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Accumulation and efficiency of nutrient use in crop systems in second crop under no-tillage

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Abstract – The objective of this work was to evaluate phytomass production, nutrient cycling, and efficiency of nutrient use by single and intercropped crop systems, in the second crop, under no-tillage. The experiment was carried out during the second crop of 2014 and 2015 in the Cerrado biome of the state of Mato Grosso, Brazil, in a randomized complete block design, with nine treatments and four replicates. In 2014, the systems were evaluated at 63, 93, 124, and 157 days after sowing; and, in 2015, they were evaluated at flowering and senescence. The concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium were determined. In 2014, the single crop systems *Urochloa ruziziensis*, *Cajanus cajan*, and *Pennisetum glaucum* showed the largest accumulations of phytomass and nutrients. In 2015, the intercropped systems showed the largest accumulations of phytomass, the largest nutrient cycling, and the highest nutrient use efficiency. In the no-tillage crop systems, *U. ruziziensis*, either in single cultivation or intercropped with corn and sunflower, increased phytomass. The most efficient systems for the use of all nutrients, in the Cerrado of Mato Grosso, are the intercropping of sunflower with *U. ruziziensis*, corn with *U. ruziziensis*, and corn with *Crotalaria spectabilis*.

Index terms: Cerrado, cover crop, macronutrient, nutrient cycling, soybean.

Acúmulo e eficiência no uso de nutrientes em sistemas de produção de safrinha em plantio direto

Resumo – O objetivo deste trabalho foi avaliar a produção de fitomassa, a ciclagem de nutrientes e a eficiência no uso de nutrientes em sistemas de cultivo solteiros e consorciados, na safrinha, em plantio direto. O experimento foi realizado durante a segunda safra de 2014 e 2015, no bioma Cerrado do estado de Mato Grosso, Brasil, em delineamento de blocos ao acaso, com nove tratamentos e quatro repetições. Em 2014, os sistemas foram avaliados aos 63, 93, 124 e 157 dias após a semeadura; e, em 2015, foram avaliados ao florescimento e à senescência. Determinaram-se as concentrações de nitrogênio, fósforo, potássio, cálcio e magnésio. Em 2014, os sistemas solteiros *Urochloa ruziziensis*, *Cajanus cajan* e *Pennisetum glaucum* apresentaram os maiores acúmulos de fitomassa e nutrientes. Em 2015, os consórcios apresentaram os maiores acúmulos de fitomassa, a maior ciclagem de nutrientes e a maior eficiência no uso dos nutrientes. No sistema plantio direto, *U. ruziziensis*, solteiro ou consorciado com milho e girassol, aumentou a fitomassa. Os consórcios mais eficientes quanto ao aproveitamento de todos os nutrientes, no Cerrado de Mato Grosso, são os de girassol com *U. ruziziensis*, milho com *U. ruziziensis* e milho com *Crotalaria spectabilis*.

Termos para indexação: Cerrado, cultura de cobertura, macronutriente, ciclagem de nutrientes, soja.

Introduction

Modern agriculture advocates an increase of efficiency for the use of water and energy resources, to which it enables technologies for a better use of mineral fertilizers applied to crops. No-tillage system (NTS) represents a set of techniques capable of exploiting the efficiency of agricultural production models by promoting synergies between the emerging properties of the soil-plant-atmosphere complex. The constant supply of phytomass by cover crops, either in rotation or succession in the second crop, promotes the inter- and intra-specific interactions of plant and animal species in this complex, enhancing the fertility, physics, and microbiology of soil (Wang et al., 2017). These interactions are propitious to the nutrient transformation processes that are extracted by the cover crops, in the chemical phase of the soil deep layers, which are not liable to be absorbed by the economic interest crops and are relocated in the organic fraction by the synergistic processes of phytomass decomposition (Assmann et al., 2017; Pissinati et al., 2018).

The knowledge on the intrinsic characteristics of cover crops as to the dynamics of phytomass production, during the second crop, is a determining factor for the contribution of nutrient amounts to the subsequent crop (Pacheco et al., 2017). For this purpose, the amount stratification of these nutrients in the stems and leaves and of the periods between flowering and senescence is essential to determine both the extraction potential and the quantity of nutrient that will be made available to the successor crops. Thus, there is an efficiency of energy resources by reusing of nutrients by cycling which will promote the plant development, without causing nutritional deficiency for a greater crop health. There is also a greater use of water resources, since well-nourished plants develop more vigorous root systems to withstand stress periods and, consequently, there is a synergism between the emerging properties in the productive systems to increase productivity (Pacheco et al., 2017; Malhi et al., 2018).

With constant phytomass under the ground, there is also a synergism between organic matter (OM) and soil animal group, which causes this organic material to deteriorate until it is liable for decomposition by the edaphic microorganisms (Cunha et al., 2015). As phytomass is brought to the soil by second crop systems, aiming at a floristic diversification, the nutritional diversity in the soil is also guaranteed, since various plant materials accumulate nutrients in different amounts and release them this way (Mendonça et al., 2015). This nutrient availability occurs in synergy with a greater microbiological activity that promotes high-quality OM accumulation and the transformation of nutrients from organic to mineral form, and synchronizing the absorption by the successor culture (São Miguel et al., 2018). This way, the use of mineral fertilizers and production costs for rural producers are reduced and, by implementing and maintaining a conservation system, it will create a stable environment for high productivity over time (Caruso et al., 2018; Semenov et al., 2019; Neal et al., 2020).

The diversification of cover crops in agricultural systems enhances the soil physical, chemical, and biological soil properties by the varied root systems that break the compacted layers, by absorbing and cycling the nutrients at greater soil depths, promoting rhizospheric interactions that result in the allocation of nutrients in the organic fraction from soil (Arai et al., 2018). Assessing the dynamics of nutrient release, that are under the soil surface in the form of phytomass, is essential for the advancement of knowledge on the nutrient cycling in agricultural systems (Sarker et al., 2018).

The objective of this work was to evaluate the phytomass production, nutrient cycling, and efficiency of nutrient use by single and intercropped systems, in the second crop, under no-tillage.

Materials and Methods

The experiment was carried out at the Universidade Federal de Mato Grosso, in the municipality of Rondonópolis, in the state of Mato Grosso, Brazil (16º27'42"S, 54º34'53"W, at 292 m altitude), during the 2014 and 2015 crop years, which were the second and third years of cultivation. The vegetation of the region is a typical of the Cerrado biome. The soil of the area was classified as Latossolo Vermelho distrófico (Santos et al., 2014), which corresponds to an Oxisol, with flat relief. The climate is CwA, tropical with hot humid altitude according to the Köppen-Geiger's classification (Souza et al., 2013). Precipitation and maximum and minimum temperatures of the experimental period are shown in Figure 1.

Before the experiment installation, the area was cleaned, followed by plowing and harrowing, with manual removal of roots. Then, soil was sampled for chemical and textural characterization (Table 1). On 08/10/2013, liming (4,000 kg ha^{-1}) was performed with limestone filler (PRNT 99.02%) and incorporated with plow harrow and leveling harrow.

The experiment was carried out in a randomized complete block design with nine crop systems as treatments, and four replicates in 7×9 m experimental units. In all crop systems, during the harvest period, soybean was grown in succession to cover crops. The experiment was installed in the second crop, with annual grains – corn, sunflower, and cowpea (*Vigna unguiculata*), and the cover crops *Pennisetum glaucum*, *Urochloa ruziziensis*, *U. brizantha*, *Crotalaria breviflora*, *Crotalaria spectabilis*, *Cajanus cajan*, and *Stylosanthes capitata* + *Stylosanthes macrocephala* (Table 2).

In the second crop of 2014, the systems were deployed on February 20th and, in 2015, on March 4th. The cover crops for single cultivation systems were sown in 0.45 m row spacing and, for intercropped systems (corn and sunflower), crops were sown between the lines. Fertilizing of annual crops sown in second crop (corn,

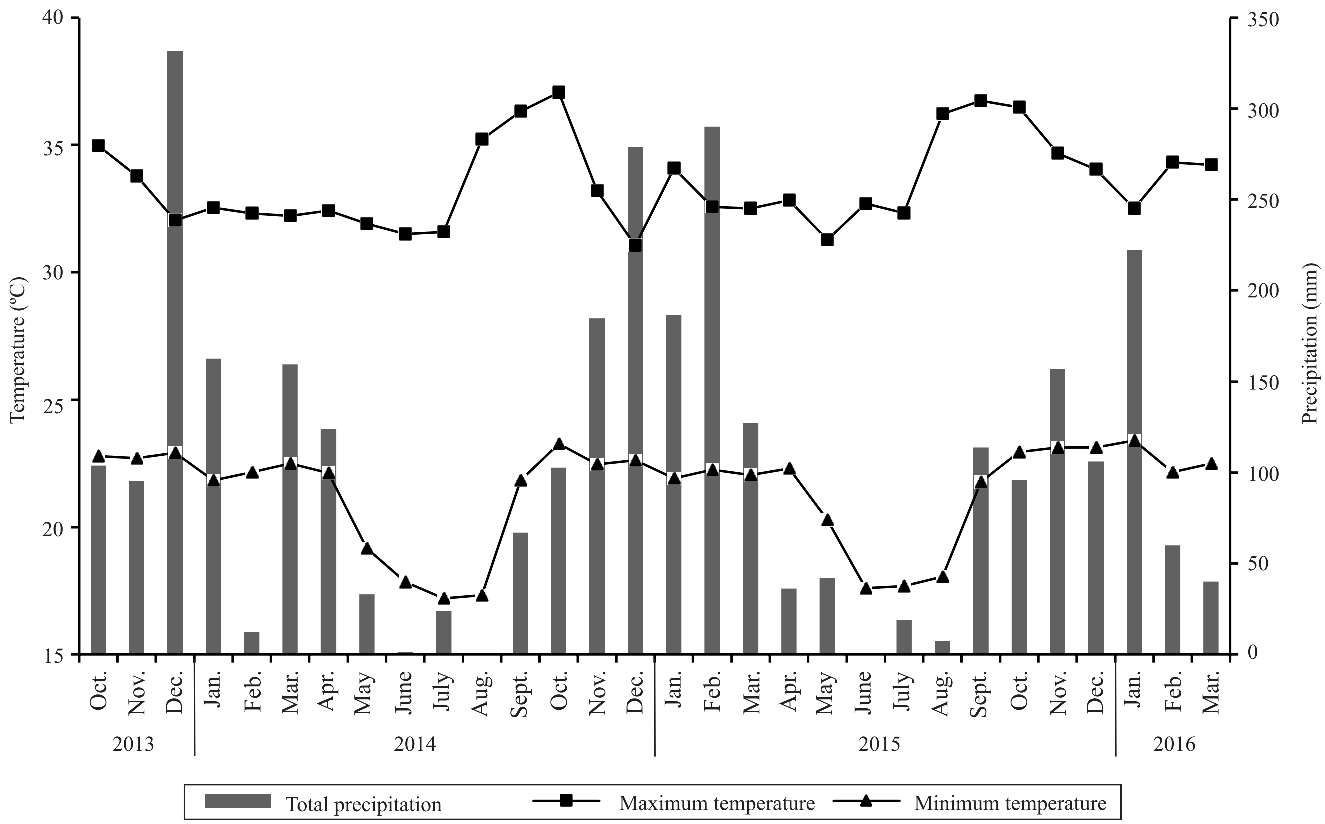

Figure 1. Monthly precipitation and minimum and maximum air temperature during the experimental period, in the municipality of Rondonópolis, in the state of Mato Grosso, Brazil.

Table 1. Chemical and textural characteristics of Oxisol before the experimental installation.

Depth (m)	pH $CaCl_2$	P	K	Ca	Mg	H+Al	T	V	OM	Sand	Silt	Clay
		----- (mg dm^{-3}) -----		---------------- (cmol$_c$ dm^{-3}) ----------------				(%)	-------------------- (g kg^{-1}) --------------------			
0.00–0.10	4.1	5.4	55	0.5	0.2	6.8	7.6	11	17.6	450	125	425
0.10–0.20	4.0	1.4	49	0.2	0.2	7.2	7.6	5.6	19.9	500	100	400
0.20-0.30	4.1	0.2	31	0.3	0.1	6.2	6.7	7.2	13.7	500	100	400

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cowpea, and sunflower) followed the recommendations by Sousa & Lobato (2004). No fertilizer was applied to the plots cultivated with single cover crops.

In 2014, cover crops were evaluated for dry matter mass at 63, 93, 124, and 157 days after sowing (DAS) according to Crusciol et al. (2005). In the second crop of 2015, the evaluations of phytomass were performed at flowering in April 2015, and after the harvest of crop grain (June to July 2015). The plant stand per meter was counted, and two plants per stand were collected at three points per plot. The leaves were separated from the stems to determine the phytomass weights per compartment. Then, leaves and stems were taken to a forced-air circulation oven at 60ºC, until a constant mass was attained, to determine the dry matter mass.

The samples were milled in a Willey type mill (2 mm mesh), and the nutrient concentration was determined. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) were determined following the methods proposed by Malavolta et al. (1997).

The stem/leaf ratio (SLR) of accumulated macronutrients was determined at flowering (F) and senescence (S) by the following equations: SLR-F = stem nutrient at flowering / leaf nutrient at flowering; SLR-S = stem nutrient at senescence / leaf nutrient at senescence

To evaluate the nutrient exports (kg ha^{-1}), the total nutrient at flowering was subtracted from the total nutrient at senescence, and the export index (ExI) was calculated by the following equation: ExI = (total nutrient at flowering – total nutrient at senescence) / total nutrient at flowering.

The nutrient use efficiency (NUE), based on kilograms of grain produced per kilogram of exported nutrients, was performed only in systems where grain yield (corn, sunflower, cowpea, and *P. glaucum*) was evaluated by the following equation: NUE = productivity / (total nutrient at flowering - total nutrient at senescence)

The results were subjected to the analysis of variance and, when significant, the Scott-Knott's test was performed, at 5% probability, with the aid of the Sisvar 5.6 software (Ferreira, 2008) and, later, with the Sigma Plot 10.0 software.

Results and Discussion

During the second crop of 2014 (from February to November), *P. glaucum* showed the highest potential for phytomass production until 93 days after sowing (DAS), and *U. ruziziensis* stood out at 157 DAS (Figure 2). The fastest growth and phenological development of *P. glaucum* occurred with the onset of the earliest senescence phase, but, due to its faster development, there was a sharp decrease in the posterior evaluations of phytomass. However, *U. ruziziensis* showed slow initial growth, intensifying its development in the final of the season, through regrowth after the initial summer rains. According to Marcante et al. (2011), *P. glaucum* growth fast because it is well adapted to low-fertility soils, besides having high nutrient extraction capacity due to its extensive, fasciculated root system that expands for greater absorption.

The species *P. glaucum*, *U. ruziziensis*, and C. *cajan* showed the highest potentials to promote nutrient accumulation in their phytomass, during the second crop and off-season (Figure 2). The correlation between phytomass production and nutrient accumulation showed that the amount of phytomass production is crucial to increase the effect of nutrient cycling by cover crops. Thus, it is evident that positive effects of phytomass production of *P. glaucum* (at the beginning of the off-season) and of the perennial species U. *ruziziensis* and *C. cajan* (at the end of the off-season) occurred on the nutrient accumulation.

Nutrient accumulation levels in the second crop of 2014 were significant, especially K (up to 140 kg ha^{-1}), N (up to 70 kg ha^{-1}), and Ca (up to 45 kg ha^{-1}). It is important to highlight the potential of *C. cajan* in the N cycling, as it is a legume with efficiency for the biological fixation of this element. This species also stood out for Ca, which may be related to its perennial habit and shrub architecture, with greater demand for this element in its structural cells (parenchyma). The accumulated Ca value is in agreement with that found by Almeida & Camara (2011). This higher accumulation of Ca by *C. cajan* may be linked to the intrinsic characteristics of the crop in absorbing this particular nutrient more efficiently than other systems from 90 DAS onwards and maintaining until the end of its cycle.

A positive effect on the phytomass production occurred in the most diverse treatments through intercropping and cover crops (corn + *C. spectabilis*;

corn + *U. ruziziensis*; sunflower + *U. ruziziensis*) in both the flowering and senescence phase of crops, during the second crop of 2015 (Figure 3). Species diversification may favor the best use of natural resources (water, nutrients, carbon dioxide, and solar radiation) for conversion to phytomass production, even after harvesting annual crop grains.

The results of nutrient accumulation reaffirm the importance of the produced phytomass amount as a decisive factor to promote nutrient cycling in agricultural systems. Annual crop and cover crops (corn + *C. spectabilis*; corn + *U. ruziziensis*; sunflower + *U. ruziziensis*) stood out in most of the evaluated nutrients, both during flowering and after plant senescence (Figures 3 and 4). It is important to highlight sunflower + *U. ruziziensis* intercropping as an important tool in nutrient cycling, as it results in significant amounts of nutrients in their phytomass production, even after plant senescence. These results are explained by the high absorption and metabolism of nutrients by sunflower plant tissues. Furthermore, the sunflower have a plant architecture that favors the development of *U. ruziziensis*, as it allows greater infiltration of solar radiation by the canopy during the intercropping period.

It is important to highlight that the phytomass production of sunflower + *U. ruziziensis* remained around 12,000 kg ha^{-1} in both flowering and senescence (Figure 3). This permanence is due to the low translocation of photoassimilates to the grain filling characteristic of sunflower. It is also noted that the proportion of sunflower stems from one season to another remained the same, but the senescence of leaves decreased; thus, the maintenance of the same amount of phytomass was by provided by *U. ruziziensis* development. The contribution of the intercropping culture is essential for the maintenance of the phytomass and nutrient input to the soil for the successive crop, because it keeps the soil microbiota

Table 2. Stem/leaf ratio (SLR) of accumulated macronutrients in the stem and leaf phytomass of the cover crops at flowering and senescence of second crop, in 2015[(1)].

Crop system	SLR-N	SLR-P	SLR-K	SLR-Ca	SLR-Mg
			Flowering		
Fallow, no-tillage	4.50a	9.31a	4.38b	19.36a	4.68b
Fallow, conventional tillage	5.08a	8.07a	9.42a	12.65b	7.09a
Crotalaria spectabilis	0.86b	1.18c	1.33d	1.10d	1.22c
Corn + *Crotalaria spectabilis*	1.28b	1.28c	1.11d	4.43c	1.61c
Pennisetum glaucum	4.07a	4.17b	2.28c	14.25b	5.57b
Urochloa ruziziensis	0.86b	1.24c	1.39d	1.00d	1.83c
Sunflower+*Urochloa ruziziensis*	0.97b	1.87c	2.52c	0.91d	2.52b
Vigna unguiculata	0.64b	1.85c	1.76d	0.43d	0.95c
Corn+*Urochloa ruziziensis*	1.14b	2.04c	2.91c	5.28c	3.07b
Coefficient of variation (%)	10.69*	11.76*	13.27*	11.86*	12.23*
			Senescence		
Fallow, no-tillage	3.88a	2.93b	2.49d	5.96b	1.60c
Fallow, conventional tillage	1.74c	3.45b	4.36b	3.72c	4.08b
Crotalaria spectabilis	5.25a	10.52a	5.41a	7.48a	10.04a
Corn + *Crotalaria spectabilis*	1.59d	2.83b	3.49c	2.73c	3.52b
Pennisetum glaucum	1.96c	1.62c	1.07e	8.07a	2.92b
Urochloa ruziziensis	1.31d	1.75c	1.31e	0.43d	1.13c
Sunflower + *Urochloa ruziziensis*	2.29c	2.80b	2.95c	3.79c	3.73b
Cowpea (*Vigna unguiculata*)	0.89d	0.63d	1.25e	0.34d	0.59c
Corn+*Urochloa ruziziensis*	2.25c	4.35b	3.84c	7.84a	3.05b
Coefficient of variation (%)	20.25	10.99*	22.10	24.14	25.25

[(1)]Means followed by equal letters, in the columns, do not differ by the Scott-Knott's test, at 5% probability. *Coefficient of variation of transformed data $[(\sqrt{x} + 1)^{0.5}]$.

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active during the whole off-season, which contributes to the system balance (Luo et al., 2020). Intercropping is also important for increasing phytomass production (Forte et al., 2018).

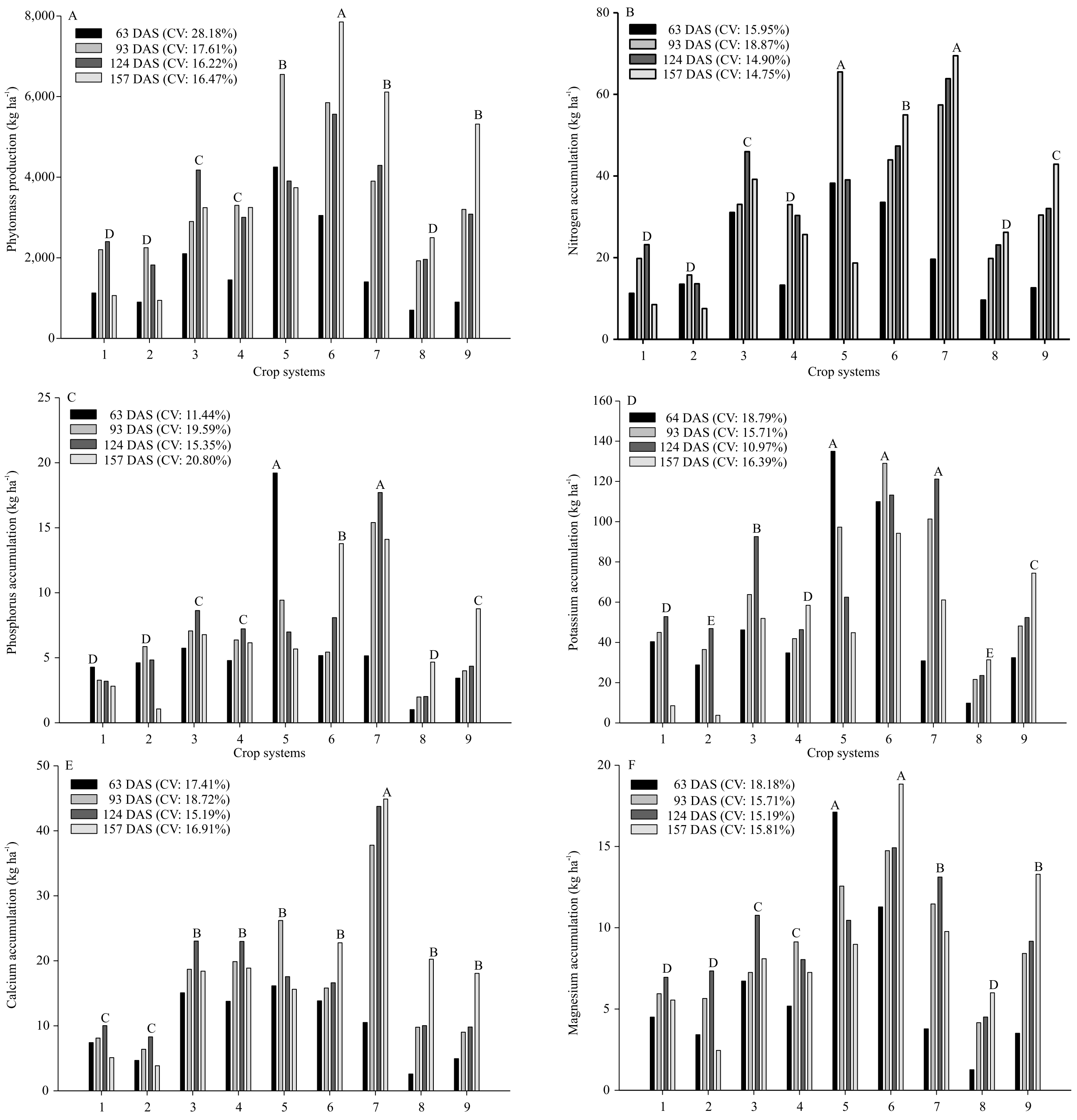

Figure 2. Phytomass production (A) and accumulation of nitrogen (B), phosphorus (C), potassium (D), calcium (E), and magnesium (F), in cultivation systems with cover crops at 63, 93, 124 and 157 days after sowing (DAS), in the second crop, in 2014. Crop systems: 1, fallow, no-tillage; 2, fallow, conventional tillage; 3, *Crotalaria spectabilis*; 4, *Crotalaria breviflora*; 5, *Pennisetum glaucum*; 6, *Urochloa ruziziensis*; 7, *Cajanus cajan*; 8, *Stylosanthes*; 9, *Urochloa brizantha*. Means followed by equal letters, in the bars, do not differ, by the Scott-Knott's test, at 5% probability.

In the second crop of 2015, it was possible to observe a higher nutrient accumulation in the stems of annual and cover crops; this fact intensified at senescence, when the accumulation in stems was even higher in leaves in most treatments (Figure 3). Treatments with cowpea, sunflower + *U. ruziziensis*, and single *U.*

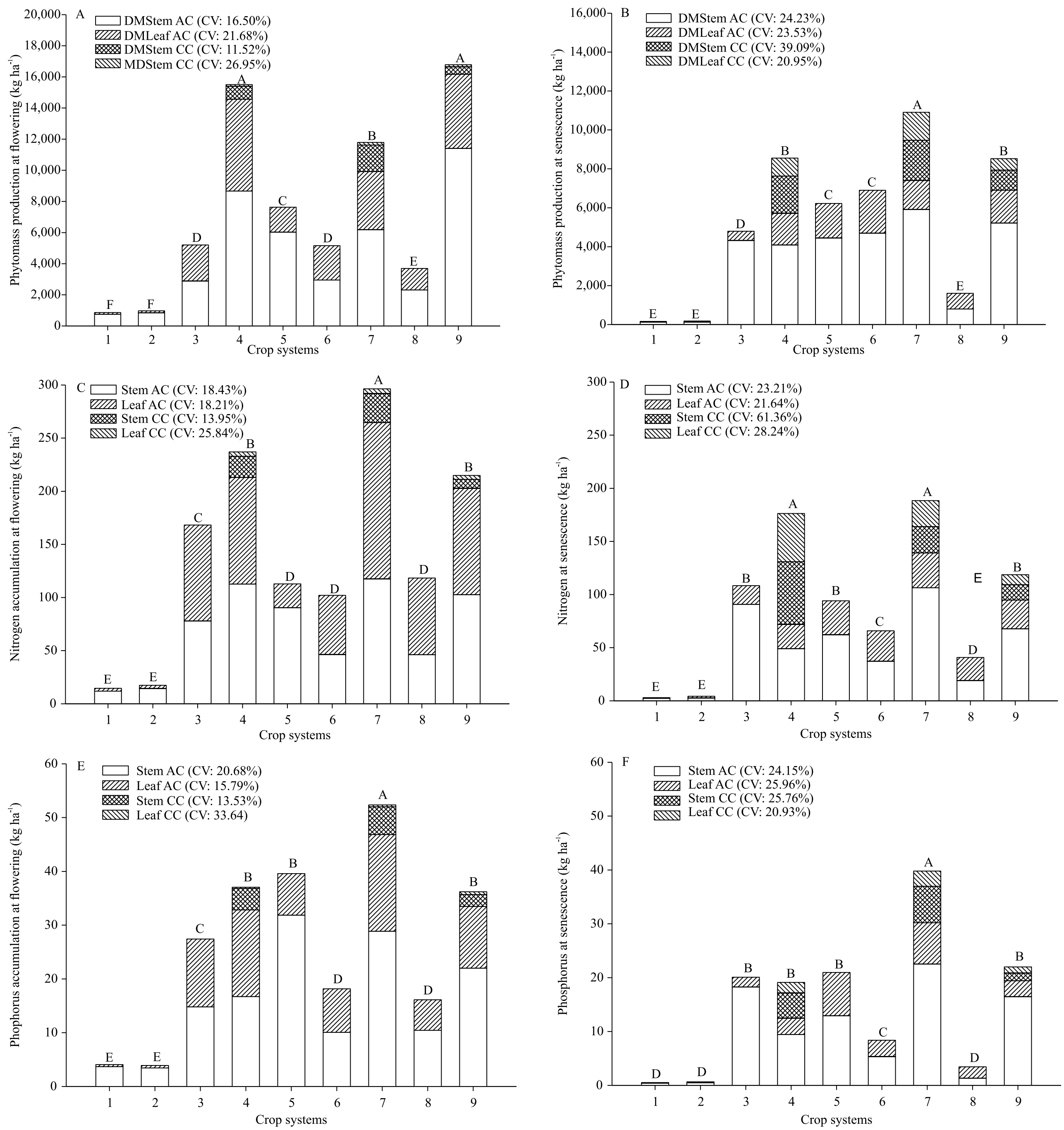

Figure 3. Phytomass production at flowering (A) and senescence (B), and accumulation of nitrogen and phosphorus – at flowering (C, and E), and at senescence (D, and F), respectively –, in the second crop, in 2015. AC, annual culture; CC, cover crop. Crop systems: 1, fallow, no-tillage; 2, fallow, conventional tillage; 3, *Crotalaria spectabilis*; 4, corn and *Crotalaria spectabilis*; 5, *Pennisetum glaucum*; 6, *Urochloa ruziziensis*; 7, sunflower + *Urochloa ruziziensis*; 8, Cowpea (*Vigna unguiculata*); 9, corn and *Urochloa ruziziensis*. Means followed by equal letters, in the bars, do not differ, by the Scott-Knott's test, at 5% probability.

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ruziziensis showed a higher nutrient accumulation in leaves than in stems during flowering. However, at senescence, nutrient accumulation was the same of other annual and cover crops. Santos et al. (2017) also found a higher leaf dry mass production than stems of *U. brizantha* in function of N doses during autumn-

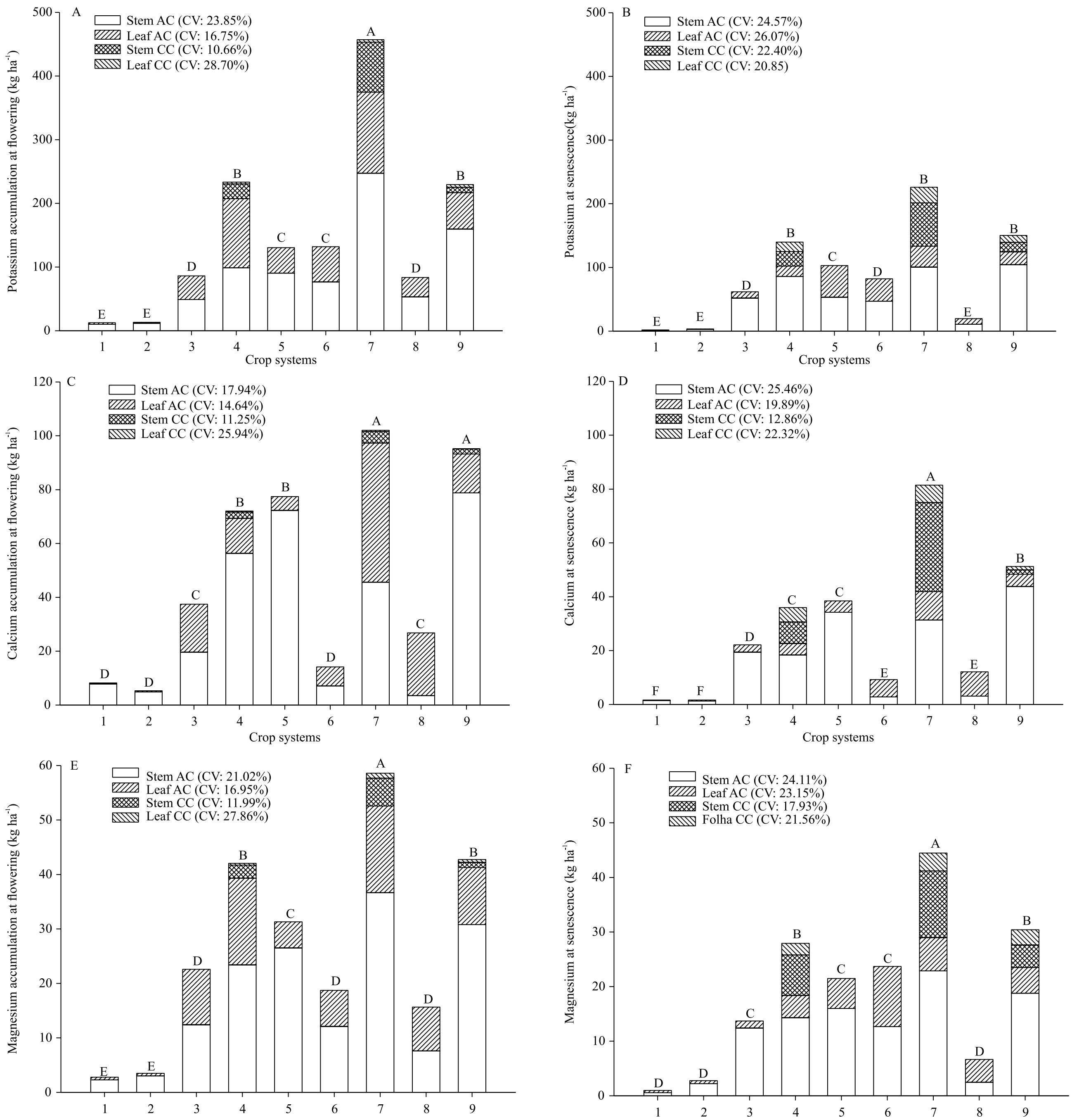

Figure 4. Potassium, calcium, and magnesium accumulation at flowering (A, C, and E, respectively), and at senescence (B, D, and F, respectively), in the second crop, in 2015. AC, annual culture, CC, cover crop. Crop systems: 1, fallow no-tillage; 2, fallow conventional tillage; 3, *Crotalaria spectabilis*; 4, corn + *Crotalaria spectabilis*; 5, *Pennisetum glaucum*; 6, *Urochloa ruziziensis*; 7, sunflower + *Urochloa ruziziensis*; 8, Cowpea (*Vigna unguiculata*); 9, corn + *Urochloa ruziziensis*. Means followed by equal letters, in the bars, do not differ, by the Scott-Knott's test, at 5% probability.

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winter in Jaboticabal, in the state of São Paulo, Brazil, due to climatic conditions that caused a reduction of stem elongation. Because of the natural loss of leaves at senescence, the presence of stems prevailed, which increased the stem/leaf ratio. Only *P. glaucum* and fallows had a higher proportion of flowering stems, which led to a lower N export index due to higher recalcitrance and, consequently, slower release of this nutrient (Table 3).

The present study shows that the phytomass produced at flowering is most accumulated during de culture cycles, when the apex of crop production is attained. However, it should be considered that for grain crops in the intercropping, it may not be possible to measure the actual amount of nutrients remaining in the system, since grains are harvested. Thus, export indices that identify these differences are necessary, to compare the effects of solute translocation on flowering for senescence, and to measure the amount and quality of the phytomass actually added to the systems.

The treatment corn + *U. ruziziensis* accumulated approximately 80% Ca on stems at flowering, and provided a high stem-leaf ratio together with *P. glaucum* (93%), corn + *C. spectabilis* (79%), fallow with no-tillage (95%), and fallow with conventional tillage (92%) (Table 3). These grasses, as well as fallow have the most rigid stem walls, and Ca is the nutrient that aids in this stiffness because it is the constituent of the middle lamella and participates in the formation of the cell wall, therefore, it was present in greater

Table 3. Total exported nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg), between flowering and senescence, and exportation index of macronutrients of cover crop phytomass, in the second crop, in 2015[(1)].

Crop system	N	P	K	Ca	Mg
			Exportation (kg ha^{-1})		
Fallow, no-tillage	11.57e	3.54e	10.48d	6.59c	1.80c
Fallow, conventional tillage	13.08e	3.25e	9.66d	3.66c	0.73c
Crotalaria spectabilis	59.82c	7.33d	24.28d	15.29b	8.89b
Corn + *Crotalaria spectabilis*	60.83c	17.90a	93.49b	36.07a	14.13a
Pennisetum glaucum	18.64e	18.64a	27.40d	38.95a	9.81b
Urochloa ruziziensis	36.14d	9.81d	49.70c	4.93c	-
Sunflower + *Urochloa ruziziensis*	107.95a	12.56c	231.11a	17.64b	14.13a
Cowpea (*Vigna unguiculata*)	77.54b	12.65c	64.14c	21.33b	9.02b
Corn+*Urochloa ruziziensis*	96.14a	14.56b	79.33b	41.90a	12.34a
Coefficient of variation (%)	20.74	21.43	22.87	22.01	19.06
			Exportation Index (ExI)		
Fallow, no-tillage	0.79a	0.86a	0.84a	0.79a	0.63a
Fallow, conventional tillage	0.75a	0.82a	0.73a	0.68b	0.18b
Crotalaria spectabilis	0.35d	0.26d	0.27d	0.40c	0.39b
Corn + *Crotalaria spectabilis*	0.25e	0.48b	0.40c	0.50c	0.33b
Pennisetum glaucum	0.16f	0.47b	0.20d	0.50c	0.31b
Urochloa ruziziensis	0.35d	0.52b	0.35c	0.33d	-
Sunflower + *Urochloa ruziziensis*	0.36d	0.24d	0.50b	0.17e	0.24b
Cowpea (*Vigna unguiculata*)	0.65b	0.78a	0.77a	0.63b	0.57a
Corn + *Urochloa ruziziensis*	0.44c	0.40b	0.34c	0.44c	0.29b
Coefficient of variation (%)	11.98	12.83	17.31	18.26	26.39

[(1)]Means followed by equal letters, in the columns, do not differ, by the Scott-Knott's test, at 5% probability. ExI = (total nutrient at flowering – total nutrient at senescence) / total nutrient at flowering.

quantity in the stems of these treatments. Pacheco et al. (2011) found that *Cenchrus echinatus* infestation in direct fallows provided, from 90 to 180 DAS, a high C/N ratio due to the proportion of stems in the phytomass, which justifies the higher Ca accumulation (30.21 kg ha^{-1}) at 90 DAS, against 5.35 kg ha^{-1} at 60 DAS. The high C/N ratio of the millet stem provides a greater resistance to decomposition, providing longer residence time of the phytomass.

At senescence, the treatment sunflower + *U. ruziziensis* translocated 80% of the total accumulation in sunflower leaves. However, this translocation was balanced by the maintenance of stem Ca and increased accumulation by *U. ruziziensis*, which resulted in a translocation of only 20% of total Ca, at flowering for senescence (Figure 4). Thus, the index and export (kg ha^{-1}) of Ca of sunflower + *U. ruziziensis* were low compared to corn + *U. ruziziensis*, *P. glaucum*, and corn + *C. spectabilis*, which exported approximately 40 kg ha^{-1}. This can be attributed to the role of Ca that acts as a secondary messenger and is present in the regulation of cell division and transcription processes, which caused the leaves to develop more than the stems, which resulted in highest accumulation (Taiz & Zeiger, 2013). Higher values of Ca were also observed on leaves than on sunflower stems, in the order of 43 g kg^{-1} at stage R9, which are close to those found in the present work (51 g kg^{-1}) in this same phase of development (Zobiole et al., 2010).

As to the Mg accumulation, sunflower + *U. ruziziensis* once again stood out in comparison to the other treatments, in the two evaluation periods (Figure 4). All treatments resulted in higher stem accumulation and, consequently, higher stem/leaf ratio (Table 2), except for cowpea, that accumulated most Mg in its leaves in both evaluations. Zobiole et al. (2010) found higher values of sunflower accumulation in leaves at all evaluation periods; however these evaluations occurred only until flowering, which could be inverted in senescence.

Among the grain crops, *P. glaucum* provided the best results of the efficiency of nutrient use (N, K, Ca, and Mg) for conversion to grain production, followed by corn + *U. ruziziensis* (P and Mg) and sunflower + *U. ruziziensis* (Mg) (Table 4). It is important to highlight that *P. glaucum* was the only grain crop that was not fertilized at sowing, which reinforces the information regarding its rusticity in nutrient absorption and metabolization, as well as its importance for nutrient cycling of a crop system. Soratto et al. (2012) state that due to its rapid establishment, rusticity in nutritional requirements and short cycle, this species is able to extract and make available significant amounts of nutrients in a short time, especially N and K.

For the phosphorus use efficiency (PUE), the system corn + *U. ruziziensis* stood out, which resulted in a high cycling, when the 14.56 kg of P exported (Table 3) were able to produce 2,594 kg ha^{-1}

Table 4. Grain yield and efficiency in the use (UE) of macronutrients by annual crops, in the second crop, in 2015[(1)].

Crop system	Yield (kg ha^{-1})	Efficiency of use (kg kg^{-1})				
		N	P	K	Ca	Mg
Fallow, no-tillage	-	-	-	-	-	-
Fallow, conventional tillage	-	-	-	-	-	-
Crotalaria spectabilis	-	-	-	-	-	-
Corn + *Crotalaria spectabilis*	2,482	17.63b	122.64b	24.04b	53.07a	119.42b
Pennisetum glaucum	2,586	145.17a	134.87b	102.79a	64.53a	255.38a
Urochloa ruziziensis	-	-	-	-	-	-
Sunflower + *Urochloa ruziziensis*	2,248	18.14b	135.36b	9.39c	43.12b	232.89a
Cowpea (*Vigna unguiculata*);	550	7.31c	45.38c	8.90c	26.83c	63.88c
Corn + *Urochloa ruziziensis*	2,594	24.44b	181.90a	28.35 b	62.66a	147.83b
Coefficient of variation (%)	21.88*	28.25*	17.97*	28.85*	18.02*	19.99*

[(1)]Means followed by equal letters, in the columns, do not differ, by the Scott-Knott's test, at 5% probability. *Coefficient of variation of transformed data $(\sqrt{x} + 1)^{0.5}$.

of grain, with an efficiency of 181.90 kg grain per kg of exported nutrient (Table 4). This system, like the other intercrops, was fertilized with 100 kg ha^{-1} of MAP; however, its efficiency was higher than the inserted fertilization. Regarding the efficiency in the use of magnesium (MgUE), *P. glaucum* and sunflower + *U. ruziziensis* resulted in 255.38 and 232.89 kg grains per kg of Mg, respectively (Table 4). These values are in agreement with the exportation made by these treatments of 14.13 kg Mg (Table 4), which favored the production of 2,586 and 2,248 kg ha^{-1} grain. The use of no-till crop systems with crop diversification is effective for accumulation and cycling to promote the nutrient efficiency and decrease the use of mineral fertilizers.

Conclusions

1. The growing of *Urochloa ruziziensis*, either in single or intercropped cultivation with corn and sunflower, increases the phytomass in no-tillage crop systems.

2. *Pennisetum glaucum* cultivated either as single crop, or in intercropped with sunflower plus *U. ruziziensis*, corn plus *U. ruziziensis*, and corn plus + *Crotalaria spectabilis*, is the most efficient crop in the use of all nutrients, in the Cerrado of the state of Mato Grosso, Brazil.

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