e-ISSN 1983-4063 - *www.agro.ufg.br/pat* - Pesq. Agropec. Trop., Goiânia, v. 52, e70513, 2022

Research Article

Do the intercropping with *Crotalaria spectabilis* and *Urochloa ruziziensis* reduce the maize agronomic performance?[1]

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ABSTRACT

Depending on the climate and soil conditions and management, the intercropping of maize with soil cover plants may reduce the cereal agronomic performance. This study aimed to assess the effects of intercropping with *Urochloa ruziziensis* and *Crotalaria spectabilis* on the maize agronomic performance and the straw production and quality after the harvest. Three treatments (single maize and maize intercropped with *U. ruziziensis* and with *C. spectabilis*) were distributed into a randomized blocks design. The growth and production components and the maize grain yield were evaluated in the three systems, as well as the straw production and nitrogen accumulation in each system. The intercropping systems did not decrease the maize yield and agronomic performance, if compared to the single crop, regardless of the evaluated species. The intercropping with *C. spectabilis* and *U. ruziziensis* presented a straw production 24 and 11 % higher, respectively, and the intercropping with *C. spectabilis* resulted in a straw nitrogen accumulation 39 % higher, when compared to the single maize crop.

KEYWORDS: *Zea mays* L., soil cover plants, straw production, no-tillage system.

RESUMO

Consorciação com *Crotalaria spectabilis* e *Urochloa ruziziensis* reduzem o desempenho agronômico de milho?

Dependendo das condições edafoclimáticas e de manejo, o consórcio de milho com plantas de cobertura pode reduzir o desempenho agronômico do cereal. Objetivou-se verificar os efeitos do consórcio com *Urochloa ruziziensis* e *Crotalaria spectabilis* no desempenho agronômico de milho e na produção e qualidade de palhada após a colheita. Utilizaram-se três tratamentos (monocultivo de milho e milho consorciado com *U. ruziziensis* e *C. spectabilis*), distribuídos em delineamento de blocos casualizados. Foram avaliados os componentes de crescimento e de produção e a produtividade de grãos de milho nos três sistemas, bem como a produção de palhada e acúmulo de nitrogênio em cada sistema. Os sistemas de consórcio não reduziram a produtividade e o desempenho agronômico do milho, em relação ao seu monocultivo, independentemente da espécie avaliada. Os sistemas consorciados com *C. spectabilis* e *U. ruziziensis* apresentaram produção de palhada 24 e 11 % maior, respectivamente, e o consórcio com *C. spectabilis* promoveu acúmulo de nitrogênio na palhada 39 % maior, em comparação ao monocultivo de milho.

PALAVRAS-CHAVE: *Zea mays* L., plantas de cobertura, produção de palhada, plantio direto.

INTRODUCTION

Intercropping has been worldwide considered as a new green revolution, since energy and grain productions may be increased in up to 38 % in the same area and the farmer's income up to 33 %, when compared to single crops (Martin-Guay et al. 2018).

The cultivation of two or more species in the same area results in economic and environmental benefits, especially soil protection from erosion, exploration of more than one economic activity in the same area, soil nutrient cycling, high soil volume exploration, increases in microorganism diversity and in soil carbon stocks, and nutrient availability for succeeding crops (Souza & Soratto 2012, Cong et al. 2015, Martin-Guay et al. 2018, Sarto et al. 2020, Mingotte et al. 2021).

Maize is among the most used species in intercropping systems because of its C4 photosynthetic metabolism; higher initial growth than other species, which favors its growth dominance in relation to other species, mainly C3 ones; and high plant size and competitive ability (Kluthcouski et al. 2000, Crusciol et al. 2013, Gebru 2015, Arf et al. 2018).

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[1] Received: Oct. 15, 2021. Accepted: Feb. 15, 2022. Published: Mar. 08, 2022. DOI: 10.1590/1983-40632022v5270513.
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Most areas with intercropping systems in the world involve maize crops, because one of the requirements for the successful implementation of intercropping systems is that the species used for soil cover or as green fertilizer do not interfere negatively with the agronomic performance of the main species or species of direct economic interest (Crusciol et al. 2013, Arf et al. 2018, Mingotte et al. 2021).

In Brazil, two maize intercropping systems are popular and widely used: Santa Brígida (Oliveira et al. 2010) and Santa Fé (Kluthcouski et al. 2000). These systems consist of intercropping maize with forage species, such as *Urochloa* (Santa Fé), and leguminous species, such as *Crotalaria* (Santa Brígida). They generate benefits such as the possibility of implementation of crop-livestock integration systems, result in a higher nitrogen (N) availability for the maize crop, and satisfactory straw production for the implementation and maintenance of a quality no-tillage system. However, the intercropping species may generate competition with the maize crop for water, light and nutrients, decreasing the maize agronomic performance (Borghi & Crusciol 2007, Crusciol et al. 2013, Mingotte et al. 2021). Therefore, studies on different production environments, soil types, intercropping models, plant arrangements and crop seasons are needed to base more reliable recommendations.

Mingotte et al. (2021) found that intercropping maize with *U. ruziziensis* with simultaneous sowing of the two species decreases the maize yield in up to 12 %, similarly to what was observed by Arf et al. (2018). In addition, Crusciol et al. (2013) concluded that intercropping maize with *U. brizantha* decreases the maize yield. However, Cambaúva et al. (2019) found that intercropping maize with leguminous plants (*Crotalaria spectabilis* and *C. ochroleuca*) does not affect the maize agronomic performance, but the intercropping with *C. juncea* decreases the maize yield in 21 %, due to the higher plant size of this green fertilizer. These results denote the need for studies on maize intercropping under different climate conditions, soils and managements for a more adequate use of intercropping systems.

In this context, this study aimed to assess the effects of intercropping with *Urochloa ruziziensis* and *Crotalaria spectabilis* on the maize agronomic performance and the straw production and quality after the harvest.

MATERIAL AND METHODS

The experiment was conducted in Jaboticabal, São Paulo state, Brazil (21º14'33''S, 48º17'10''W and mean altitude of 565 m). The climate of the region is Aw, tropical wet with rainy summer and dry winter, according to the Köppen classification. The soil of the experimental area is classified as Typic Hapludox (USDA 2014), or Latossolo Vermelho Eutroférrico (Santos et al. 2018), of clayey texture and slightly wavy relief. A soil fertility analysis was carried out before sowing and showed the following results: pH ($CaCl_2$) = 5.5; organic matter = 21 g dm^{-3}; P (resin) = 57 mg dm^{-3}; K = 5.4 mmol$_c$ dm^{-3}; Ca = 48 mmol$_c$ dm^{-3}; Mg = 33 mmol$_c$ dm^{-3}; H + Al = 24 mmol$_c$ dm^{-3}; cation exchange capacity = 110 mmol$_c$ dm^{-3}; base saturation = 78 %.

The experimental area had been cultivated for 15 years with annual crops (maize, common bean and rice), using conventional soil physical management, with fallow periods. However, the no-tillage system has been used from the summer of 2008, with maize and *Urochloa* species grown in succession to common bean in the 2008/2009, 2009/2010, 2010/2011 and 2012/2013 crop seasons.

A millet cultivar (ADR-300) was sown on August 26 (2014), with the aim of homogenizing the area, control nematodes, cycling nutrients and, mainly, producing straw for the no-tillage system. The plants were desiccated with glyphosate (1,860 g a.i. ha^{-1}) at 30 days before the implementation of the maize crop systems.

A randomized blocks experimental design was used, with six replications and plots consisting of single maize and maize intercropped with *Urochloa ruziziensis* and with *Crotalaria spectabilis*. The plots consisted of five 5-m rows of maize plants, spaced 0.90 m apart. The two external rows and 0.50 m from each end of the rows were considered as borders.

The single maize crop and intercrops were sown mechanically under no-tillage on December 15 (2014). The early-maturation maize hybrid Impact was sown with spacing of 0.90 m for a final population of 65,000 plants ha^{-1}. For the intercrops, *U. ruziziensis* and *C. spectabilis* seeds were sown simultaneously to the maize, using 11 and 12 kg ha^{-1} of seeds, respectively, and two rows of the soil cover plants between the maize rows.

The soil fertilizer application for the maize crop was carried out using 16 kg ha^{-1} of N, 33 kg ha^{-1} of

K_2O and 58 kg ha^{-1} of P_2O_5. Topdressing fertilization was carried out using 90 kg ha^{-1} of N and 45 kg ha^{-1} of K_2O on January 12 (2015), when the maize plants had six developed leaves (V6 phenological stage) (Cantarella et al. 1997, Fornasieri Filho 2007). Fifteen millimeters of water were applied after the topdressing fertilization. The harvests of the single maize and intercrops were carried out mechanically on May 25 (2015), at 161 days after sowing.

The climate data were monitored and recorded during the experiment (Figure 1). The mean maximum and minimum temperatures were 29.9 and 18.8 ºC, respectively, and the accumulated rainfall was 819 mm during the experiment. The maize plants were irrigated up to 60 days after sowing, using a conventional sprinkler system, because of the low rainfall depths at the beginning of the experiment. The irrigation management was supplemental to the rainfall, i.e., supplying the crop water needs considering the rainfall events.

Fifteen leaves from the base of the main ear of the plants within the evaluation area of each plot were collected at the maize full flowering stage to determine the N leaf contents (Cantarella et al. 1997). The middle thirds of these leaves were dried in a forced air circulation oven at 65 ºC, until constant weight. The samples were then ground in a Wiley mill and the N contents determined following the methodology proposed by Malavolta et al. (1997).

The plant height from the ground level to the flag leaf and main ear insertion height from the ground level to the main ear insertion were measured in ten plants of each plot at the end of the maize cycle with the aid of a ruler. The stem diameter at the second internode from the base was determined using a caliper in these same plants.

Ten representative ears of each plot were collected at the harvest to determine production components (number of grains per ear and 1,000-grain weight - determined by weighing four subsamples of 1,000 grains, with a standardized moisture of 0.13 kg kg^{-1}). The grain yield was estimated by the harvest of all ears in the evaluation area of each plot, also with standardized moisture of 0.13 kg kg^{-1}.

The management of crop residues was carried out after the harvest, using a straw crusher. At twenty days after this management, the production and N accumulation of the straw left by the maize crop systems were determined. The amount of left straw was determined by collecting two samples over 0.25 m^2 of the evaluation area of each plot. The plant residues were placed in paper bags, washed and then dried in a forced air circulation oven at 65 ºC, until constant weight. The straw N accumulation was evaluated using the samples collected to determine the straw production. After dried and weighed, the plant material was ground in a Wiley mill, followed by sulfuric acid digestion (Malavolta et al. 1997). The results for straw dry matter production and

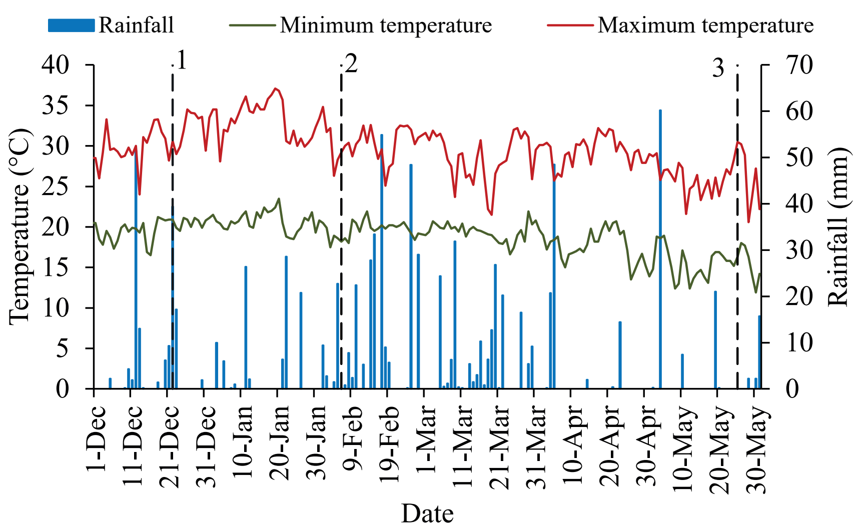

Figure 1. Rainfall depths and maximum and minimum temperatures during the experiment [1: emergence (Dec 22, 2014); 2: flowering (Feb 06, 2015); 3: harvest (May 25, 2015)]. Source: Agroclimatic station of the Universidade Estadual Paulista (Jaboticabal, São Paulo state, Brazil).

N contents were used to determine the straw N accumulation.

The collected data were subjected to analysis of variance by the F test and the means compared, when needed, by the Tukey test at 5 % of probability.

RESULTS AND DISCUSSION

The crop systems affected the plant height, main ear insertion height, stem diameter and number of grains per ear of the maize crop (Table 1). The maize plant height and main ear insertion height were higher for the intercropping with *C. spectabilis* (8 and 5 % higher, respectively, if compared to the mean found for the other two systems) (Figure 2). This is explained by the maize crop high sensitivity to light and photoperiod (Liu et al. 2018). Thus, when intercropping maize with higher plants, such as *Crotalaria* species, a higher shading and competition for light may occur, causing the etiolation of culm internodes (Hussain et al. 2019). Maize plants may have a better access to solar radiation through etiolation, what explains the higher heights of maize plants in the intercropping with *C. spectabilis*, when compared to the intercropping with *U. ruziziensis*. Thus, plant height is a variable that can be used in intercropping systems to indirectly evaluate the effect of shading on maize plants (Hussain et al. 2019). However, this variable does not necessarily indicate a decrease in grain yield and in the interspecific competition level.

The stem diameters were smaller in plants in the intercropping with *U. ruziziensis*, what

Table 1. Analysis of variance for leaf nitrogen content (LNC), plant height (PH), main ear insertion height (EIH), stem diameter (SD), number of grains per ear (NGE), 1,000-grain weight (1000GW) and grain yield (GY) of maize in different crop systems.

Factors	LNC	PH	EIH	SD	NGE	1000GW	GY
	$g\ kg^{-1}$	m		mm		g	$Mg\ ha^{-1}$
CV (%)	10.96	4.31	6.01	4.37	4.35	3.88	11.61
F value	1.12^{ns}	20.05**	4.61^{ns}	14.49**	6.93*	4.05^{ns}	2.25^{ns}
General mean	31.77	2.14	1.33	19.43	538.21	343.95	10.19

** Significant by the F test at 1 % of probability. * Significant by the F test at 5 % of probability. ^{ns} Not significant by the F test at 5 % of probability.

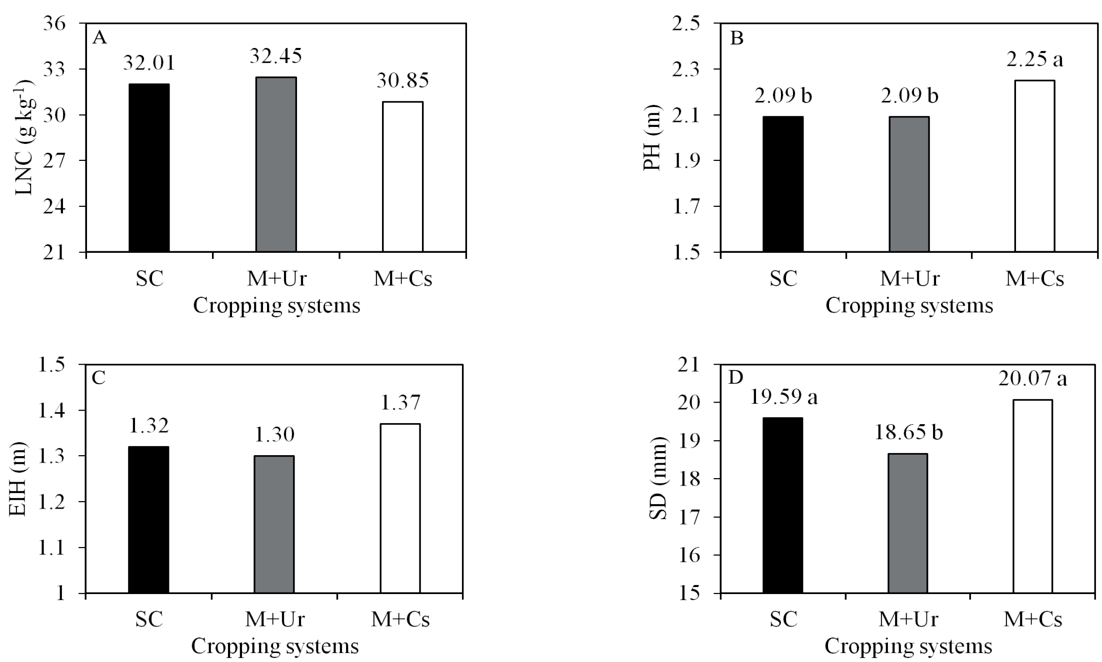

Figure 2. Leaf nitrogen content (LNC; A), plant height (PH; B), main ear insertion height (EIH; C) and stem diameter (SD; D) of maize plants in a single crop (SC) and intercropped with *Urochloa ruziziensis* (M + Ur) and *Crotalaria spectabilis* (M + Cs). Means followed by the same letter in the bars are not different from each other by the Tukey test at 5 % of probability.

may be connected to an interspecific competition (Figure 2). The stem is an organ that supports the leaves and floral parts, and is a reserve of sucrose for translocation to ears (Fornasieri Filho 2007). In situations of scarcity of vital elements to plants, it supplies reserves immediately to the drains, decreasing the concentration of these substances in the culm, resulting in smaller diameters, as observed by Mingotte et al. (2014) and Mingotte et al. (2021), when comparing single maize crops to intercropping systems with *U. ruziziensis*.

No interspecific competition was observed for maize intercropped with *C. spectabilis*, as the stem diameter was larger than that of the other intercrops, and, in addition, it presented higher plant heights, denoting that the accumulated reserves were enough to fill the stem and satisfactorily occupy all its extension. Cambaúva et al. (2019) evaluated an intercropping of maize with *Crotalaria* species and found that the maize stem diameters were not affected for the intercropping with *C. spectabilis* and *C. ochroleuca*, whereas the maize stem diameters in the intercropping with *C. juncea* were smaller than those in the single maize crop. They also found that the stem diameter can be a reliable variable for the evaluation of competition of soil cover plants with maize, since only in the intercropping with *C. juncea*, the same system that decreased the maize stem diameters, resulted in a lower maize grain yield than the single maize crop.

The maize leaf nitrogen contents showed no differences between the single maize crop and the intercrops (Figure 2), and were within the adequate range for the crop (27-35 g kg^{-1}) (Cantarella et al. 1997). These similar results denote that there was no supplying of nitrogen fixed by the *C. spectabilis* to the maize plants, what is consistent with Oliveira et al. (2010), who reported that plants that perform biological nitrogen fixation in intercropping systems do not provide the nutrient to the other crop in simultaneous crop systems. In addition, there was no competition for N in the intercropping systems, mainly with the grass species *U. ruziziensis*, considering the similar leaf N content between the treatments. Deienno et al. (2021) found that the intercropping of maize with *U. ruziziensis* may decrease the maize leaf N contents to critical limits, depending on the N rate applied as topdressing to the maize crop, denoting the competition for the nutrient between the intercropped plants.

The number of maize grains per ear was higher for the single maize crop, but it did not affect the grain yield, which was not statistically different among the crop systems (Figure 3). This result differs from those of Kappes & Zancanaro (2015), who found lower maize yields for intercropping with forage (*U. ruziziensis*) and leguminous (*Crotalaria ochroleuca*, *C. juncea* and *C. spectabilis*) species, when compare to the single maize crop, and explained this result by interspecific competition; however, the intercropping with *C. spectabilis* resulted in a lower competition, with more similar yields to that obtained for the single crop.

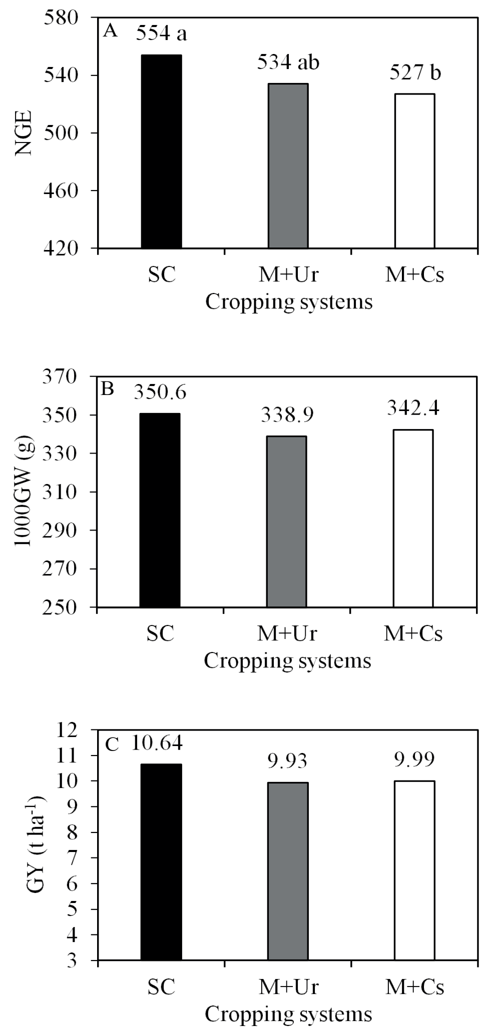

Figure 3. Number of grains per ear (NGE; A), 1,000-grain weight (1000GW; B) and grain yield (GY; C) of maize in a single crop (SC) and intercropped with *Urochloa ruziziensis* (M + Ur) and *Crotalaria spectabilis* (M + Cs). Means followed by the same letter in the bars are not different from each other by the Tukey test at 5 % of probability.

Oliveira et al. (2010) observed a yield 12 % lower for maize plants intercropped with *C. spectabilis*, when compare to the single maize crop. Cambaúva et al. (2019) found similar results between single maize crop and intercropping with *C. spectabilis* and *C. ochroleuca*, but with a lower maize yield for the intercropping with *C. juncea*. Mingotte et al. (2014) noticed no differences in maize yield between the single crop and intercropping with *U. ruziziensis*. These contrasting results denote that the positive effect of the intercropping depends on the species and the management used for the soil cover crops, as well as main crops and climate and soil conditions (Kappes & Zancanaro 2015). In the present study, the maize crops grown in the summer season, using an early-maturation hybrid (Impact), with spacing of 0.90 m between rows and simultaneous sowing of soil cover plants, in a soil with high natural fertility (Eutrophic), presented no significant differences in grain yield between the single crop and intercropping with *U. ruziziensis* and *C. spectabilis*.

Focused on sustainability, the use of intercrops is a way of integrating financial return and soil protection (Mingotte et al. 2021). Thus, the present study shows that maize intercropping systems are viable, and may possibly be part of crop-livestock integration systems, since there are no decreases in grain yield, when compared to single maize crops.

Maize grain yield is affected by climate factors, mainly temperature at the tasseling, flowering and pollination stages, and the occurrence of temperatures higher than 32 ºC in these periods accelerates the processes of differentiation of reproduction parts and cause high abortion rates of young grains (Fornasieri Filho 2007). In the present study, the crop climatic demands were met, which, together with the soil fertility and adequate management, contributed to obtaining high maize yields.

Regarding the crop residues, the maize crop systems affected the straw production and N accumulation (Table 2). The maize intercropping with *C. spectabilis* resulted in a higher straw production, which was 24 and 11 % higher than those of maize plants in a single crop and intercropped with *U. ruziziensis*, respectively (Figure 4). These results are consistent with those of Kappes & Zancanaro (2015) and Deienno et al. (2021), who found a higher straw production for maize plants intercropped with *C. spectabilis*, when compared to single maize crops or maize intercropped with *U. ruziziensis*. The intercropping of grass species, such as maize and *U. ruziziensis*, may result in an inhibition of the plant development, mainly when using species with low plant heights, since grass species tend to be more competitive for light than leguminous ones (Zhai et al. 2018). This explains the lower total dry matter production found for the maize intercropped with *U. ruziziensis*, when compared to the intercropping with *C. spectabilis*.

The straw production in the intercropping systems was determined soon after the maize harvest (20 days). However, the *Urochloa* species can be kept in the area after harvesting for a longer time to

Table 2. Analysis of variance for straw production and nitrogen (N) accumulation in maize crop systems.

Factors	Straw production (Mg ha^{-1})	Straw N accumulation (kg ha^{-1})
CV (%)	6.01	41.63
F test	62.48**	6.82**
General mean	6.71	43.01

** Significant by the F test at 1 % of probability.

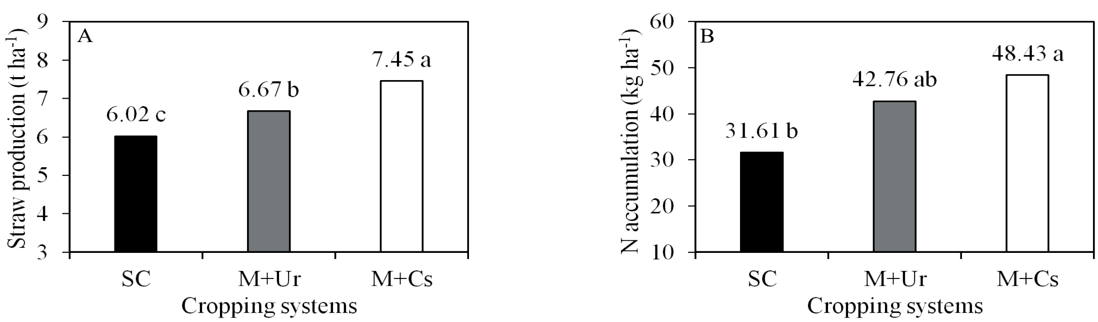

Figure 4. Straw production (A) and nitrogen (N) accumulation (B) in the straw of maize plants in a single crop (SC) and intercropped with *Urochloa ruziziensis* (M + Ur) and *Crotalaria spectabilis* (M + Cs). Means followed by the same letter in the bars are not different from each other by the Tukey test at 5 % of probability.

increase the biomass and straw production for the no-tillage system. Researchers found higher amounts of straw from maize with *U. ruziziensis*, when compared to single maize crops, ranging from 7 to 17 Mg ha^{-1} of dry matter (Souza & Soratto 2012, Carmeis Filho et al. 2014, Cunha et al. 2015, Mingotte et al. 2020).

Oliveira et al. (2010) did not find higher amounts of plant residues for maize intercropped with *C. spectabilis*, when compared with single maize crops. This variation denotes that the amounts of plant residues depend on the intercropped species (Borghi & Crusciol 2007), climate, soil and crop management.

Although the intercropping with *U. ruziziensis* presented a 10 % lower straw production, the straw N accumulation was statistically equal to that of the intercropping with *C. spectabilis*, and the single maize crop showed lower values for both variables. Carmeis Filho et al. (2014) observed a higher straw N accumulation in maize intercropped with *U. ruziziensis*, when compared to the single maize crop. Similarly, Mingotte et al. (2020) found straw productions of up to 34 % higher for maize intercropped with *U. ruziziensis*, with up to a 32 % higher straw N accumulation.

Oliveira et al. (2010) found higher N contents for maize intercropped with *C. spectabilis*, when compared to the crop residues of the single maize crop. Cambaúva et al. (2019) noticed that the straw production of maize intercropped with *C. juncea* was 33 % higher than that of the single maize crop, and presented a higher N accumulation. In addition to the straw N accumulation, the intercropping with leguminous species generates a higher N accumulation in the soil due to biological N fixation (Oliveira et al. 2010). This capacity increases the soil N contents and, consequently, the N absorption by plants, since crop residues present a low C/N ratio, which increases their decomposition and availability to subsequent crops (Kappes & Zancanaro 2015).

Therefore, the intercropping of maize with *C. spectabilis* is viable for the no-tillage system, since it results in a high straw production for soil cover and high atmospheric N fixation. Despite the low C/N ratio of the leguminous crops residues, which favors decomposition, maize is a grass species whose straw presents a high C/N ratio; thus, the use of maize in intercrops results in a relative balance between maintenance of soil cover for the no-tillage system and decomposition for the supplying of nutrients to plants. According to Marcelo et al. (2012), different plant residues are mixed on the soil surface, resulting in an intermediate C/N ratio, with favorable characteristics for soil protection, mainly due to grass residues, and for the supplying of N by leguminous plants.

The use of *Urochloa* species for intercropping with maize present some other advantages. In addition to the higher C/N ratio of the straw of *Urochloa* species, which favors a longer time of soil cover maintenance and protection against erosion, these species can be used in crop-livestock integration systems, for being a nutritive food for animals (Kluthcouski et al. 2000, Mingotte et al. 2020). Moreover, the N accumulated in residues of intercropping systems with *Urochloa* species can be better used by succeeding crops, decreasing the need for N application (Cong et al. 2015, Mingotte et al. 2020).

CONCLUSIONS

1. The intercropping of maize with *Urochloa ruziziensis* and *Crotalaria spectabilis* do not decrease the maize yield, when compared to the single maize crop, under the climate, soil and management conditions of the present study;
2. The intercropping with *C. spectabilis* and *U. ruziziensis* presented a straw production 24 and 11 % higher, respectively, and the intercropping with *C. spectabilis* resulted in a straw nitrogen accumulation 39 % higher, when compared to the single maize crop, favoring the soil protection and implementation or maintenance of a quality no-tillage system.

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