient accumulation by the forage species.

MATERIAL AND METHODS

Two field trials were carried out throughout the 2014/2015 growing season, in Brazil. The season experiment was carried out in Taquarituba, São Paulo state (23º35'14.1"S, 49º14'55.2"W and altitude of 630 m). The soil of the area is classified as a Hapludalf (USDA 1998) or Nitossolo (Santos et al. 2013), with 657 g kg^{1} of clay, 253 g kg^{1} of silt and 90 g kg^{1} of sand. The off-season experiment was conducted in Maringá, Paraná state (23º17'41.9"S, 51º53'31.0"W and altitude of 515 m). The soil is classified as an Oxisoil (USDA 1998) or Latossolo (Santos et al. 2013), with 541 g kg^{-1} of clay, 289 g kg^{-1} of silt and 170 g kg^{-1} of sand. According to the Köppen classification updated by Alvares et al. (2013), both the regions have a Cfa climate, characterized as humid subtropical, with hot summers. The weather data were collected during the experimental period (Figure 1).

The soil (0.0-0.2 m of depth) chemical composition was analyzed before the beginning of the experiment. The results for the season and off-season were, respectively, pH in $CaCl_2$ of 5.3 and 6.3, soil organic matter of 24 g dm^{-3} and 18 g dm^{-3}, P (resin extractor) of 24 g dm^{-3} and 30 mg dm^{-3}, K of 5.4 $mmol_c$ dm^{-3} and 3.2 of $mmol_c$ dm^{-3} and base saturation of 61 % and 84 %.

The trials were performed in a split-plot randomized block design, with four treatments for the main plots and three treatments for the subplots, with five replications. The farming systems consisted of corn monocropping and three forage grasses of the *Brachiaria* (syn. *Urochloa*) genus intercropped with corn: *Brachiaria* hybrid Mulato II (Convert HD 364) cultivar, *B. brizantha* cv. Marandu and *B. ruziziensis*. The subplots consisted of three forage biomass collection periods after the corn harvesting, which were 0 days after harvesting (DAH), when samples were taken at the corn harvesting, 30 DAH and 60 DAH for the season; and 0 DAH, 30 DAH and 45 DAH for the off-season (Figure 1). The third collection in the off-season was not performed at 60 DAH because the area was being prepared for soybean planting at the season.

Where corn was planted in the season, the area had been previously cultivated for 15 years with *B. brizantha* pasture and in the last 5 years with cash crops such as soybean, corn, sorghum and oats, in a no-tillage system. Planting occurred on 12 November 2014, on black oat residues (*Avena strigosa*). Where

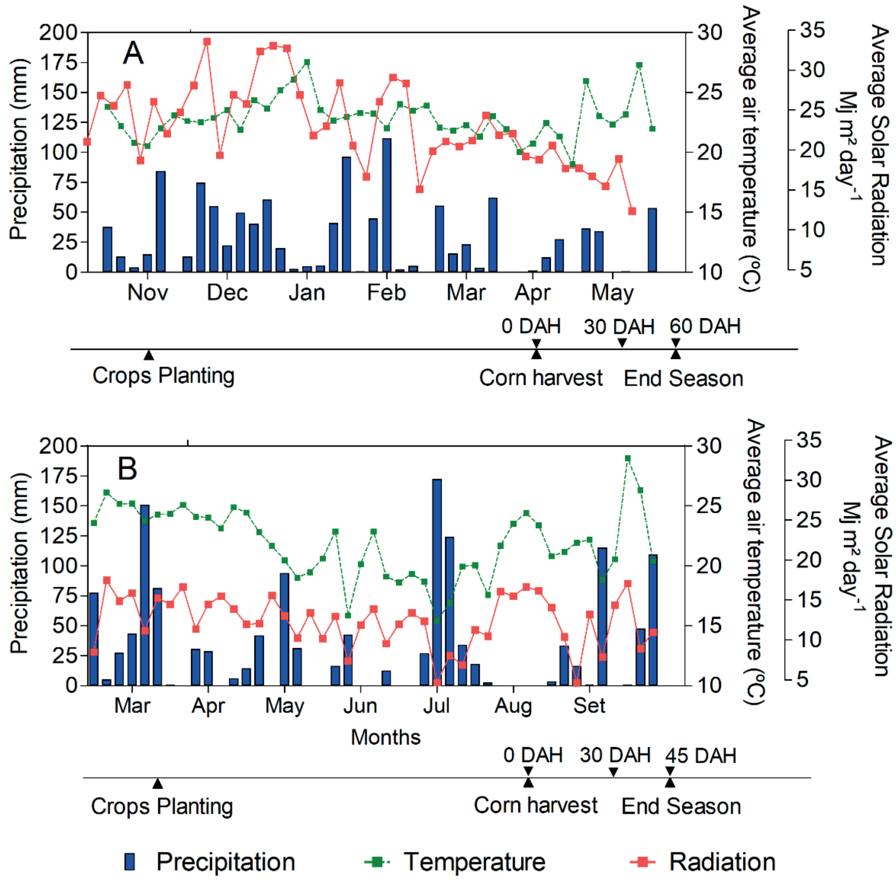

Figure 1. Planting date, precipitation, average air temperature and solar radiation during the study period for the season of 2014 (A) and off-season of 2015 (B). The crops planting, corn harvest and end season indicated the planting data of both the corn and forage crops, corn grains harvest and last forage sampling, respectively. DAH: days after harvest.

corn was sown off-season, the experimental area had been used since 2006 under no-tillage management and with soybean, corn and wheat crop rotation. Planting occurred on 2 March 2015, on soybean residues. The 30137HX and B188 corn hybrids were planted in the season and off-season, both at a density of 60,000 plants ha^{-1} and a row spacing of 0.9 m. *Brachiaria* species were planted on the same day as the corn. Planting was performed manually in 5-cm deep furrows between the corn rows and with 4.5 kg ha^{-1} of viable seeds. All plots received 640 g ha^{-1} of glyphosate acid equivalent before sowing for weed control. Then, 3,250 g a.i. ha^{-1} of atrazine and 25 g a.i. ha^{-1} of nicosulfuron were applied in post-emergence, when the *Brachiaria* species issued the first tiller for the monocropping and intercropping arrangements.

In the planting time, 50 kg ha^{-1} of P_2O_5 were applied as triple superphosphate and 50 kg ha^{-1} of K_20 as KCl. Topdressing mineral fertilizer was applied at the V3 growth stage (Ritchie et al. 1986) by using 150 kg ha^{-1} and 120 kg ha^{-1} of N as ammonium sulfate, which were applied as cover in the season and off-season, respectively.

The grain yield was standardized to 13 % of moisture and the corn biomass yield and nutrient contents were obtained from four plants collected in the center of the plots and divided into grains and stover (stem, leaves, cob, tassel and ear wing). *Brachiaria* samples were obtained by cutting the plants present in a 1-m² area at the ground level, during each sampling period. The biomass yield, N, K and P values were obtained by the sum of the values of the corn samples obtained in the grain harvest plus the last *Brachiaria* sampling. In the corn monocropping plots, spontaneous vegetation was also recorded to assess the biomass and nutrient balance. Spontaneous plants were taken from 1-m² areas at the plot center, when the last sampling procedure was performed: 60 and 45 DAH for the season and off-season, respectively.

The concentration of N in the plant tissues was determined from Kjeldahl distillation. K and P concentrations were determined by X-ray fluorescence (EDXRF) (Tezotto et al. 2013), in samples ground to dry and loose powder.

The data underwent tests of normality and homogeneity of variance, followed by analysis of variance by the F test at 5 % of probability, using the SAS software, version Windows 9. The main plot treatment of the *Brachiaria* species and corn, collecting period and their interactions were considered the model fixed effects. Each sampling site was independently analyzed. If the null hypothesis was rejected, the Tukey test at $p \leq 0.05$ and regression analyses were performed for the *Brachiaria* sampling across the days, after the corn harvest.

RESULTS AND DISCUSSION

The corn grain yield was not affected by the farming systems, being 6.8 ± 0.7 Mg ha^{-1}, 5.7 ± 0.8 Mg ha^{-1}, 5.8 ± 0.5 Mg ha^{-1} and 7.0 ± 0.4 Mg ha^{-1}, respectively for corn monocropping, corn-*B.* Convert, corn-*B. brizantha* and corn-*B. ruziziensis*, in the season. For the off-season, the grain yields were 6.5 ± 0.2 Mg ha^{-1}, 6.6 ± 0.1 Mg ha^{-1}, 6.3 ± 0.3 Mg ha^{-1} and 6.6 ± 0.1 Mg ha^{-1}, respectively for corn monocropping, corn-*B.* Convert, corn-*B. brizantha* and corn-*B. ruziziensis*. In the season, a large population of *Spodoptera frugiperda* was recorded between V4 and V6, which likely affected all treatments at the same level, although it lowered the mean grain yield of the experimental area.

The dry biomass values for grain, stover and whole plants were not affected by the intercropping system ($p > 0.05$). The total biomass values were 14.5 Mg ha^{-1} and 14.7 Mg ha^{-1}, respectively for the season and off-season (Figure 2).

Intercropping also did not affect the accumulation of nutrients in the corn grains, stover or total biomass ($p > 0.05$), in both the planting seasons. On average, corn accumulated 179 kg ha^{-1}

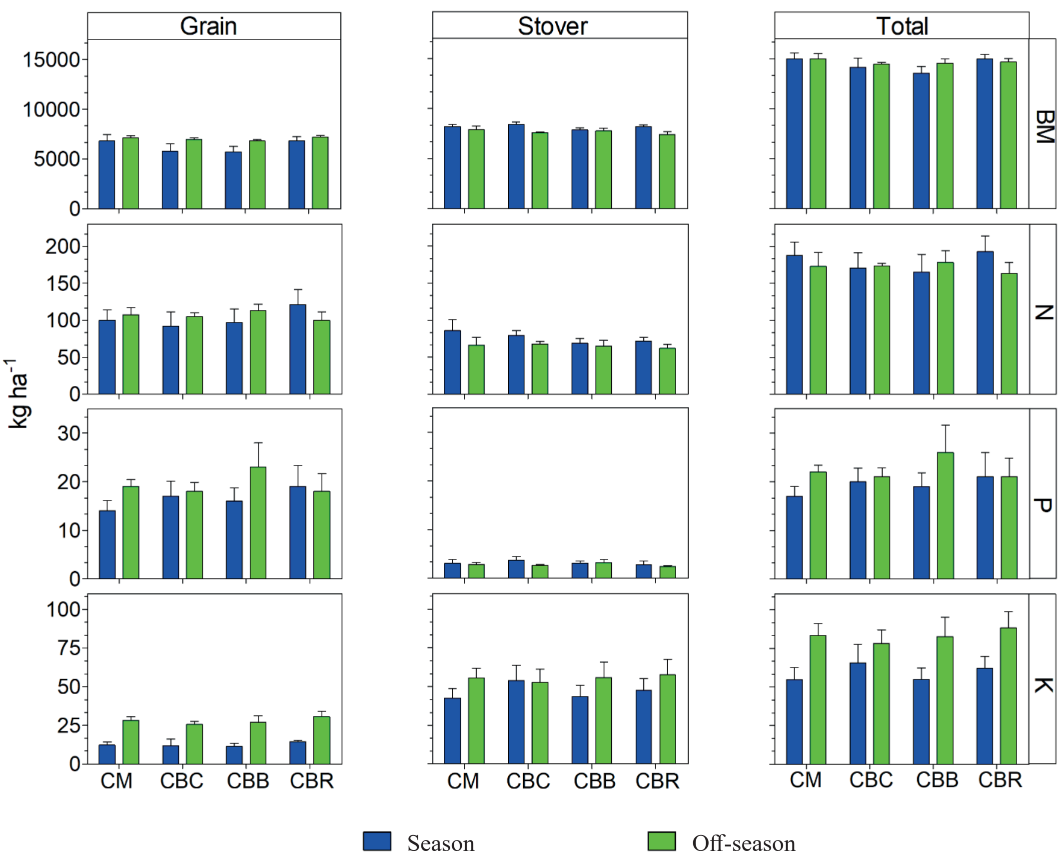

Figure 2. Influence of farming systems on biomass (BM), nitrogen (N), phosphorus (P) and potassium (K) and nutrient partitioning in corn. CM: corn monocropping; CBC: corn-*B.* Convert; CBB: corn-*B. brizantha*; CBR: corn-*B. ruziziensis*. Vertical bars indicate standard error from the data.

of N, 20 kg ha^{-1} of P and 59 kg ha^{-1} of K (Figure 2). In the off-season, corn accumulated 172 kg ha^{-1} of N, 22 kg ha^{-1} of P and 83 kg ha^{-1} of K (Figure 2). Apparently, the K content recorded in the off-season could be greater. Several factors may affect the K content in corn, but differences between hybrids arise herein as a major effect, since the biomass values were similar.

Besides the lack of effect on corn grain yield, results previously reported by Almeida et al. (2017a, 2017b), as well as results of the present study, prove that the intercropping did not affect the partition and accumulation of biomass, N, P and K on corn. In some instances, the intercropping between two or more crops resulted in significant effects on the biomass yield and nutrients partitioning (Hu et al. 2016, Lowry & Brainard 2016), but considerable biomass values are registered for both intercropping patterns. In the present study, a low biomass yield (170-1,020 kg ha^{-1}) was achieved by *Brachiaria* species from planting at zero days after the corn harvesting (Table 1). Regardless of the growing season, it was not enough to affect the corn and its partitioning dynamics.

In the season, there was a large number of interactions between *Brachiaria* species and samples (Table 1). However, the accumulation of biomass and nutrients increased in the *Brachiaria* species throughout the sampling dates (Figure 3). Overall, *Brachiaria* species affected the biomass production and nutrient accumulation only after the grain harvesting. Starting from zero days after the corn harvesting and using values showed in equations (Figure 3), 66 kg ha^{-1} day^{-1}, 44 kg ha^{-1} day^{-1} and 31 kg ha^{-1} day^{-1} of accumulated biomass were registered for *B. brizantha*, *B. ruziziensis* and *B.* Convert, respectively. Interactions between species and collection dates were recorded for N, P and K (Table 1). *B. brizantha* was also the species with the greatest nutrient accumulations after the corn harvesting. On average, *B. brizantha* accumulated 1.2 kg ha^{-1} day^{-1} of N, 0.07 kg ha^{-1} day^{-1} of P and 0.7 kg ha^{-1} day^{-1} of K (Figure 3).

Interactions between date sampling and species were also recorded for the off-season. As previously reported for the season, biomass and nutrient accumulations in *Brachiaria* species increased throughout the sampling dates (Table 1). Overall, *B. brizantha* accumulated the largest amount of biomass. After the grain harvesting, 17 kg ha^{-1} day^{-1}, 15 kg ha^{-1} day^{-1} and 14 kg ha^{-1} day^{-1} were respectively accumulated for the B. *brizantha*, *B.* Convert and *B. ruziziensis* biomass (Figure 3). On average, *B. brizantha* was the species that most

Table 1. Biomass, N, P and K contents of *Brachiaria* species in the season and off-season.

Days after harvesting	Species/ seasons	Biomass		N		P		K	
		kg ha^{-1}							
		Season	Off-season	Season	Off-season	Season	Off-season	Season	Off-season
0	*B. brizantha*	1,020	350	13.2	6.5	0.8	0.4	11.7	5.5
	B. Convert	950	170	13.4	3.3	0.7	0.2	9.9	2.4
	B. ruziziensis	930	370	13.6	7.1	0.7	0.4	11.7	5.6
Mean		967 C	297 C	13.4 C	5.6 B	0.7 C	0.3 C	11.1 B	4.5 B
30	*B. brizantha*	2,030	910	27.7	16.5	1.4	0.7	15.1	10.3
	B. Convert	1,320	560	19.2	11.5	1.1	0.6	11.1	7.1
	B. ruziziensis	1,810	760	27.1	16.5	1.3	0.8	19.6	8.1
Mean		1,720 B	740 B	24.7 B	14.8 A	1.3 B	0.7 A	15.3 B	8.5 A
60/45[Ŧ]	*B. brizantha*	5,020	1,080	87.5	15.7	5.4	0.9	57.4	12.4
	B. Convert	2,800	880	51.2	16.2	3.3	0.9	33.2	10.4
	B. ruziziensis	3,550	980	68.8	16.9	3.6	1.1	44.9	12.9
Mean		3,790 A	980 A	69.2 A	16.3 A	4.1 A	1.0 A	45.2 A	11.9 A
Source of variation		Anova Pr > F							
Brachiaria species (BS)		*	*	*	*	*	*	*	*
Sampling (S)		*	*	*	*	*	*	*	*
BS * S		*	*	*	*	*	**	*	*
CV (%)		14.11	5.6	5.6	12.3	7.1	7.8	7.9	14.6

[Ŧ] Last sampling at 60 and 45 days after the corn harvesting, respectively in the season and off-season. Uppercase letters compare the means among samplings. [ns] not significant ($p > 0.05$). * Significant at $p < 0.05$.

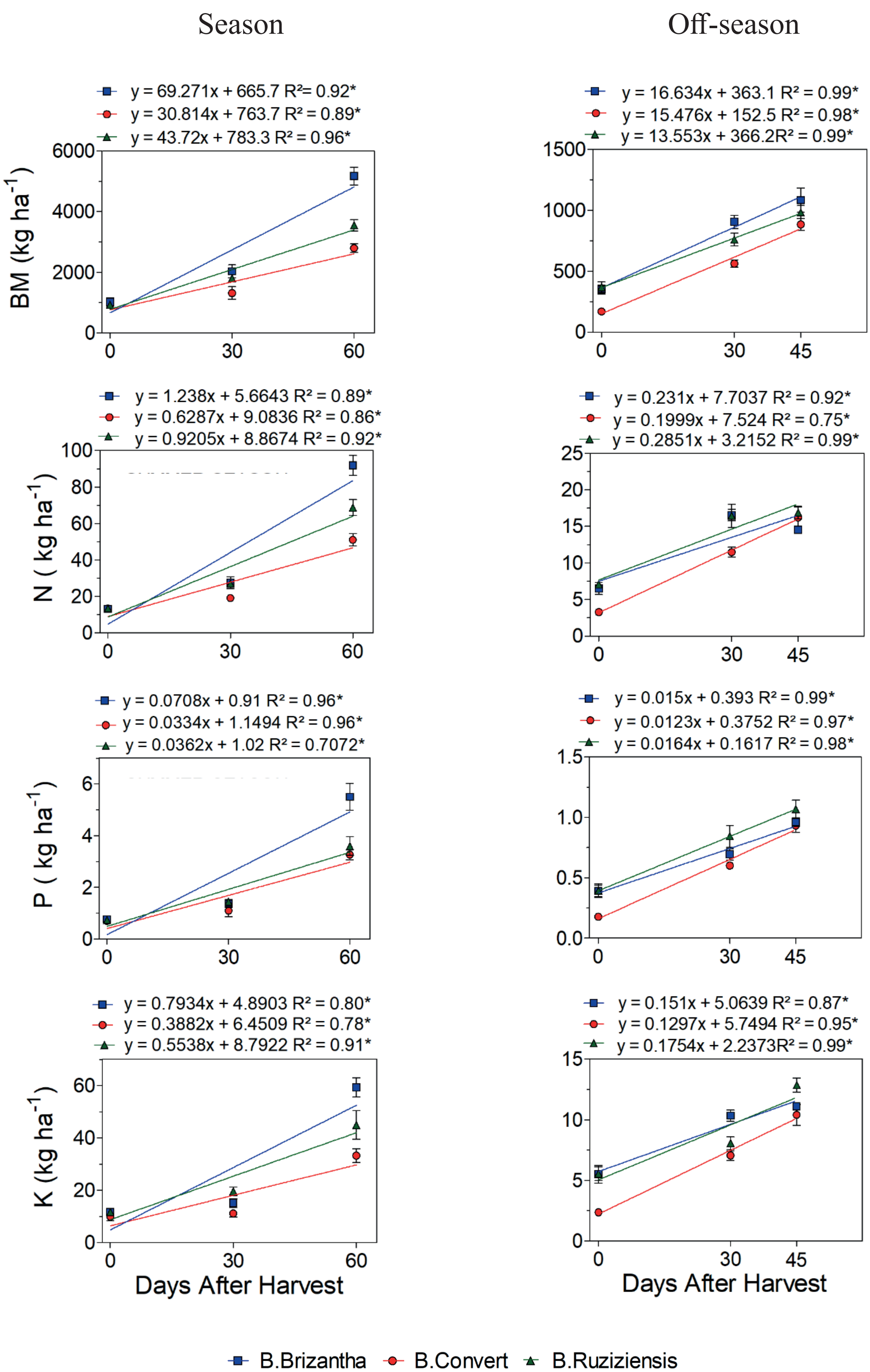

Figure 3. Amount of biomass (BM), nitrogen (N), phosphorus (P) and potassium (K) content among the *Brachiaria* species after the corn harvesting. * Significance at $p < 0.05$. Vertical bars indicate standard error from the data.

accumulated nutrients: 0.23 kg ha^{-1} day^{-1} of N, 0.015 kg ha^{-1} day^{-1} of P and 0.15 kg ha^{-1} day^{-1} of K. The nutrient uptake in plants is closely related to the total above ground biomass accumulation. In the present study, because *B. brizantha* showed the highest biomass production, it was also expected that it showed the greater nutrient accumulation.

The biomass accumulation of *Brachiaria* species in the off-season was potentially lower than in the season, which usually ranged between 50 kg ha^{-1} day^{-1} and 130 kg ha^{-1} day^{-1} (Cruz et al. 2008, Crusciol et al. 2013, Almeida et al. 2017a). However, the *Brachiaria* biomass measured in the present study for the off-season (13-16 kg ha^{-1} day^{-1}) is in accordance with other authors (3-44 kg ha^{-1} day^{-1}) (Brambilla et al. 2009, Richart et al. 2010, Batista et al. 2012). Accordingly, the lower biomass, post-harvest nutrient accumulation and nutrient cycling were not enough to affect the balance in the off-season. Nonetheless, all *Brachiaria* species accumulated more biomass during the post-harvest period than the fallow area proceeded by corn monocropping.

Among the *Brachiaria* species, *B. brizantha* had the highest biomass accumulation (66 kg ha^{-1} day^{-1} and 17 kg ha^{-1} day^{-1} in the season and off-season, respectively). This can be explained by the erect canopy in *B. brizantha*, which allows a higher light interception. Previous studies have also reported a higher biomass and forage yields for *B. brizantha*, if compared to other species of this genus (Pariz et al. 2010, Cabral et al. 2013). Additionally, *B. brizantha* shows a smaller stem elongation rate under shade environments, improving the energy use on leaf spawn and leaf elongation (Pacciullo et al. 2011).

The biomass accumulation and nutrient cycling registered herein with *Brachiaria* species were close to those reported for annual crops traditionally grown after corn. In a study with common oat (*Avena sativa*), Hashemi et al. (2013) observed biomass values between 28 kg ha^{-1} day^{-1} and 58 kg ha^{-1} day^{-1}, with N accumulation values between 0.68 kg ha^{-1} day^{-1} and 0.85 kg ha^{-1} day^{-1}. These values are similar to those in the range of 1.2 ha^{-1} day^{-1} and 0.62 kg ha^{-1} day^{-1} of N cycled by *B. brizantha* and *B. ruziziensis*, respectively, in the season (Figure 3). In common oat and white lupine (*Lupinus albus*), Pissinati et al. (2016) observed a cycling of 0.013-0.026 kg ha^{-1} day^{-1} of P and 0.12-0.24 kg ha^{-1} day^{-1} of K, which are very close to the mean amount accumulated by the *Brachiaria* species in this study. These results suggest that corn intercropped with *Brachiaria* species is an effective farming system to enhance the N, P and K cycling.

In the season, the total biomass and nutrient accumulation were positively affected by the intercropping systems ($p < 0.05$), except for N. Regarding the corn monocropping, the intercropped systems increased the total biomass (~ 2,700 kg ha^{-1}), N (~ 53 kg ha^{-1}), P (~ 7 kg ha^{-1}) and K (~ 36 kg ha^{-1}) (Figure 4).

Most contributions to the biomass yields and P contents came from corn components (Figure 4). Nonetheless, the contribution of *B. brizantha* to the total N accumulation in the production system was similar to those of corn components, stover and grain. The *B. ruziziensis* and *B. brizantha* species

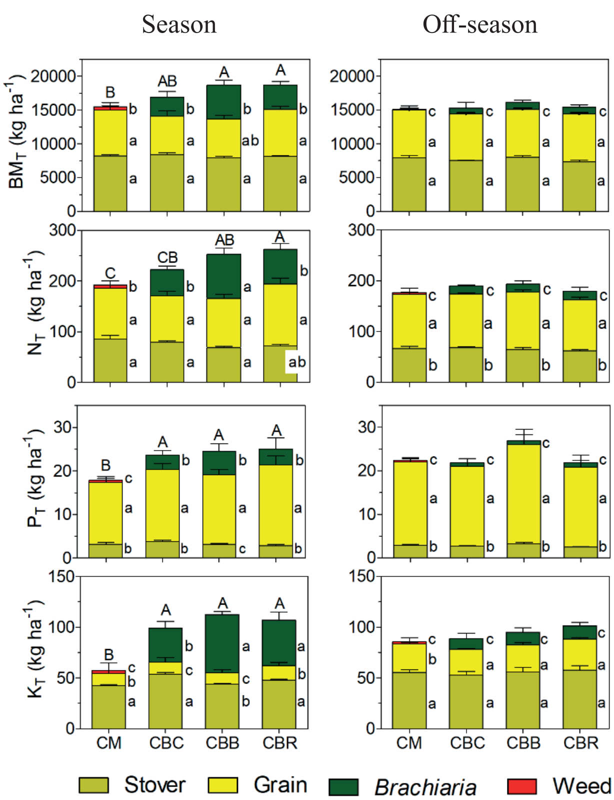

Figure 4. Influence of the farming systems on total (corn and *Brachiaria*) values of biomass (BM_T), nitrogen (N_T), phosphorus (P_T) and potassium (K_T). CM: corn monocropping; CBC: corn-*B.* Convert; CBB: corn-*B. brizantha*; CBR: corn-*B. ruziziensis* (CBR). Lowercase letters indicate significant differences ($p > 0.05$) among the compartments within each farming system; uppercase letters significant differences ($p > 0.05$) among the farming systems; and vertical bars the standard error of the data.

contributed equally or more, if compared to corn stover, for total K accumulation. The component with the lowest contribution to the K accumulation was corn grain.

In the off-season, intercropping did not affect the total accumulation of biomass and nutrients ($p > 0.05$). Overall, 15.5 Mg ha^{-1} of biomass, 185 kg ha^{-1} of N, 24 kg ha^{-1} of P and 94 kg ha^{-1} of K were accumulated (Figure 4). The contribution of the *Brachiaria* species to the total biomass and nutrients was the same among the farming systems ($p > 0.05$). Corn stover and grain were the components with the greatest contribution to the biomass and nutrient accumulation in the off-season.

CONCLUSIONS

1. The *Brachiaria* species did not affect the biomass and nutrient dynamics in corn during intercropping. Overall, *B. brizantha* had the greater accumulation of biomass after the grain harvesting;
2. Intercropping between corn and *Brachiaria* species increased the N, P and K accumulation, relatively to corn monocropping, but only when the intercropping was performed during the season;
3. In corn production systems, the intercropping between corn and *Brachiaria* is a viable alternative for increasing the post-harvest biomass of corn, and thus it could provide significant benefits to the N and K cycling. The establishment of intercropping with *B. brizantha* during the season was the best approach to increase the biomass yield, as well as the N, P and K cycling.

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