University of São Paulo
"Luiz de Queiroz" College of Agriculture

Nutrients dynamics in corn-*Brachiaria* intercropping systems

Silas Maciel de Oliveira

Thesis presented to obtain the degree of Doctor in Sciences. Area: Crop Science

Piracicaba
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Agronomist

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versão revisada de acordo com a resolução CoPGr 6018 de2011

Advisor:
Prof. Dr. **JOSÉ LAÉRCIO FAVARIN**

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This work is dedicated to my mother Amelia
and father Daguillo (in memory).

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CONTENTS

RESUMO

Dinâmica de nutrientes nos sistemas de consórcio milho-*Brachiaria*

O consórcio entre milho (*Zea mays* L) e espécies de *Brachiaria* spp. (syn. *Urochloa* spp.) desempenha importante função no manejo da agricultura tropical, produzir resíduos ou forragem em áreas intensivamente cultivadas. Apesar de estudos anteriores fornecerem valiosas informações sobre efeitos do consórcio sobre o manejo do solo e produção de biomassa, um melhor entendimento de como este sistema de cultivo afeta a dinâmica de nutrientes (exógenos ou endógeno) é necessário. Dois experimentos foram conduzidos durante a safra e segunda safra. No primeiro, os monocultivos de milho e braquiária (*Brachiaria brizantha* cv. Marandu) foram comparados com dois padrões de consórcio, direcionado a produção de resíduos ou forragem, com simulação do pastejo animal. Biomassa, acúmulo de nitrogênio (N), N- fertilizante e balanço de N foram avaliados. As variáveis respostas praticamente não foram afetadas pelos sistemas de cultivos durante o período de coexistência. Após a colheita do milho, os sistemas consórciados acumularam mais biomassa (0,6 -11 Mg ha^{-1}) e N (12-318 kg ha^{-1}) comparado ao pousio precedido pelo monocultivo de milho, apesar destes incrementos afetarem apenas o acúmulos totais (pré+pós-colheita) do cultivo de safra. A recuperação do N-fertilizante foi semelhante entre os sitemas de cultivo. Quando o consórcio objetivou a implantação de pasto, o pastejo simulado após a colheita do milho influênciou o balanço de N, com deficit de aproximadamente -221 kg ha^{-1}.O segundo experimento foi conduzido para investigar a influência das espécies de *Brachiaria* sobre o particionamento de nutrientes no milho e a ciclagem pós-colheita de grãos. Produção de biomassa, quantidades de N, fósforo (P) e postássio (K) acumuladas foram avaliadas no monocultivo de milho e em três espécies de *Brachiaria* spp. (*B. Brizantha* cv Marandu, *B. ruziziensis*, and *B.* hibrido cultivar Mulato II, Convert HD 36) em consórcio com milho. Biomassa e acúmulo de nutrientes não foram afetados no consórcio do milho com as espécies de *Brachiaria*. Após a colheita do milho, o acúmulo de biomassa e nutrientes das espéceis de braquiária classificadas em ordem decrescente foram: *B. brizantha* > *B. ruziziensis* > *B. convert*. Comparado ao monocultivo de milho, o consórcio aumentou a biomassa total (milho+braquiária) e o acúmulo de nutrientes apenas quando cultivado na safra. Entre os 6 locais/anos, os benefícios do consórcio ocorreu após acolheita do milho, especialmente para o cultivo de safra. O milho consorciado com espécies de *Brachiaria* não afetou a recuperação do N-fertilizante nem sua distribuição nos componentes do sistema solo-planta. Entretanto, o consórcio proporcionou maior acúmulo de biomassa após a colheita do milho se comparado ao pousio precedido pelo monocultivo de milho, aumentando a porção de nutrientes alocados no compartimento planta do sistema. Nossos resultados sugerem que a integração entre atividades de lavoura e pastejo aumenta a demanda por N do sistema de produção. O consórcio entre milho e *Brachiaria brizantha* cv Marandu no cultivo de safra foi a melhor estratégia para aumentar a produção de biomassa e a ciclagem de nutrientes no sistema de produção do milho.

Palavras-chave: *Zea mays*; *Urochloa*; ^{15}N; Metódo da diferença; Ciclagem de nutrientes; Práticas de conservação; Semeadura direta; Integração lavoura pecuária; Cultura de cobertura

ABSTRACT

Nutrients dynamics in corn-*Brachiaria* intercropping systems

Corn (*Zea mays* L.) intercropped with *Brachiaria* spp. plays an important role in tropical agriculture management, providing residues or forage to areas intensively cropped. Although previous studies provide useful information about effects of intercropping on soil management and crop yield, a better understanding of how corn-*Brachiaria* intercropping systems impacts exogenous and endogenous nutrient dynamic is needed. Two experiments were performed in the both conventional and late planting season. In the first, corn and palisadegrass (*Brachiaria brizantha* cv. Marandu) monoculture were compared with two intercropping patterns, directed for production of residues or forage, with simulated animal grazing. Biomass, crop nitrogen (N) content, N derived from fertilizer and N budget were measured. Among farming systems, variable responses remained almost unchanged during period of simultaneous growth. After corn harvest, intercropping patterns achieved greater biomass (0.6-11 Mg ha^{-1}) and N content (12-318 kg ha^{-1}) relative to fallow preceded by corn monoculture, but it results in overall gains (pre and post-harvest) only to conventional planting season. N fertilizer recovery was not affected by intercropping patterns. When corn and *Brachiaria* were intercropped to establish pasture, simulated grazing after grain harvest had a tightly influence on N budget, approximately -221 kg ha^{-1}. The second experiment investigated the influence of *Brachiaria* species on corn nutrients partitioning and their cycling after corn harvest. Biomass, N, phosphorus (P) and potassium (K) content were evaluated using corn intercropped with three species of *Brachiaria* (B. Brizantha cv Marandu, B. ruziziensis, and B. hybrid cultivar Mulato II, Convert HD 36) and corn monoculture. Biomass and nutrient content was not affect when corn was intercropped with *Brachiaria* species. After corn harvest, *Brachiaria* nutrient content and biomass yield were ranking from greater to lower following the order: *B. brizantha* > *B. ruziziensis* > *B.* convert. Relative with the corn monoculture, intercropping treatments enhanced the total biomass (corn + *Brachiaria*) and the nutrient accumulation only when planted at conventional season. Over 6 site-yr, benefits of intercropping appear after corn harvest, particularly at conventional planting season. Corn intercropped with *Brachiaria* species either had no effect N fertilizer recovery or affect N-fertilizer distribution within components of soil-plant system. Nonetheless, intercropping provide greater biomass accumulation after harvest compared with corn monoculture, resulting in larger nutrient content stored in plant component. Our results suggest a larger N requirements when crop-livestock activities was integrated. Corn intercropped with *B. brizantha* during conventional season was the best approach to enhanced crop yield and nutrient cycle for corn production systems.

Keywords: *Zea mays*; ^{15}N; Difference method; Nutrient cycling; Conservation practices; No-tillage; Crop-livestock integration; Cover crop

FIGURE LIST

TABLE LIST

1. INTRODUCTION

Grain production systems are known to allocate a considerable amount of resources such as water and fertilizer. Adoption of conservation practices might be useful to reduce agricultural impacts on environmental variables, particularly under intensive cropping systems (Scopel et al. 2013). In tropical and subtropical conditions, intercropping between perennial grass species and cash crops perform as an alternative approach to achieve greater crop yield and enhanced ecological services. Among intercroppings, corn (*Zea mays* L.) intercropped with *Brachiaria* spp. (syn. *Urochloa* spp.) is the most common option.

In no-tillage, after corn is harvest, *Brachiaria* intercropped is used to keep the soil covered (Borghi et al., 2012, Ceccon et al., 2013, Crusciol et al., 2013) or as a nurse crop to establish pastures (Pariz., 2016) in crop-livestock integrated systems (CLI). Corn intercropped with *Brachiaria* can use resources in complementary ways. Previous studies registered effects of intercropping on nutrient cycling (transference of nutrients among the components of crop systems: soil, crop and residue) and nutrients recovery efficiency (Janegitz et al., 2016; Fortes et al., 2017). However, growth conditions and crop rotation are widely different between corn production system, and it may affect nutrients cycling.

Overall, most intercropping studies were performed over conventional planting season, when corn is planted early and the post-harvest timing ranged between 2 to 6 months (Brambilla et al., 2009; Andrade et al., 2016). Nonetheless, approximately 65% of the corn area in Brazil has been cultivated at late season following soybean harvesting (CONAB, 2017). Few studies measured intercropping impacts on nutrient cycling and nutrient recovery efficiency between planting seasons, particularly when crop livestock integration is adopted. Furthermore, it is known that several factors may interact with *Brachiaria* growing after corn harvest, such as growth period, weather conditions and *Brachiaria* management (e.g. grazing) (Cruz et al., 2011, Pariz et al., 2017).

The objectives of this study were to: investigate corn-*Brachiaria* intercropping effect on corn and relative biomass of each component species; characterize nitrogen (N), phosphorus (P) and potassium (K) dynamic, particularly after corn harvest when *Brachiaria* remains on field; quantify N fertilizer recovery in soil-plant system, and evaluate farming systems impact (intercropping and theirs monocultures) on N budget.

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2. CORN-PALISADEGRASS INTERCROPPING EFFECTS ON N BUDGET

Abstract

There is a considerable interest in tropical agriculture regarding corn (*Zea mays* L.) intercropped with palisadegrass (*Brachiaria brizantha* cv. Marandu) given their importance to provide residues and forage. However, the inclusion of palisadegrass in corn systems and the influence on fertilizer dynamic and nitrogen (N) budget remains poorly understood. Fields studies were performed on two growing seasons at conventional and late planted corn to assess crop yield, plant N content, N derived from fertilizer (NDFF) and apparent N budget. Farming systems evaluated were: corn and palisadegrass monocultures, and two intercropping patterns, directed for production of residues and forage, with simulated grazing. Fertilizer N was applied based on corn yield potential, with conventional planting time receiving 150 and late-planted with 120 kg N ha^{-1}. Intercropping patterns did not affect biomass yield and N dynamics. Post-harvest, intercropping patterns achieved greater biomass and plant N content compared with fallow after corn. Overall, total NDFF content was the same among monocultures and intercropping patterns. The contribution of palisadegrass intercropped on the fertilizer N recovery was low, in-season (~4.5 kg ha^{-1}) or after corn harvest (~2.4 kg ha^{-1}). For conventional planting time, different apparent N budget was recorded, approximately -220 kg ha^{-1} when grazing was simulated to intercropping and monoculture palisadegrass. Most advantages of corn-palisadegrass intercropping were observed at conventional planting, despite yearly variation in weather conditions. Corn-palisadegrass intercropping is a viable option for production of residues and forage; nonetheless the negative budget with simulated grazing suggests larger N requirements when crop-livestock activities were integrated.

Keywords: Difference method; ^{15}N tracer; N fertilizer; Nitrogen recovery efficiency; NDFF

2.1 Introduction

For many agricultural landscapes, intercropping between two or more crops emerge as a farming system to enhanced crop yield and provide several others ecosystem services (Malezieux et al., 2008; Scopel et al., 2013; Emanuela et al., 2017). In Brazil, cash crops intercropped with tropical perennial grasses is a strategy to reduced soil erosion and diversify cropping system within areas prone to drought (Borgui et al., 2014; Ceccon et al., 2013; Crusciol et al., 2016). The intercropped corn (*Zea mays* L.) and palisadegrass (*Brachiaria* spp., Syn. *Urochloa brizantha* spp.) has been well-adopted in Brazil (Borgui et al., 2014; Almeida et al., 2017a). For the past 15 years, corn intercropped with palisadegrass has been adopted in large-scale on several farmer fields (Crusciol et al., 2015). Overall, the intercropping is planted under no-tillage and receive the same cultivation practices that the monoculture corn. After corn harvesting, the palisadegrass continue to grow (50-130 kg ha^{-1} day^{-1}), utilized as cover crop, pasture or both in crop-livestock integration (Costa et al., 2016; Pariz et al., 2016; Almeida et al., 2017b).

Nitrogen (N) availability is one of main resources determining intercropping yield (Poffenbarger et al., 2016; Lorin et al., 2016). Previous studies reported that intercropping corn-palisadegrass productivity was positively correlated with N supply, N release and effects on following crop (Torres et al., 2008; Crusciol et al., 2015; Pereira et al., 2016; Pariz et al., 2016). However, an approach for determining the fate of the fertilizer (Almeida et al., 2017a) and nutrient budget (defined as the difference between N input and output) is yet poorly investigated. Recent studies reported that post-harvest management on palisadegrass (e. g, grazing) might affect N budget of the cropping system (Januscklewicz et al., 2015; Pariz et al., 2016; 2017). Moreover, Dubeux et al. (2007) registered greater nutrient removal among cropping systems when the intercropped system includes a grazing component such as palisadegrass after corn harvest.

The success on early-establishment of the intercropping system and their potential nutrients cycling are also closely linked to planting date (Schott et al., 2010; Lorin et al., 2016). In intensive production systems, corn monoculture and corn-palisadegrass intercropping are planted in late season, preceded more often by soybeans [*Glycine max* (L.) Merr]. Inter-species competition and period available for grass growing after harvest could affect biomass production as well as the fate of the fertilizer and the overall N budget.

Current knowledge of N budget is limited around corn-palisadegrass intercropping patterns and their monoculture crops. To establish better management strategies, additional studies are needed to better understand the effect of intercropping on the N cycle. The aims of this study were to investigate: 1) How does the biomass of the alternative farming systems (intercropping and monoculture systems) differ from each other?; 2) Is the corn-palisadegrass intercropping more effective for improving plant N content and fertilizer N recovery throughout the growing season?; 3) How do the different intercropping management strategies (i.e., planting season, grazing post-harvest) impact N budget?

2.2 Material and methods

2.2.1 Experimental sites

Two field trials were conducted in southwest Brazil during two growing seasons in 2013-2014 and 2014-2015, which site 1 and 2 were performed conventional and late planting season experiments, respectively. Plot size was 4 m x 20 m for each treatment. The site I was located in São Paulo State, Taquarituba city at 23° 587' S, 49°248' W at 646 m of altitude. The crops were planted on soil classified as Typic Hapludalf, with a clay loam texture and under low oat residues from grazing. The site II was located in Paraná State, Maringá city at 23° 295' S, 51°892' W at 515 m of altitude. Preceded by soybean crop, harvested in March, crops were planted on a soil classified as Typic Oxisoil with a clay loam texture. Sites have been cultivated using no-tillage practices.

Before the onset of the study, a soil chemical analysis in the 0.2 m soil layer was carried out, presenting the following results for site 1 and 2, respectively: pH (Ca Cl_2) soil 5.5 and 6.3; total soil organic matter of 32 and 18 g kg^{-1}; P (resin extractable) 24 and 18 g kg^{-1}; exchangeable K of 5.4 and 3.2 mmol dm^{-3}. Plating date, crop rotation and climatological data for experimental sites is summarized in Fig.1.

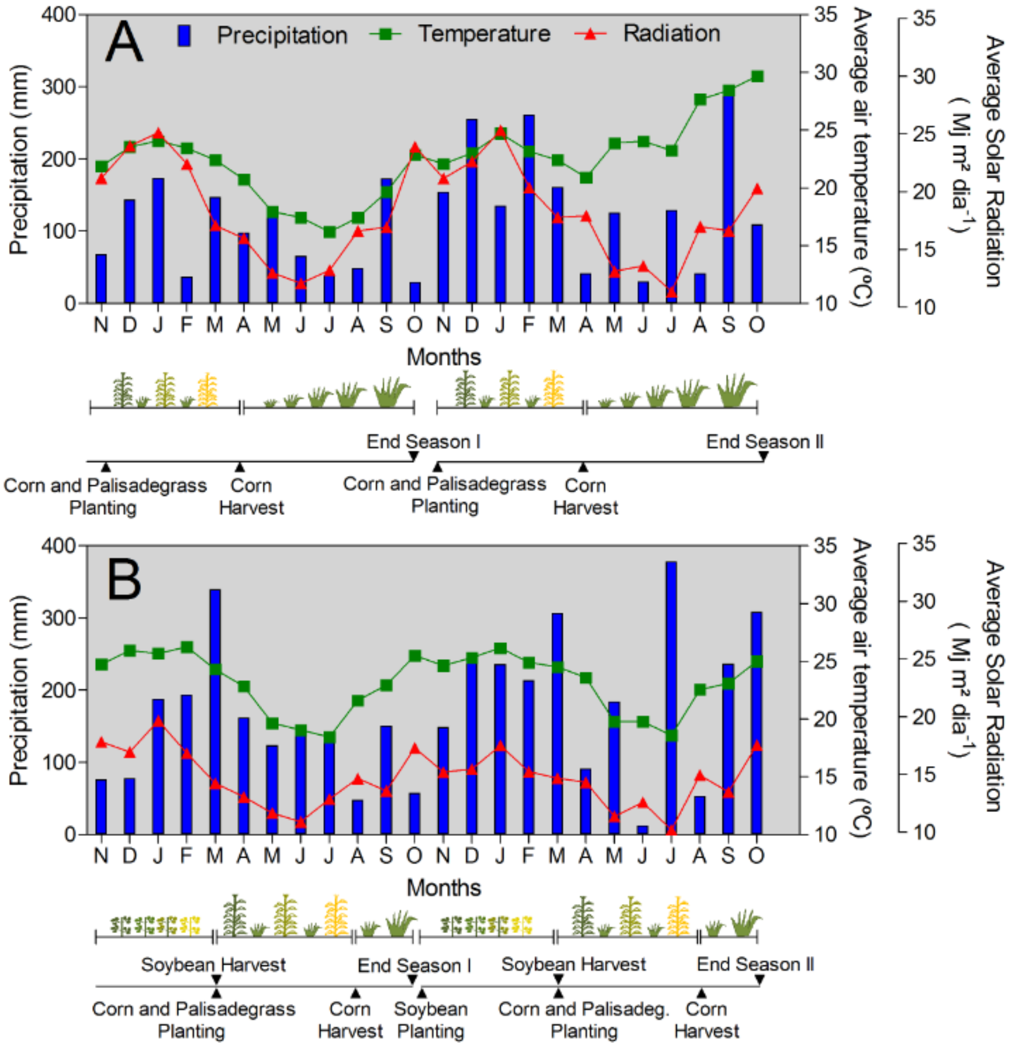

Figure 1. Precipitation, average air temperature and solar radiation during the study period for (A) conventional and (B) late planting season at experimental area. Timing of planting and harvesting are indicated for each planting season.

Nitrogen fertilizer was applied as ammonium sulfate at a rate of 150 kg N ha^{-1} and 120 kg N ha^{-1} to conventional and late-planted season, respectively. The fertilizer N was applied when at three leaf growth stage, V3 (Ritchie and Hanway, 1989) for all farming systems. Phosphorus (P) and potassium (K) were supplied at planting time, with 50 kg P_2O_5 ha^{-1} as triple superphosphate and 50 kg K_2O ha^{-1} as KCl.

2.2.2 Experimental setup

Monoculture system was planted in 4 rows spaced at 0.9 m. For the intercropping pattern, the palisadegrass seeds were manually planted between corn rows spaced at 0.9 m. Thus, corn-palisadegrass intercropping was spaced at 0.45 m. For all farming systems, crops were planted on the same day at 5 cm depth, corn at the density of 60,000 plants ha^{-1}, palisadegrass using 3.4 kg viable seed ha^{-1}. Corn hybrid DK390PRO and B188 were planted to the conventional and late-planted system, respectively. The palisadegrass used was *B. brizantha* cv. Marandu (syn. *Urochloa brizantha* cv. Marandu).

The experimental design was a randomized complete block (RCB) with four replications in year #1 and five replications in year #2. Treatments consisted of four farming systems: i) corn monoculture; ii) palisadegrass monoculture; iii) corn- palisadegrass intercropping with palisadegrass for cover crop (ICC); and iv) corn-palisadegrass intercropping with palisadegrass for grazing, such as performed on crop-livestock integration (ICLI).

Corn-palisadegrass intercropping patterns received the same management from planting to corn harvest. Afterwards, ICC represented the palisadegrass remain growing on soil surface as cover crop and ICLI was subjected to the simulated grazing applied full time on palisadegrass monoculture. For simulated grazing animals, the palisadegrass canopy was manually cut from 0.6 m to 0.3 m each time the plants have reached 0.6 m. Biomass harvested above 0.3 m was defined as forage, and basal portion of stems and leaves left after simulated grazing was termed as stubble (Allen et al., 2011). The corn monoculture plots remained under fallow after grain harvest, and weeds were sampled at the end of season (at termination of the palisadegrass for the intercropping systems).

2.2.3 Sampling and crop measurements

Corn grain harvest occurred at physiological maturity from the usable area of plots. Grain yield was standardized to 13% moisture. For N evaluations, four plants were cut at ground level and divided into grain and stover plant fractions (ear, cob, stem, leaves and tassel). The remaining corn plants, excluded grains, were ground a ~3 cm mesh sieve and evenly distributed on aboveground at the same harvest day.

The palisadegrass sampling was done in 1 m² in the year #1 and 0.5 m² in the year #2. The area was lower in year #2 due the microplots utilized for ^{15}N methods. In ICC treatment, biomass was obtained by cutting plants at ground level. When grazing was simulated, the palisadegrass biomass was sampled according with forage and stubble settings. Biomass from each simulated grazing and stubble remained at corn harvest time or end season was accounted for calculating total biomass. The plant material collected was dried for 72 h in a forced-air oven at 60 °C to measure dry mass and ground in a Wiley Mill with a 2-mm mesh sieve.

2.2.4 N calculations

For the first experimental year, the N derived from fertilizer (NDFF) was calculated utilizing the difference method (eq. 1), a non-isotopic measure of fertilizer recovery.

$$\mathrm{NDFF}\ (\mathrm{kg\ ha^{-1}}) = [(\mathrm{a} \times \mathrm{b}) - (\mathrm{c} \times \mathrm{d})] \qquad 1$$

where *a* is the percent of N contained in the sample of the fertilized plot; *b* is dry mass sample of the fertilized plot; *c* is the percent of N contained in the sample of the unfertilized plot; *d* is dry mass sample of the unfertilized plot. Biomass was expressed in kg ha^{-1}.

Isotopic ^{15}N method was used in year 2. ^{15}N-labeled fertilizer was applied as ammonium sulfate labeled to 3 % ^{15}N atoms. Labeled fertilizer was applied on two microplots, located at the center of each plot for a total area of 0.9 m^2 within each treatment. Microplot 1 and 2 were collected at corn harvest and at the end of the season, respectively. All treatments received labeled fertilizer at V3 corn growth stage, as described in the conventional fertilizer N application.

When ^{15}N labeled fertilizer was used (year 2), N distribution in soil layers was also measured in all farming systems. Soil labeled samples were collected after corn harvest and at the end season. Sampling was collected between 0-0.2 m and 0.2-0.4 m depth using a soil probe. The samples were air-dried and ground a 2-mm mesh sieve. Plants and soil samples were collected at the center of each microplot.

The total N concentration and $^{15}N/^{14}N$ isotope ratio were measured in an automated mass spectrometer coupled to an ANCA-GSL N analyzer (Sercon Co., UK). The NDFF in the labeled samples was calculated used equation 2:

$$\text{NDFF (kg ha}^{-1}) = \left[\frac{e - f}{g - f}\right] \cdot \text{Total N} \qquad 2$$

where *e* is the abundance of ^{15}N atoms in the sample (%), *f* is the natural abundance of ^{15}N atoms (0.366%), *g* is the abundance of ^{15}N atoms in the fertilizer (3 % atoms), and Total N is the total of N ($^{15}N+^{14}N$) contained in the sample (kg ha^{-1}).

Apparent N budget and fertilizer N budget were calculated for each farming system at the end of the season. The input for all systems consisted on the fertilizer N applied. The output consisted of the total N exported (grain and forage) for the calculation of the apparent N budget and the N fertilizer removed for the calculation of the fertilizer N budget. The difference between the input and the output was expressed in kg ha^{-1}.

2.2.5 Statistical analysis

Before analysis, the observations from the response variables were tested for homoscedasticity through Box–Cox test (Box and Cox 1964) in SAS (SAS Institute Inc 2009). If needed, an appropriate transformation of the data were implemented. Two experimental years for each site were analyzed together using Proc MIXED. If the null hypothesis was rejected, Tukey mean comparison tests were performed at $P < 0.05$ to the variables presented a significant influence on the response factor. In the first research period, from planting to corn grain harvest, there was no difference between intercropping patterns (ICC and ICLI) and management practices. Therefore, both ICC and ICLI were grouped for this period, named as "Intercropping means". All figures were made using GraphPad Prism 6.

2.3 Results

2.3.1 Crop yield

The farming system did not affect corn yield and their interactions with year to both conventional and late-planted season (P>0,05), although difference between years (P<0,05). Grain yield was approximately 10.8 Mg ha^{-1} and 7.3 Mg ha^{-1} for the conventional and late-planted systems, respectively (Fig. 2). Forage yield was different by farming system and year (P<0,05), without presenting interactions. Palisadegrass monoculture achieved greater forage yield for all planting systems (Fig. 2).

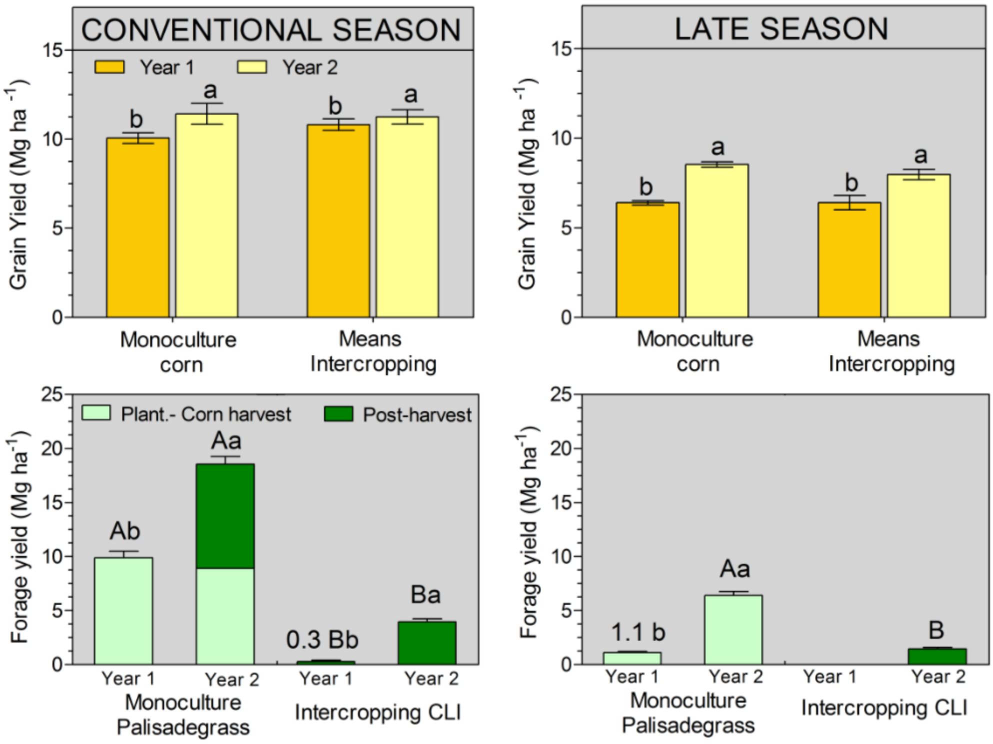

Figure 2. Influence of farming systems on grain/forage yield. Uppercase letters indicate differences among farming systems. Lowercase letters indicate differences between years. Vertical bars indicate the standard error from the data.

During corn growth period, the palisadegrass monoculture biomass was lower than when corn was included in the farming system, regardless of the planting season (Table 1; Fig. 3). Palisadegrass contribution was also poor to intercropping patterns in corn growth period. In contrast, palisadegrass monoculture obtained the largest biomass post-harvest, followed by palisadegrass from intercropping patterns (Fig. 3). It is suggested that palisadegrass growth post-harvest was penalized when coming from intercropping, but show a clear advantage relative with fallow preceded by corn.

Table 1. Combined analysis of variance between framing systems and years for the biomass, plant N content and NDFF.

Source variation	Conventional season			Late season		
	Planting - Corn harvest	Post-harvest	Total	Planting - Corn harvest	Post-harvest	Total
			Biomass			
Year (Y)	ns	***	***	***	***	***
Farm. System (FS)	***	***	***	***	***	***
Y*FS	ns	***	**	*	***	*
			N content			
Year (Y)	***	***	***	***	ns	***
Farm. System (FS)	ns	***	***	***	***	**
Y*FS	*	***	***	**	**	**
			NDFF			
Year (Y)	***	***	***	*	**	***
Farm. System (FS)	ns	***	ns	**	***	***
Y*FS	ns	***	ns	ns	***	ns

* Significance at $P < 0.05$ level; ** Significance at $P < 0.01$ level; *** Significance at $P < 0.001$ level; and ns not significant.

During conventional plating season, largest difference in total biomass was registered in year #2 (Fig. 3). Intercropping patterns enhanced total biomass from 4.4-11.3 Mg ha^{-1} when compared with their monocultures. In late planting season, palisadegrass monoculture was the farming system with the lower total biomass across the years. No differences were noted between corn monoculture and corn-palisadegrass intercropping.

2.3.2 N content and NDFF

Plant N content was not affected by farming systems between planting and grain harvest, except for year #1 late planting season, when palisadegrass monoculture was the farming system with lower plant N content (Table 1; Fig. 4A). The plant N content post-harvest depends on environmental factors in each year to conventional planting season. The lower plant N content in year #1 is partially explained by temperatures close to the basal palisadegrass growth, 17 ºC (Fig. 1A; Cruz et al., 2011), when palisadegrass was negatively affected (Fig. 3). In year #2, the greater plant N content was registered to farming systems that receive simulated grazing, ICLI and palisadegrass monoculture. For late planting season, palisadegrass monoculture was the farming system with greater plant N content at post-harvest. Intercropping patterns increasing post-harvest N content relative to the corn monoculture in post-harvest.

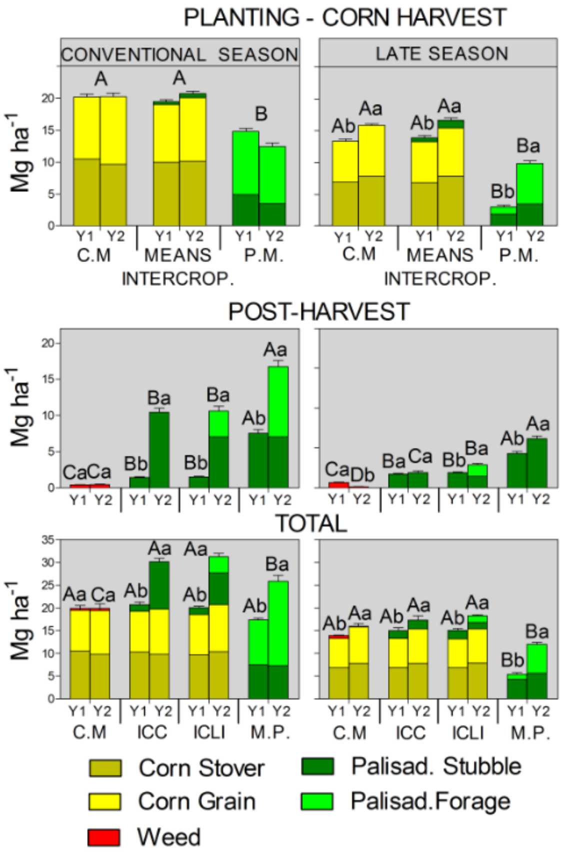

Figure 3. Influence of farming systems on biomass. Corn monoculture, C.M.; corn-palisadegrass intercropping to cover crop, ICC; corn-palisadegrass intercropping to crop-livestock integration, ICLI; palisadegrass monoculture, P.M. Uppercase letters indicate differences among farming systems. Lowercase letters indicate differences between years. Vertical bars indicate the standard error from the data.

Total plant N content was largely affected by the post-harvest N content (Fig. 4A). In conventional planting season, intercropping patterns affected total plant N content only in year #2, it has been enhanced from 200-330 kg N ha^{-1} compared with corn monoculture. In late planting season, N accumulated by palisadegrass intercropped was not enough to affect total plant N content (Fig. 4A). Except for year 1, when we registered lower total plant N content to palisadegrass monoculture, there was no differences among farming systems.

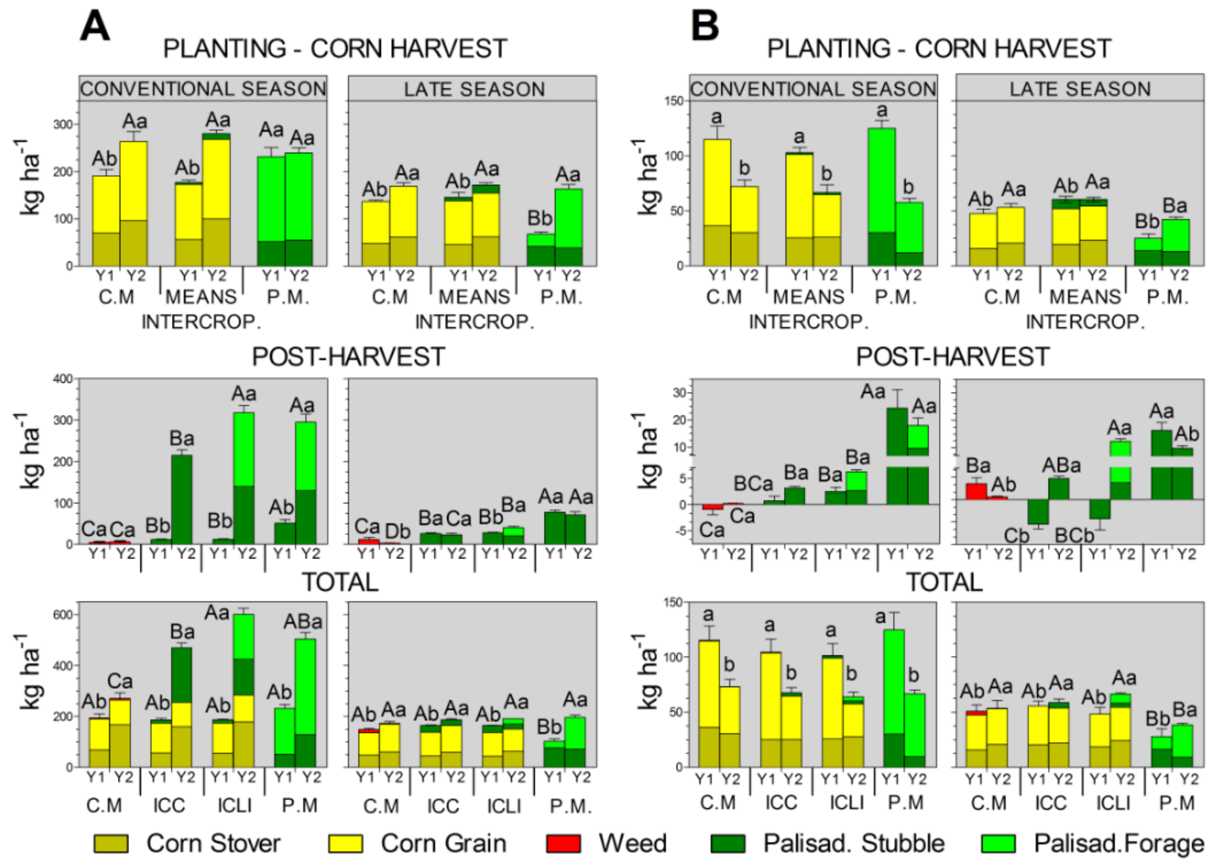

Figure 4. Influence of farming systems on (A) crops N content and (B) NDFF. Corn monoculture, C.M.; corn-palisadegrass intercropping to cover crop, ICC; corn-palisadegrass intercropping to crop-livestock integration, ICLI; palisadegrass monoculture, P.M. Uppercase letters indicate differences among farming systems. Lowercase letters indicate differences between years. Vertical bars indicate the standard error from the data.

According to plant N content, almost all NDFF content values were the same among the farming systems and planting seasons until corn harvest (Fig. 4B). N and NDFF content responses indicated low differences between farming systems and N dynamic during corn growth period. Whilst plant N content responses in post-harvest were wide different among farming system, years and planting season, was registered low variation to NDFF content. Overall, palisadegrass monoculture was the farming system with the largest NDFF content at post-harvest. For intercropping patterns, only 1 out of 4 yr-season had greater NDFF content gains (12 kg ha^{-1}), ICLI late planting season (Fig. 4B), suggesting low impact of intercropping patterns on fertilizer cycling post-harvest.

Total NDFF content was not affected by farming systems in conventional planting season (Table 1; Fig. 4B). On average over four farming systems crop N fertilizer account was 73 and 56 kg ha^{-1} to year #1 and #2, respectively. In late season, NDFF content to palisadegrass monoculture was 22 kg ha^{-1} less than the average NDFF content of farming systems with corn included.

2.3.3 Soil NDFF content and N budget

Farming systems did not affect the soil NDFF content with the exception of the late season at corn harvest (Table 2). Relative to corn monoculture and intercroping patterns, palisadegrass monoculture increased 8 kg N ha^{-1} of NDFF content at the soil layer (0-20 cm). The palisadegrass monoculture had also a larger NDFF content in entire soil profile (0-40 cm).

Table 2. Distribution of N derived from fertilizer (NDFF) at corn harvest and end of the season from 0-20 cm, 20-40 cm, and overall 0-40 cm.

Farming system	Conventional season			Late season		
	0 - 20 cm	20 - 40 cm	0 - 40 cm	0 - 20 cm	20 - 40 cm	0 - 40 cm
	---------- kg ha^{-1} ----------					
	Corn harvest					
Corn Monoculture	27 ± 3	7 ± 1	34 ± 4	19 ± 3 B	12 ± 6	31 ± 5 B
I. Cover Crop	26 ± 3	6 ± 2	32 ± 3	24 ± 2 B	12 ± 4	38 ± 3 AB
I. Crop livestock Integration	28 ± 5	7 ± 1	35 ± 5	21 ± 3 B	9 ± 5	30 ± 3 B
Palisadegrass monoculture	30 ± 5	9 ± 1	38 ± 5	30 ± 4 A	9 ± 4	39 ± 4 A
Mean	28	7	35	24	11	35
ANOVA Pr>F	ns	ns	ns	*	ns	*
	End of the season					
Corn Monoculture	27 ± 4	7 ± 1	35 ± 5	20 ± 2	8 ± 1	28 ± 3
I. Cover Crop	30 ± 5	7 ± 2	37 ± 6	30 ± 4	11 ± 2	41 ± 5
I. Crop livestock Integration	31 ± 4	6 ± 1	38 ± 4	30 ± 5	9 ± 1	38 ± 4
Palisadegrass monoculture	35 ± 6	7 ± 1	43 ± 4	23 ± 4	10 ± 2	33 ± 5
Mean	31	7	38	25	10	35
ANOVA Pr>F	ns	ns	ns	*	ns	*

± standard error; ns not significant; * significant at 5% probability of error by the F test. Uppercase letter indicates differences among farming systems.

Apparent N budget differed across farming systems (Table 3). From planting to harvest, the lowest values were often obtained to palisadegrass monoculture (Fig 5A). There was no difference between corn monoculture and intercropping patterns, regardless of the planting season. Nevertheless, in year 2 of conventional planting season a significantly shift in apparent N budget was associated with simulated grazing applied post-harvest. The N exported by forage from palisadegrass monoculture or ICLI was approximately 230 kg N ha^{-1}. In late planting season, apparent N budget was not affected among all the farming systems evaluated.

Table 3. Combined analysis of variance between framing systems and years for the apparent N budget and fertilizer N budget.

Source variation	Apparent N budget		Fertilizer N budget	
	Conventional season	Late season	Conventional season	Late season
	Planting - Corn Harvest		Planting - Corn Harvest	
Year (Y)	***	***	***	ns
Farm. System (FS)	**	ns	ns	**
Y*FS	*	***	ns	**
	Planting – End of season		Planting – End of season	
Year (Y)	***	***	***	**
Farm. System (FS)	***	***	ns	**
Y*FS	***	**	ns	*

* Significance at $P < 0.05$ level; ** Significance at $P < 0.01$ level; *** Significance at $P < 0.001$ level; and ns not significant.

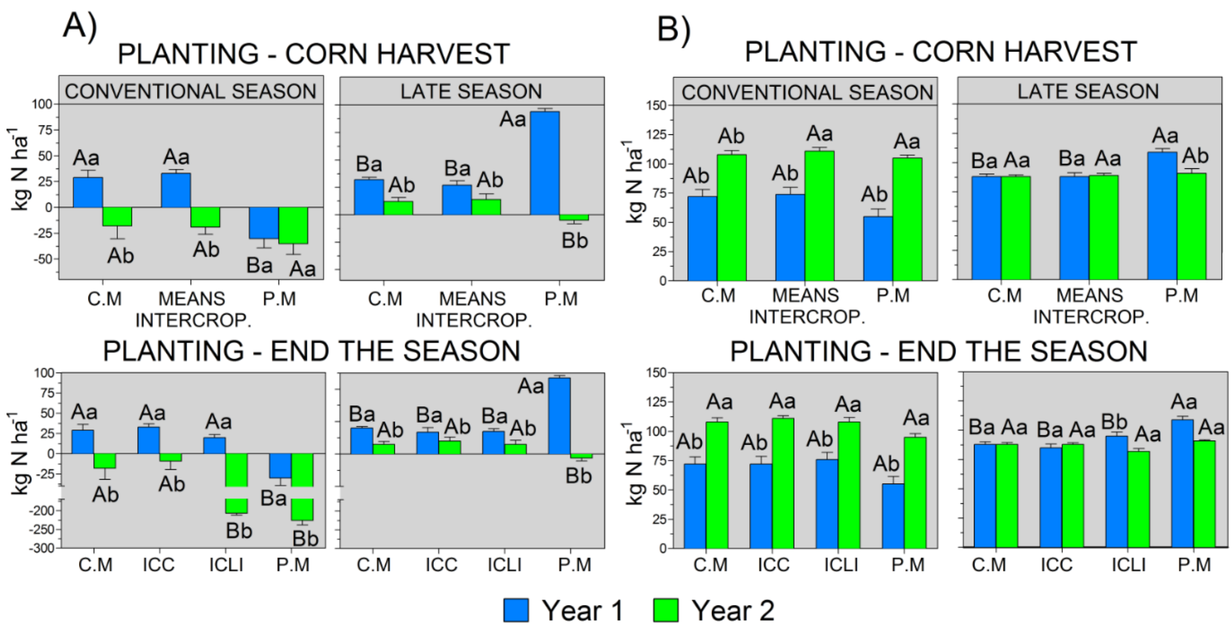

Figure 5. Influence of farming systems on (A) apparent N budget and (B) fertilizer N budget. Corn monoculture, C.M.; corn-palisadegrass intercropping to cover crop, ICC; corn-palisadegrass intercropping to crop-livestock integration, ICLI; palisadegrass monoculture, P.M. Uppercase letters indicate differences among farming systems. Lowercase letters indicate differences between years. Vertical bars indicate the standard error from the data.

In both conventional and late planting season, the fertilizer N budget was poorly affected by farming systems (Table 3). Results post-harvest were closely linked by fertilizer budget reported between planting and grain harvest (Fig. 5B). The lack of effect was most likely due low fertilizer recovery post-harvest.

2.4 Discussssion

We performed this study to address the following concern about corn-palisadegrass intercropping: 1) crop yield among monoculture and intercropped farming systems; 2) total plant N content and N fertilizer recovery; and 3) N budget. To approach the first concern, it is important to discern corn growth and post-harvest periods.

Competition and yield advantage in plant associations are closely associated with biomass production (Li et al., 2001; Hamzei et al., 2016). During a period of simultaneous growth, the palisadegrass biomass represented only ~3% of relative biomass intercropping and it did not affect biomass yield. Previous studies have found that corn grain yield may be penalized when intercropped with legumes and non-leguminous (Ngwira et al., 2012; Gou et al., 2016; Rahman et al., 2017), however corn partners achieved total biomass relative between 16-45% of corn crop. In our study, low palisadegrass biomass also explain the lack of effect on corn grain yield, plant N content and NDFF content during corn growth period.

In post-harvest, our results suggested that crop yield was improved under conventional planting season, when palisadegrass growth for longer time during the growing season. Timing for growing also is a limitation for others intercropping systems (Schott et al., 2010; Lorin et al., 2016). Nevertheless, even the low amount of post-harvest biomass also be useful, particularly when used under dry winter conditions found in Brazil. For example, in year #2 the forage produced by ICLI treatment provided an equivalent to 11 grazing days under stocking rate of 2 animal unit (A.N.; one unit = 450 kg) ha^{-1} to late planting season (Flores et al., 2008; Euclies et al., 2009). Also, positive effects on soil organic matter are reported when intercropping was included in cropping rotation (Loss et al., 2012; Crusciol et al., 2015).

After harvest, intercropping contribution to N cycling was registered for conventional season. Others have also highlighted nutrient cycling of corn-palisadegrass intercropping planted in conventional season (Crusciol et al., 2015; Fortes et al., 2017), enhanced yield and nutrient concentration to the following crop. Indeed, previous studies carried out at conventional season reported N cycling gains depending on corn maturity group, grass species, plant density and row distance (Ceccon et al., 2013; Crusciol et al., 2013; Borght et al., 2013). Accordingly, these interactions should be investigated further to improve corn-palisadegrass intercropping and avoid grain or forage yield penalizes on late planting season.

In opposite to the plant N content, corn-palisadegrass intercropping did not affect NDFF content. Even when palisadegrass N content was greater at post-harvest (Fig. 4A), N fertilizer contribution was ~2% of total N (Fig. 4B). In early studies, Rekhi and Bajwa (1993) and Yan et al. (2014) also reported low N fertilizer residual recovery for subsequent crops, ranged from 1% to 5%. For the same authors, low N recovery could be attributed to the timing between subsequent N supply and N demand to the following crop. However, palisadegrass growth just after corn harvesting did not affect NDFF content. It is suggested that potential N fertilizer recovery to the following crop is low (~2.4%), regardless of the degree of synchrony between N supply and crop N demand.

Only when plant NDFF content was low, the soil NDFF content was affected. In this case, palisadegrass monoculture planted in late season obtained larger soil NDFF content. The low N fertilizer recovery post-harvest may be explained for immobilization process once combination of residues (carbon) and weather conditions were favorable (Sugihara et a., 2010; Fujita et al., 2013).

During coexistence period, available N was not limited to corn-palisadegrass intercropping, because apparent N budget between intercropping and their monocultures were the same or greater. Nonetheless, apparent N budget was much negative when grazing was simulated post-harvest at conventional planting season. The outcome of this study supports the results previously reported by Oelmann et al. (2007) and Ammann et al. (2009). Those authors reported that N budget was tightly affected when forage harvesting were applied. Although the inclusion of domestic herbivores increasing N cycling on crop-livestock fields (He et al., 2008; Soussana and Lemaire, 2014), our results suggest that N demands by corn-palisadegrass intercropping is larger when applied crop and livestock activities. These results allow estimating the N demands for achieving greater intercropping yield, and avoid that following crop to be penalized due previous N output.

Low effects of fertilizer N budget on farming systems shows a widely difference between N and N fertilizer cycling. There was a lack of effect to N fertilizer recovery post-harvest (~3%), suggesting that greater N rate at planting and apparent N budget should not be expected. Nonetheless, Borghi et al. (2014) reported ~75% fertilizer recovery was supplied just after corn harvest.

2.5 Conclusion

During a period of simultaneous growth, corn-palisadegrass intercropping has low impacts on crop yield and N dynamic to both conventional and late planting season. Throughout the growing season intercropping patterns enhanced plant N content and biomass when planted at conventional season, although seasonal weather variation influenced the response between years. The N cycling within intercropping was tightly related to biomass yield and has been driven by N derived from soil, which represented ~98% palisadegrass N content at post-harvest. Our study demonstrates that the relationship between intercropping systems and N budget was affected with simulated grazing, suggesting larger N demand when crop-livestock activities are integrated under field crops. Corn-palisadegrass intercropping is recommended as a strategy to enhanced biomass and soil N cycling in conventional planting corn for tropical agriculture. Further studies should investigate the effect of different crop rotation, planting management, and level of intensification on the N budget for this complex intercropping biological systems.

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3. INTERCROPPING CORN WITH *BRACHIARIA* SPECIES: NUTRIENT CYCLING

Abstract

The present study investigated the dynamics of biomass, nitrogen (N), phosphorus (P), and potassium (K) for intercropping corn (*Zea mays* L.) and the *Brachiaria* spp. species (syn. *Urochlo* spp.). Two periods were evaluated: the intercropping period and the post-harvest period, when only *Brachiaria* remained in the field. Field experiments were performed in two growing seasons, the conventional and late planting seasons. The treatments were composed of three *Brachiaria* species (*B. Brizantha* cv Marandu, *B. ruziziensis*, and *B.* hybrid cultivar Mulato II, Convert HD 36) intercropped with corn and corn monoculture. Compared to the monoculture, the *Brachiaria* species did not affect corn nutrient accumulation and partitioning during the intercropping period. After corn harvest, *B. brizantha* had the highest accumulation of biomass in the conventional (69 kg ha^{-1} day^{-1}) and late planting season (17 kg ha^{-1} day^{-1}). Nutrient accumulation varied widely between *Brachiaria* species and planting seasons after corn harvesting: 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 N, P, and K accumulation after corn harvesting for both plating seasons was found for: *B. brizantha* > *B. ruziziensis* > *B.* convert. Compared with the corn monoculture, intercropping treatments enhanced the total biomass (corn + *Brachiaria*) and nutrient accumulation only when planted at conventional planting season. Our results suggest that corn- *Brachiaria* intercropping has a greater impact on nutrient cycling and balance when carried out in conventional planting season. Intercropping between corn and *B. brizantha* grown in the conventional planting season was the best strategy to achieve greater biomass and N, P, and K cycling.

Keywords: Nutrient cycling; *Zea mays* L.; *Brachiaria*; *Urochloa*; Crop residue; Cover crop

3.1 Introduction

Cover crops have been included in crop rotation to meet challenges such as nutrient losses and deterioration of soil physical. 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 (Shipley et al., 1922; Snapp et al. 1992, Poffenbarger et al., 2015).

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

Recent studies have reported that biomass and nutrient accumulation in *Brachiaria* species cultivated in monoculture are affected by agricultural practices, such as method of implantation and period of forage planting (Silva et al, 2008; Pariz et al., 2010). However, biomass and nutrient accumulation among the *Brachiaria* species intercropped with corn remains poorly understood. Besides corn effects on *Brachiaria* growth in the intercropping period, biomass and nutrient accumulation might also be regulated by planting season. In short, later planting of corn and *Brachiaria* diminish the probability of rainfall, solar radiation, and time available for forage vegetation after corn harvesting.

Soil nutrient availability, biomass accumulation, and period available for growing affect nutrient cycling by cover crops (Fageria et al., 2005; Lorin et al., 2016). In this manner, better understanding the amount of nutrients accumulated by the *Brachiaria* species is important for determining the benefits of nutrient cycling and soil fertility. Following this rationale, the first goal of this study was to investigate the accumulation and partitioning of biomass, nitrogen (N), phosphorus (P), and potassium (K) when intercropping corn and *Brachiaria* species in the both conventional and late planting season. The second goal is to known the cycling of these nutrients after corn harvesting, given that intercropping benefits are closely associated with biomass and nutrient accumulation during these periods.

3.2 Material and Methods

3.2.1 Site description

Two field trials were conducted during growing season of 2014-2015 in Brazil. Conventional planting season experiment was carried out in Taquarituba, São Paulo State (49° 248'W, 23° 587'S, and altitude of 630 m). The soil of the area is classified as Hapludalf (USDA, 1998) with 657 g of clay, 253 g of silt, and 90 g kg^{-1} of sand. The late planting season experiment was conducted in Maringá, Paraná State (51° 892'W, 23° 295'S, and altitude of 515 m). The soil is classified as Oxisoil (USDA, 1998) with 541 g of clay, 289 g of silt, and 170 g kg^{-1} of sand. According to the Koppen classification, both regions have a Cfa climate characterized as humid subtropical with hot summers. Climatic data during the experimental period are shown in Fig. 6.

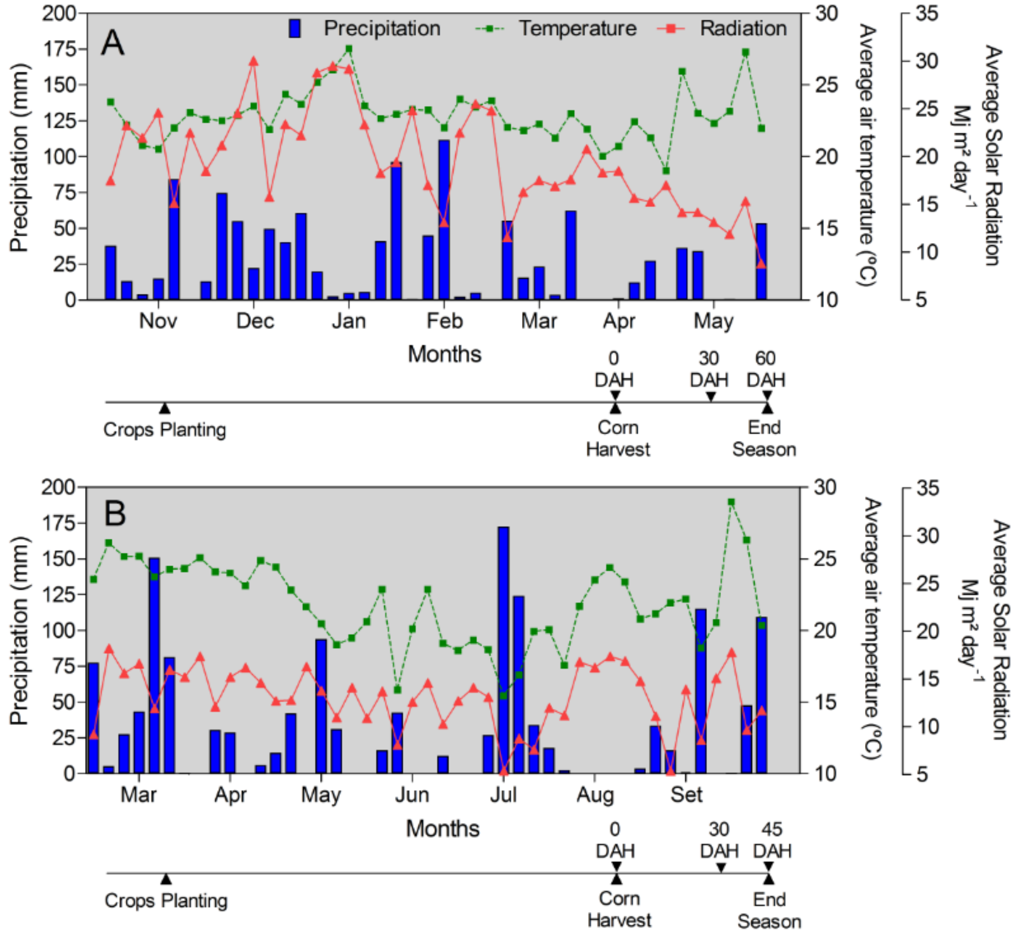

Figure 6. Precipitation, average air temperature and solar radiation during the study period for (A) conventional and (B) late planting season. Days after harvest, DAH.

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

3.2.2. Experimental design and treatments

Experiments were performed in a randomized block design with four treatments, plots subdivided into time and five replications. The treatments consisted of corn monoculture and three forage grasses of the genus *Brachiaria* (syn. *Urochloa*) intercropped with the corn: *B.* hybrid cultivar Mulato II (Convert HD 364), *B. brizantha* cv. Marandu and *B. Ruziziensis*. The subplots consisted of three forage biomass collection times after corn harvesting, which were 0 days after harvesting (DAH), 30 DAH, and 60 DAH for the conventional planting season and 0 DAH, 30

DAH, and 45 DAH for the late planting season (Fig. 6). The third collection in the late planting season was not performed at 60 DAH since the area was being prepared for soybean planting.

3.2.3 Crop management

The conventional planting season area was 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 no-tillage. Planting occurred in November 2014 on black oat residues (*Avena strigosa*). The late planting season area has been used since 2006 under no-tillage management and soybean, corn, and wheat crops rotation. Planting occurred in March 2015 on soybean residues. The 30137HX and B188 corn hybrids were planted in the conventional and late season, both at a density of 60,000 plants ha^{-1} and line spacing of 0.9 m. In the intercropping treatments, the *Brachiaria* species were planted on the same day as the corn. Sowing was performed manually in 5 cm deep furrows between the corn rows and with 4.5 kg ha^{-1} of viable seeds.

In the planting, 50 kg ha^{-1} of P_2O_5 were used as triple superphosphate and 50 kg ha^{-1} of K_20 as KCl. Topdressing mineral fertilizer was applied at V3 (Ritchie et al., 1986) growth stage, 150 kg, and 120 kg of N ha^{-1} as ammonium sulphate were applied as cover in the conventional and late planting season, respectively. All plots receive with 640 grams of glyphosate acid equivalent ha^{-1} before sowing for weed control. Then, 3,250 GAI ha^{-1} (grams of active ingredient) of atrazine and 25 GAI ha^{-1} of nicosulfuron were applied post-emergence when the species of *Brachiaria* issued the first tiller for monoculture and intercropping treatments.

3.2.4 Sampling and analysis

Grain yield was standardized to 13% moisture. Total dry matter and nutrient content of corn were obtained from four plants collected in the center of the plots and divided into grains and stover (stem, leaves, cob, tassel, and stover). *Brachiaria* plants present in 1 m² were collected at ground level. Total biomass, N, K, and P values were obtained by the sum of the values of the corn samples obtained in the grain harvest plus *Brachiaria* sampling at 60 DAH and 45 DAH for the conventional and late planting season, respectively. In the corn monoculture, spontaneous vegetation present in the plots in the last sampling was also recorded.

N concentration in 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.

3.2.5 Statistical analysis

Results underwent tests of normality and homogeneity of variance, followed by analysis of variance by the F test at 5% of probability using the program "Statistical Analysis System version Windows 9". 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* collected across the days after corn harvest.

3.3. Results

3.3.1 Corn evaluations

Corn grain yield was not affected by intercropping in both planting seasons (Table 4). On average, 6.3 and 6.5 Mg ha^{-1} of grains were produced in the conventional and late planting season, respectively. In the conventional season, a large population of *Spodoptera frugiperda* was recorded between V4-V6, which likely affected the mean grain yield of the experimental area. The dry biomass of the grain, stover and whole plant, was not affected by the intercropping system ($P > 0.05$). Total biomass was 14.5 Mg ha^{-1} and 14.7 Mg ha^{-1} conventional and late planting season, respectively (Fig. 7).

Table 4. Influence of farming systems on corn grain yield.

Treatment	Conventional planting season	Late planting season
	Mg ha^{-1}	
Corn monoculture	6.8 ± 0.7	6.5 ± 0.2
Corn-*B.* convert	5.7 ± 0.8	6.6 ± 0.1
Corn-*B. brizantha*	5.8 ± 0.5	6.3 ± 0.3
Corn-*B. ruziziensis*	7.0 ± 0.4	6.6 ± 0.1
Means	6.3^{ns}	6.5^{ns}

± standard error; ns not significant.

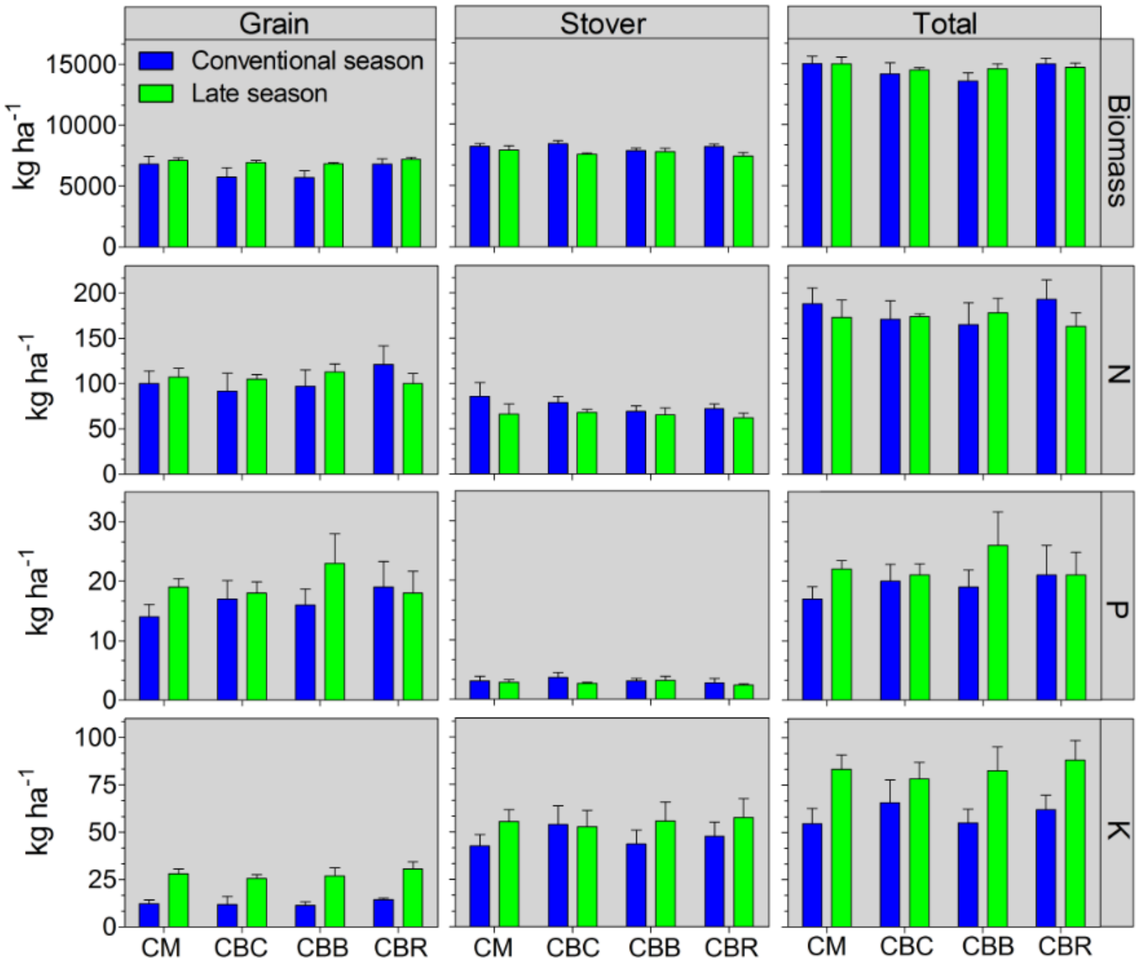

Figure 7. Influence of farming systems on biomass and nutrient partitioning in corn. Vertical bars indicate standard error from the data. Corn monoculture, CM; corn *B.* convert, CBC, corn *B. brizantha*, CBB; corn *B. ruziziensis*.

Intercropping also did not affect the accumulation of N, P, and K in the grains, stover or total biomass of corn plants (P > 0.05) in both planting seasons. In the conventional season, the total biomass of corn accumulated 179, 20, and 59 kg ha^{-1} of N, P, and K, respectively. In the late season, the total biomass accumulated 172, 22, and 83 kg ha^{-1} of N, P, and K, respectively.

3.3.2 *Brachiaria* evaluations

In conventional planting season, there was a large number of interactions between species and samples (Table 5). However, the accumulation of biomass and nutrients increased in the *Brachiaria* species over sampling dates. Overall, *Brachiaria* influenced biomass production and nutrient accumulation only after grain harvesting. After the grain harvest, 66, 44, and 31 kg ha^{-1} day^{-1} of biomass were accumulated for *B. brizantha*, *B. ruziziensis*, and *B.* convert, respectively (Fig. 8). Interactions between species and collection dates were recorded for N, P, and K (Table 5). *B.*

brizantha was also the species with the greater nutrient accumulation after corn harvesting. On average, *B. brizantha* accumulated 1.2, 0.07, and 0.7 kg ha^{-1} day^{-1} of P and K, respectively (Table 5. Fig. 8).

Interactions between date sampling and species were also recorded for the late planting season. Biomass and nutrient accumulation in *Brachiaria* increased over the sampling dates (Table 5). Overall, *B. brizantha* accumulated the largest amount of biomass. After grain harvesting, 17, 15, 14 kg ha^{-1} day^{-1} of B. *brizantha*, *B.* convert, and *B. ruziziensis* biomass were accumulated, respectively (Fig. 8). On average, *B. brizantha* was the species with the most nutrient accumulation: 0.23, 0.015 and 0.15 kg ha^{-1} day^{-1} of N, P, and K, respectively (Fig. 8).

Table 5. Biomass, N, P, and K content of *Brachiaria* species at conventional and late planting season.

		Biomass		N		P		K	
		-------------------	-------------------	-------------------	kg ha^{-1}	-------------------	-------------------	-------------------	-------------------
Days after harvest	Species/Seasons	Convent.	Late	Convent.	Late	Convent.	Late	Convent.	Late
	B.brizantha	1020	350	13.2	6.5	0.8	0.4	11.7	5.5
0	*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
	Means	967 C	297 C	13.4 C	5.6 B	0.7 C	0.3 C	11.1 B	4.5 B
	B.brizantha	2030	910	27.7	16.5	1.4	0.7	15.1	10.3
30	*B.*Convert	1320	560	19.2	11.5	1.1	0.6	11.1	7.1
	B. ruziziensis	1810	760	27.1	16.5	1.3	0.8	19.6	8.1
	Means	1720 B	740 B	24.7 B	14.8 A	1.3 B	0.7 A	15.3 B	8.5 A
	B.brizantha	5020	1080	87.5	15.7	5.4	0.9	57.4	12.4
60/45[Ŧ]	*B.*Convert	2800	880	51.2	16.2	3.3	0.9	33.2	10.4
	B. ruziziensis	3550	980	68.8	16.9	3.6	1.1	44.9	12.9
	Means	3790 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 Specie (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 was performed at 60 and 45 days after corn harvest to conventional and late planting season, respectively. Lowercase letters compare the means among *Brachiaria* speceis. Uppercase letters compare the means among sampling. NS: not significant (P > 0.05). *Significant at P < 0.05.**Significant at P < 0.01 .***Significant at P < 0.001

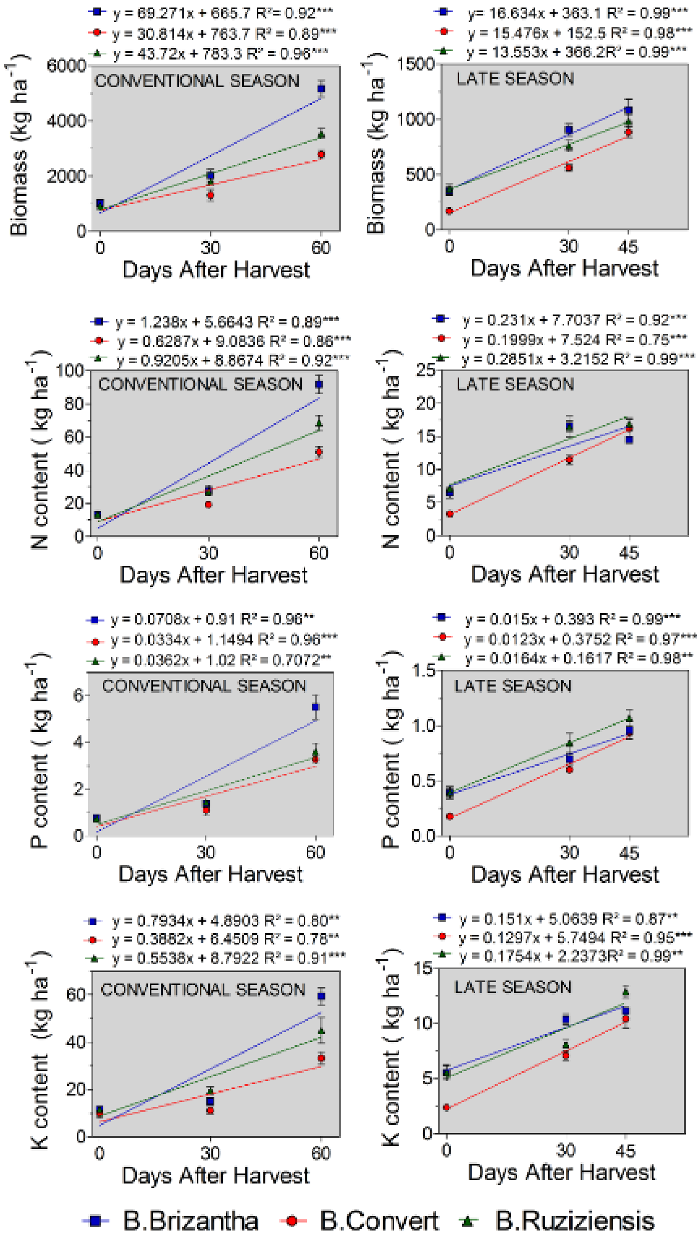

Figure 8. Amount of biomass, N, P and K content among *Brachiaria* species after corn harvest. * Significance at $P < 0.05$ level; ** Significance at $P < 0.01$ level; *** Significance at $P < 0.001$ level. Vertical bars indicate standard error from the data.

3.3.3 Biomass and nutrient balance

Except for N in corn-*B.* convert intercropping, biomass and nutrient accumulation was positively affected by the intercropping systems (P<0.05). Regarding the corn monoculture, the intercropped systems increased the total accumulation of biomass (~ 2700 kg ha^{-1}), N (~ 53 kg ha^{-1}) P (~ 7 kg ha^{-1}), and K (~ 36 kg ha^{-1}) (Fig. 9).

Corn grain and straw were the components that most contributed to the total accumulation of biomass and P of the conventional planting season (Fig. 9). The contribution of

B. brizantha to total N accumulation of the production system was comparable to that of corn straw and grain. The species *B. ruziziensis* and *B. brizantha* contributed equally or more compared to corn straw for total K accumulation (Fig. 9). The component with the lowest contribution to K accumulation was corn grain.

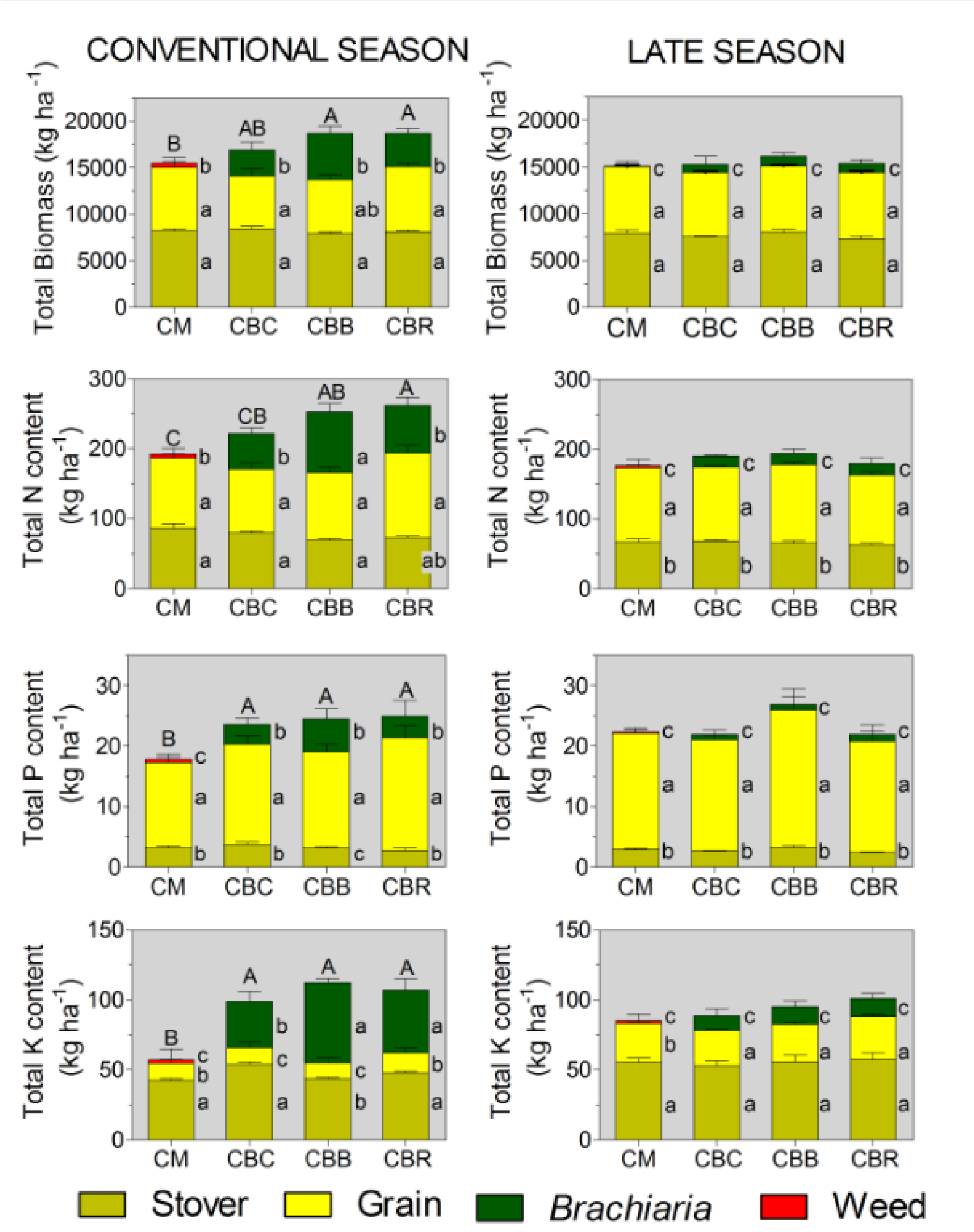

Figure 9. Influence of farming systems on total biomass, N, P and K content. Corn monoculture, CM; corn *B.* convert, CBC, corn *B. brizantha*, CBB; corn *B. ruziziensis*. Lowercase letters indicate significant differences (P > 0.05) among compartiments within each farming system. Uppercase letters indicate significant differences (P > 0.05) among farming systems. Vertical bars indicate standard error from the data.

In late planting season, intercropping did not significantly affect the total accumulation of biomass and nutrients ($P > 0.05$). Overall, 15.5 Mg ha^{-1}, 185 kg ha^{-1}, 24 kg ha^{-1}, and 94 kg ha^{-1} of biomass, N, P, and K were accumulated, respectively (Fig. 9). The contribution of the *Brachiaria* for the total biomass and nutrients was the same among the farming systems ($P > 0.05$). Corn straw and grain were the components with the greatest contribution to biomass and nutrient accumulation in late planting season.

3.4. Discussion

Direct restrictions on nutrient, solar radiation and water affect photosynthesis, as well as remobilization of carbon and nutrients in corn organs (Thomas and Ougham, 2014; Ning et al., 2017). Beyond the lack of effect on corn grain yield, result previously reported (Maia et al., 2014; Almeida et al.,2017a; Almeida et al., 2017b), intercropping did not affect the partition and accumulation of corn biomass and nutrients. Thus, negative effects of intercropping on C partitioning, grain yield or nutrient use efficiency are unlikely when corn is intercropped with *Brachiaria* species.

The accumulation of *Brachiaria* biomass registered in the present study for late planting season (13-16 kg ha^{-1} day^{-1}) is in accordance with other authors (3-44 kg ha^{-1} day^{-1}) (Brambilla et al. al., 2009; Richart et al., 2010; Batista et al., 2011). Biomass accumulation of *Brachiaria* species in the late planting season was less than in conventional planting season, which usually ranged between 50-130 kg ha^{-1} day^{-1} (Silva Cruz et al., 2008; Crusciol et al., 2013; Almeida et al., 2017a). Due to decreased biomass accumulation, nutrient accumulation by post-harvest *Brachiaria* was not enough to affect the balance in the late planting season. However, all *Brachiaria* species accumulated more biomass during the post-harvest period than the fallow area preceded by corn monoculture.

Among the *Brachiaria* species, *B. brizantha* presented the highest biomass accumulation, which was 66 and 17 kg ha^{-1} day^{-1} in the conventional and late planting season, respectively. In monoculture, previous studies have reported higher biomass and forage yields for *B. brizantha* compared to other species of the genus (Pariz et al., 2010; Cabral et al., 2013).

Biomass accumulation and nutrient cycling obtained with *Brachiaria* species was close to that reported for annual crops traditionally grown after corn. In a study with common oat (*Avena sativa*), Hashemi et al (2013) observed biomass values between 28-58 kg ha^{-1} day^{-1} with N accumulation values between 0.68-0.85 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* in the conventional planting season (Fig. 8). In common oat and white lupine (*Lupinus albus*), Pissinati et al. (2016) observed 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 is very close to the mean amount accumulated by the *Brachiaria* species in this study (Fig. 8). These results suggest that corn intercropped with *Brachiaria* species is effective farming system to for enhanced the N, P, and K cycling.

Total biomass and nutrient accumulation were affected only in the conventional planting season. Other authors have also reported the benefits of carbon and nutrient cycling when using *Brachiaria* as cover crop during conventional planting season (Pachecco et al., 2011, Loss et al., 2012, Crusciol et al., 2013). In summary, our results suggest that the benefits of intercropping for nutrient cycling in the late planting season are smaller when compared to those of the conventional planting season. However, studies that evaluate the effect of the addition of *Brachiaria* on nutrient cycling and soil organic matter in the long term are necessary for late planting season.

In this study, *Brachiaria* species effectively contributed to biomass and nutrient accumulation for crop cultivation, particularly N and K. The contribution of *B. brizantha* in total K accumulation was equal to or greater than that of corn organs (Fig. 9). The K cycled by *Brachiaria* reduces leaching loss and also provides nutrients to the subsequent crop (Carpim et al., 2008), since nutrient release in *Brachiaria* residue is fast, which is ~ 50% 25-40 days after kill by herbicides (Torres et al., 2008, Santos et al., 2014). Moreover , Cusciol et al. (2015) and Fortes et al. (2017) documented increased grain yield, exchangeable soil K and K content in cash crops grown after intercropping.

3.5 Conclusions

The *Brachiaria* species did not affect biomass and nutrient dynamic in corn during intercropping. Overall, *B. brizantha* had the greater accumulation of biomass after grain harvesting, which was 69 kg ha^{-1} day^{-1} in the conventional planting season and 16 kg ha^{-1} day^{-1} in the late planting season. Intercropping between corn and *Brachiaria* species increased N, P, and K accumulation relative to corn monoculture, but only when intercropping was performed at conventional planting season. Nonethless, investigating the effect of accumulated *Brachiaria* biomass after corn harvesting in the long term is necessary to further understand the impact of intercropping in the production system within late planting season.

In corn production systems, corn-*Brachiaria* intercropping is a viable alternative to increase post-harvest biomass production of corn and thus provide significant benefits to N and K cycling. The establishment of intercropping with *B. brizantha* during conventional planting season was the best approach to increase biomass yield and nutrient cycling for corn production systems.

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4. FINAL CONSIDERATIONS

The introduction of *Brachiaria* modified nutrient uptake dynamics in corn productions systems. Total biomass yield, as well as the contribution to the total nutrient content during period of simultaneous crops was not affected by intercropping. Nonetheless, use of intercropping systems enhanced nutrients cycling after corn harvest, with respect to the fallow preceded for corn monoculture.

Corn intercropped with *Brachiaria* is a promising strategy to provide N cycling, but was not correlated with greater fertilizer recovery. N derived from soil accounted for most of the nutrient cycling by *Brachiaria*, which represented approximately 98% of N content at post-harvest. Despite the simulated grazing did not affect total N content relative the intercropping used as cover crop, the management resulted in a greater nutrient extraction and negative apparent N budget. These results suggest that N demand is larger when crop and livestock activities are integrated.

Nutrients cycling were mainly attributed to the intercropping performed at conventional planting season. Among *Brachiaria* species, greater biomass yield and nutrients cycling was achieved by intercropping corn-*B. brizantha*. In intensive grain production systems, corn intercropped with *Brachiaria* species must be accomplished to improved nutrient allocation at plant compartment; their relative effect will vary by seasons and *Brachiaria* species used.