Research Article

Cover plants in second crop: nutrients in straw and cotton yield in succession[1]

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ABSTRACT

The cultivation of cover plants is a strategy for improving the agricultural production environment and providing straw for soil cover in the no-tillage system, in addition to cycling and providing nutrients to succeeding crops. This study aimed to assess the dry matter yield and nutrients accumulation by cover plants grown alone or intercropped in the second crop after soybean and their effects on cotton grown in succession. The treatments were: *Urochloa ruziziensis*; *Pennisetum glaucum* (millet); *Zea mays* (corn); *Crotalaria spectabilis*; *Crotalaria ochroleuca*; *Cajanus cajan* (pigeon pea); corn + *U. ruziziensis*; *C. spectabilis* + *U. ruziziensis*; *C. ochroleuca* + *U. ruziziensis*; pigeon pea + *U. ruziziensis*; corn + *C. spectabilis*; corn + *C. ochroleuca*; and corn + pigeon pea. The experimental design consisted of randomized blocks, with four replications, and the experiment was carried out in two crop seasons. In the cotton pre-seeding, the maximum amount of corn straw dry matter was 2,699 kg ha^{-1}, with low macronutrient contents. The pigeon pea intercropped with *U. ruziziensis* produced between 8,400 and 12,941 kg ha^{-1} of dry matter, with a maximum content of 223 and 323 kg ha^{-1} of nitrogen and potassium, respectively. The *U. ruziziensis*, grown alone or intercropped, provided between 140 and 323 kg ha^{-1} of potassium in the straw. A high yield is obtained by cotton grown in the no-tillage system in succession to *C. spectabilis*.

KEYWORDS: *Urochloa ruziziensis*, *Gossypium hirsutum* L., green manures, no-tillage system.

RESUMO

Plantas de cobertura em segunda safra: nutrientes na palhada e produtividade de algodoeiro em sucessão

O cultivo de plantas de cobertura é uma estratégia para a melhoria do ambiente de produção agrícola e aporte de palhada para cobertura do solo no sistema plantio direto, além de ciclar e disponibilizar nutrientes às culturas sucessoras. Objetivou-se avaliar a produtividade de matéria seca e o acúmulo de nutrientes por plantas de cobertura cultivadas de forma solteira ou consorciada em segunda safra após a soja e seus efeitos sobre o algodoeiro cultivado em sucessão. Os tratamentos foram: *Urochloa ruziziensis*; *Pennisetum glaucum* (milheto); *Zea mays* (milho); *Crotalaria spectabilis*; *Crotalaria ochroleuca*; *Cajanus cajan* (guandu); milho + *U. ruziziensis*; *C. spectabilis* + *U. ruziziensis*; *C. ochroleuca* + *U. ruziziensis*; guandu + *U. ruziziensis*; milho + *C. spectabilis*; milho + *C. ochroleuca*; e milho + guandu. O delineamento experimental foi o de blocos ao acaso, com quatro repetições, e o experimento realizado em duas safras agrícolas. Na pré-semeadura do algodão, a quantidade máxima de matéria seca da palhada de milho foi de 2.699 kg ha^{-1}, com baixos conteúdos de macronutrientes. O guandu consorciado com *U. ruziziensis* produziu entre 8.400 e 12.941 kg ha^{-1} de matéria seca, com conteúdo máximo de 223 e 323 kg ha^{-1} de nitrogênio e potássio, respectivamente. A *U. ruziziensis*, cultivada de forma solteira ou consorciada, disponibilizou na palhada entre 140 e 323 kg ha^{-1} de potássio. Alta produtividade é obtida pelo algodoeiro cultivado sob sistema plantio direto em sucessão a *C. spectabilis*.

PALAVRAS-CHAVE: *Urochloa ruziziensis*, *Gossypium hirsutum* L., adubos verdes, sistema plantio direto.

INTRODUCTION

Almost all Brazilian herbaceous cotton grows in the Cerrado (Brazilian Savanna), where soils are naturally acidic and weathered, with low saturation levels of exchangeable bases, reduced cation exchange capacity and low levels of organic matter and macronutrients (Lopes & Guilherme 2016). Therefore, to achieve adequate yields in this environment, high investments in fertilizers become necessary (Borin et al. 2019), which are usually the most significant item in the cost of cotton production.

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The Brazilian dependence on imported fertilizers, especially potassium, is high. Thus, soil management and conservation practices are also extremely important factors for improving the efficiency of fertilization and the use of nutrients.

The no-tillage system is a conservationist agricultural production technology and part of Brazilian public policies targeted at achieving low-carbon agriculture (UNFCCC 2022). One of its principles is the permanent soil coverage by the straw of crops used in rotation or by cover plants, alive or their residues. However, this requirement is often not met, observing the lower amount of straw produced and insufficient soil protection, despite the crop cultivation happening without disturbing the soils with mechanical equipment.

Soybean is the main crop used in rotation with cotton. Customarily, Brazilian cotton growers do not diversify their production system. It is typical that the areas, after the soybean harvest, remain fallow until cotton sowing in the subsequent crop, without adequate soil protection and cover. However, growing cover plants and green manures in the off-season after soybean, including intercropping with second-crop corn (Ceccon et al. 2013), is a better option (Ferreira et al. 2018).

Cover plants play a fundamental role in the no-tillage system, providing more straw on the soil, especially considering the insufficient soil cover and persistence of dry matter from cotton (Boyer et al. 2018), soybean or corn crop residues. Some cover plants, such as *Brachiaria*, can develop roots even in the deepest soil layers, exhibiting a larger root volume and a higher potential for potassium (K) absorption (Rosolem et al. 2019, Resende et al. 2021), including in the non-exchangeable form (Volf et al. 2018). Cover plants protect the soil from erosion (Zuazo & Pleguezuelo 2008), prevent or reduce the loss of nutrients such as K (Calonego & Rosolem 2013) and nitrogen (N) (Basche et al. 2014) by leaching, and provide nutrients to crops in succession (Pacheco et al. 2017). However, discrepant results of dry matter yield and nutrient accumulation in cover plants straw are found in the literature (Garcia et al. 2008, Sousa et al. 2019), according to the environment, species, sowing date and cultivation time. In addition, there are few studies addressing cotton grown in the no-tillage system.

Therefore, to improve the no-tillage system in cotton crops, this study aimed to assess the dry matter yield and content of nutrients in cover plants grown in the second crop after soybean - in a single or intercropped system - and their effects on cotton grown in succession.

MATERIAL AND METHODS

The study was conducted in the 2015-2016 (year one) and 2016-2017 (year two) crop seasons, in Santo Antônio de Goiás, Goiás state, Brazil (16º29’37.2”S; 49º17’56.9”W), in a Typic Acrustox (clay, kaolinitic, thermic Typic Acrustox) soil or red Latosol (Oxisol) with clayey texture (Santos et al. 2018). The experimental area was previously cultivated with soybean, pasture and millet in a no-tillage system. At the beginning of the study, the soil presented the chemical characteristics described in Table 1, with granulometry corresponding to 463, 143 and 394 g kg^{-1} of clay, silt and sand, respectively.

Thirteen treatments were performed in a no-tillage system consisting of plants grown in the off-season after soybean. The species and respective amounts of seeds, with 100 % of germination and purity, were: *Urochloa ruziziensis* (4 kg ha^{-1}); *Pennisetum glaucum* - millet (15 kg ha^{-1}); *Zea mays* - corn (66,667 seeds ha^{-1}); *Crotalaria spectabilis* (15 kg ha^{-1}); *Crotalaria ochroleuca* (8 kg ha^{-1}); *Cajanus cajan* - pigeon pea (25 kg ha^{-1}); corn + *U. ruziziensis*

Table 1. Results of the soil analyzes in the general area, in the 0-5, 6-10, 11-20 and 21-40 cm deep layers, before the beginning of the experiment, in 2015.

Depth (cm)	pH in water[1]	P[2]	K[3]	Ca[4]	Mg[5]	Al[6]	Clay	Silt	Sand
		mg dm^{-3}	cmol$_c$ dm^{-3}				g kg^{-1}		
0-5	5.7	3.8	0.27	1.37	0.70	0.02	365	158	477
6-10	5.6	8.5	0.24	1.23	0.59	0.05	480	176	344
11-20	5.5	3.5	0.18	1.21	0.58	0.07	501	125	374
21-40	5.7	0.7	0.15	1.00	0.46	0.00	480	143	377

[1] pH in water (soil:water = 1:2.5); [2] available phosphorus and [3] exchangeable potassium, extracted by Mehlich-1; [4] exchangeable calcium and [5] magnesium and [6] aluminium, extracted by KCl 1 mol L^{-1}.

(66,667 seeds ha^{-1} + 3 kg ha^{-1}); *C. spectabilis* + *U.ruziziensis* (9 + 3 kg ha^{-1}); *C. ochroleuca* + *U. ruziziensis* (4.8 + 3 kg ha^{-1}); pigeon pea + *U. ruziziensis* (15 + 3 kg ha^{-1}); corn + *C. spectabilis* (66,667 seeds ha^{-1} + 9 kg ha^{-1}); corn + *C. ochroleuca* (66,667 seeds ha^{-1} + 4.8 kg ha^{-1}) and corn + pigeon pea (66,667 seeds ha^{-1} + 15 kg ha^{-1}). In the intercropping treatments, each species was sown in alternate rows spaced at 0.45 m. Each plot was 7 x 8 m, and the experimental design consisted of randomized blocks, with four replications.

The Diquat dibromide herbicide (400 g ha^{-1} of the active ingredient) was applied before sowing the cover plants and corn (SYN7205 TLTG Viptera cultivar). The soil was mechanically furrowed superficially, with a spacing of 0.45 m between lines. The cover plants and corn were sown manually on March 25, 2015 (year one) and March 16, 2016 (year two). The cover plants were neither irrigated nor fertilized. Corn was cultivated under rainfed conditions and fertilized during sowing with 20 kg ha^{-1} of N, 100 kg ha^{-1} of P_2O_5 and 40 kg ha^{-1} of K_2O. On coverage, at thirty days after emergence, the fertilization for corn consisted of 50 kg ha^{-1} of N and 40 kg ha^{-1} of K_2O.

The dry matter from the cover plants shoots and the corn crop residues were assessed on December 04, 2015 (year one) and December 14, 2016 (year two). An iron frame (0.5 x 0.5 m) was used for sampling, randomly thrown three times in each experimental plot. The dry matter was quantified and the results transformed into kg ha^{-1}. There were 254 days in 2015 and 273 days in 2016 between the species sowing and sampling. After the collection, the area was desiccated with glyphosate (1,400 g ha^{-1} of the active ingredient) at twenty days before the direct cotton sowing.

The contents of nitrogen, phosphorus, potassium, calcium, magnesium and sulfur in the dry matter were analyzed according to Malavolta et al. (1997). In the intercroppings, the species were sampled, processed and analyzed together. The nutrient content (kg ha^{-1}) was determined based on the dry matter and shoot yield. The cotton (FM975WS cultivar) was sown on December 17, 2015 and January 05, 2017. The row spacing was 0.76 m, with a population of 105,264 plants ha^{-1}. During the cultivation of the cover plants (Figure 1) and cotton (Figure 2), data on rainfall and monthly maximum and minimum temperatures were recorded each year.

The cotton fertilizations were identical for all treatments. In the year one, 172.5, 135 and 127.5 kg ha^{-1} of N, P_2O_5 and K_2O were applied, respectively. All the phosphate fertilizer was applied during sowing, together with 22.5 kg ha^{-1} of N and 67.5 kg ha^{-1} of K_2O. The rest of the N and K_2O were added in cover fertilization at the first floral bud emission (B1), with 90 kg ha^{-1} of N, and at the opening of the first flower (F1), with 60 kg ha^{-1} of N and K_2O. In the year two, 127.5, 130 and 110 kg ha^{-1} of N, P_2O_5 and K_2O were applied to the cotton, respectively. All the phosphate fertilizer was applied during sowing, with an additional 27.5 kg ha^{-1} of N and 60 kg ha^{-1} of K_2O. In B1, the first topdressing fertilization was performed with 50 kg ha^{-1} of N, and, in F1, with 50 kg ha^{-1} of N and K_2O.

The cotton was harvested manually on May 31, 2016 (year 1) and August 10, 2017 (year 2). Before harvesting, the height of five plants randomly taken was assessed. The data were subjected to analysis of

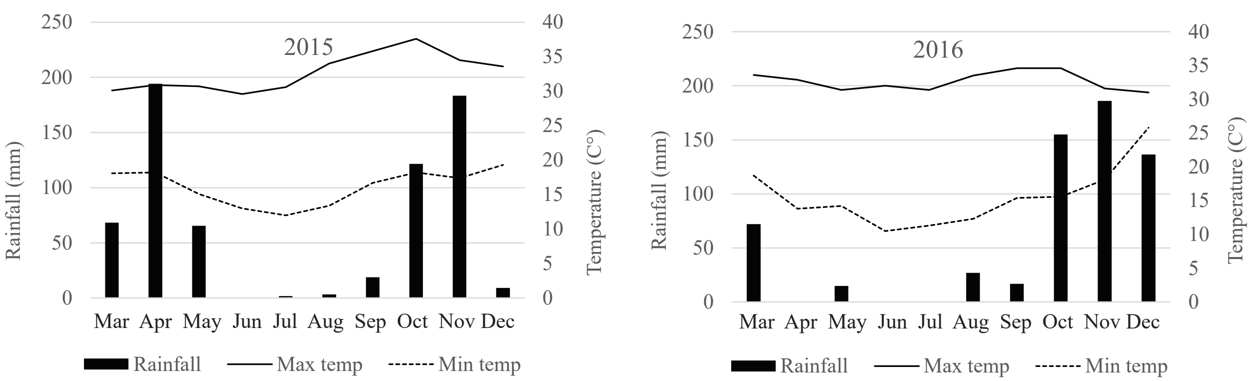

Figure 1. Rainfall and monthly maximum (Max temp) and minimum (Min temp) temperatures, during the two years of cover crops cultivation (Santo Antônio de Goiás, Goiás state, Brazil).

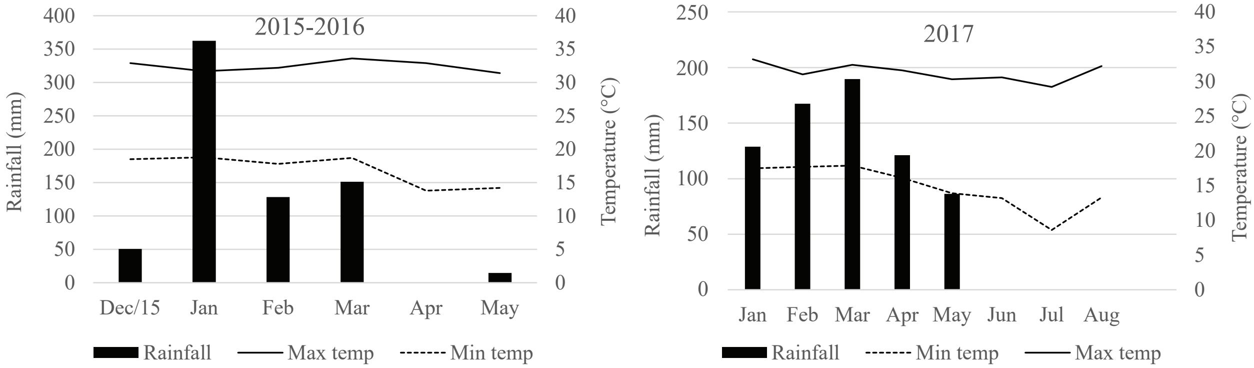

Figure 2. Rainfall and monthly maximum (Max temp) and minimum (Min temp) temperatures during the cotton cultivation, from December 17, 2015 to May 31, 2016, and from January 05, 2017 to August 10, 2017 (Santo Antônio de Goiás, Goiás state, Brazil).

variance considering the year effect, and the means were grouped for each year using the Scott-Knott test at 5 % of significance.

RESULTS AND DISCUSSION

The effects of cover plants and year were significant for all characteristics, except for the year on dry matter yield (Tables 2 and 3). The interaction between cover plants and years was significant, except for plant height (Table 2). The interaction between cover plants and years was not significant only for plant height (Table 3). For intercropping, with the presence of *U. ruziziensis*, the highest means for dry matter were obtained in 2015 (Table 2). In 2016, the significantly greatest amount of dry matter was produced by pigeon pea and pigeon pea + *U. ruziziensis*, with 11,908 and 12,941 kg ha^{-1}, respectively. The better performance of pigeon pea for biomass production in 2016 can be explained by drought tolerance due to vigorous root growth (Pípolo & Pípolo 1994).

The nutrient contents varied according to the cover plants and years (Table 2). In general, the greatest amounts occurred in the treatments with a higher dry matter yield, as also observed by Tanaka et al. (2019). According to Wendling et al. (2016), plants increase the nutrient content in their tissues through a higher dry matter yield and increasing nutrient content. For the two years and the overall average of the treatments, the accumulation of macronutrients in the shoots was: K > N > Ca > Mg > S > P (Table 2).

Corn grown alone in the second crop exhibited the lowest values for all the characteristics assessed in the two crop seasons (Tables 2 and 3). Crop residues were 2,699 and 1,433 kg ha^{-1} in 2015 and 2016, respectively (Table 2). Consequently, the N, P, K, Ca, Mg and S contents were grouped with the treatments with lower values (Table 2). The low corn dry matter contribution and, consequently, the reduced nutrient content probably occurred due to the late sowing of corn (March 25, 2015 and March 16, 2016), which culminated in a low water availability during the autumn, mainly in 2016 (Figure 1).

Another factor contributing to the low P and N contents in corn straw is that 67 % of P and 50 % of N absorbed by the corn plants are exported to the grains (Resende et al. 2019). Another reason may be related to the beginning of the decomposition of corn crop residues after the first spring rains, since the biomass deposited on the soil was collected in the first half of December, twenty days before the direct sowing of cotton. High temperatures and high rainfall (Figure 1) in October and November 2015, and from October to December 2016, may have favored the decomposition of corn crop residues. These climatic conditions favor the action of soil microorganisms (Conant et al. 2011) and influence key enzymes that catalyze the straw biochemical degradation and nutrient cycling (Guan et al. 2020). As in the present study, Ceccon et al. (2013) found lower amounts of nutrients in the dry matter of corn grown as a second crop.

After the corn and cover plants sowing on March 16, 2016, it rained only 86.8 mm (Figure 1). Between March 28 and May 12, there was no rainfall, the same happening in June and July. The unharvested millet had the grains dispersed on the soil. Between

Table 2. Dry matter yield (kg ha^{-1}) and content (kg ha^{-1}) of nutrients in the shoots of cover plants, in 2015 and 2016.

Treatments	Dry matter	N	P	K	Ca	Mg	S
Cover plants (CP)	**	**	**	**	**	**	**
Year	ns	**	**	**	**	**	**
CP x year	**	**	**	**	**	**	**
Coefficient of variation (%)	23.2	30.3	65.5	28.2	30.1	39.3	53.2
Cover plants				2015			
Millet	1,313 c	9 b	0.2 b	2 d	7 c	3 d	1.1 b
Crotalaria spectabilis	5,171 b	68 a	1.5 b	91 c	49 a	15 b	8.2 a
Crotalaria ochroleuca	3,172 c	22 b	0.2 b	21 d	16 c	6 d	1.5 b
Pigeon pea	6,414 b	88 a	5.0 a	67 c	48 a	13 c	4.9 b
Urochloa ruziziensis	6,521 b	44 a	2.5 b	140 b	42 a	22 b	5.2 b
C. spectabilis + U. ruziziensis	10,283 a	85 a	5.4 a	195 a	61 a	34 a	11.8 a
C. ochroleuca +U. ruziziensis	8,991 a	67 a	3.7 a	213 a	51 a	20 b	6.5 a
Pigeon pea + *U. ruziziensis*	8,418 a	78 a	3.7 a	199 a	53 a	20 b	8.2 a
Corn	2,699 c	7 b	0.2 b	5 d	9 c	5 d	0.7 b
Corn + *U. ruziziensis*	7,803 a	61 a	2.5 b	148 b	43 a	23 b	7.1 a
Corn + *C. spectabilis*	6,965 b	53 a	1.2 b	41 d	36 a	16 b	4.1 b
Corn + *C. ochroleuca*	2,596 c	12 b	0.3 b	5 d	7 c	5 d	0.6 b
Corn + pigeon pea	5,981 b	55 a	1.5 b	26 d	29 b	11 c	4.3 b
Means	5,871	50	2.1	89	35	15	4.9
Cover plants				2016			
Millet	6,562 c	109 c	7.6 c	190 b	45 c	11 b	11.5 b
Crotalaria spectabilis	2,988 d	40 d	3.3 d	52 d	27 d	6 c	6.2 b
Crotalaria ochroleuca	2,199 d	39 d	2.2 d	39 d	14 e	5 c	4.9 c
Pigeon pea	11,908 a	204 a	11.0 b	172 b	91 a	10 b	6.3 b
Urochloa ruziziensis	6,030 c	80 c	3.8 d	172 b	34 d	16 a	7.4 b
C. spectabilis + U. ruziziensis	5,688 c	99 c	6.9 c	186 b	34 d	14 b	8.5 b
C. ochroleuca +U. ruziziensis	5,510 c	77 c	6.1 c	162 b	31 d	11 b	6.9 b
Pigeon pea + *U. ruziziensis*	12,941 a	223 a	18.2 a	323 a	89 a	19 a	19.9 a
Corn	1,433 d	11 d	0.2 d	2 d	5 e	1 c	1.0 c
Corn + *U. ruziziensis*	9,189 b	109 c	9.4 b	287 a	50 c	19 a	7.5 b
Corn + *C. spectabilis*	1,987 d	38 d	2.3 d	34 d	23 e	3 c	4.5 c
Corn + *C. ochroleuca*	3,339 d	39 d	2.2 d	40 d	19 e	5 c	3.0 c
Corn + pigeon pea	8,735 b	146 b	7.0 c	113 c	66 b	10 b	6.2 b
Means	6,039	93	6.2	136	41	10	7.2

ns and **: not significant at 5 % and significant at 1 % of probability, respectively, by the F test. Within each year, means grouped by the same letter in the column do not differ by the Scott-Knott test, at 5 % of significance. N: nitrogen; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; S: sulfur.

October and the time close to the dry matter assessment, there was an accumulated rainfall of 154.8 mm in 2015 and 317.4 mm in 2016. The second year had better water conditions between the end of winter and spring for the germination and development of volunteer millet plants, a fact also observed by Pacheco et al. (2017). Consequently, the dry matter yield of millet in 2016 was five times higher than in 2015, and the accumulated amounts of N, P, K, Ca, Mg and S were, respectively, about 12, 38, 95, 6, 4 and 10 times higher than those observed in 2015 (Table 2). Even so, the millet produced a low amount of dry matter in the off-season for the cotton in the no-tillage system (Table 2), especially in 2015, when the amount of rainfall in the autumn-winter period was lower than in 2016, despite being considered a species tolerant to water deficit (Assis et al. 2018). According to Carvalho et al. (2013), the soil coverage and protection provided by millet are usually insufficient because of the high proportion of stalks in the dry matter of millet, in addition to the fast decomposition of its straw (Silva Filho et al. 2018). Ferreira et al. (2018), also assessing millet cultivation in the off-season in the Cerrado, observed that it contributed little with dry matter to the cotton in the no-tillage system.

Crotalaria spectabilis in 2016 and *C. ochroleuca* in both years exhibited a low dry matter yield and reduced macronutrient contents in the phytomass of shoots. In 2015, *C. spectabilis*

Table 3. Cotton seed yield and height in the no-tillage system on straw cover plants, in 2015-2016 and 2016-2017.

Treatments	Yield (kg ha^{-1})		Height (cm)	
Cover plants (CP)	**		**	
Year	**		**	
CP x year	*		ns	
Coefficient of variation (%)	7.3		7.3	
Cover plants	2015-2016	2016-2017	2015-2016	2016-2017
Millet	3,103 c	4,980 b	67 c	113 b
Crotalaria spectabilis	4,383 a	5,376 a	92 a	127 a
Crotalaria ochroleuca	3,802 b	5,252 a	81 b	128 a
Pigeon pea	3,159 c	5,120 a	64 c	119 b
Urochloa ruziziensis	3,423 c	4,922 b	67 c	113 b
C. spectabilis + *U. ruziziensis*	3,907 b	5,623 a	78 b	124 a
C. ochroleuca +*U. ruziziensis*	3,216 c	5,324 a	62 c	112 b
Pigeon pea + *U. ruziziensis*	3,547 c	5,156 a	66 c	118 b
Corn	3,450 c	4,916 b	72 c	116 b
Corn + *U. ruziziensis*	3,432 c	4,773 b	65 c	110 b
Corn + *C. spectabilis*	3,489 c	4,935 b	69 c	120 b
Corn + *C. ochroleuca*	3,460 c	4,761 b	71 c	116 b
Corn + pigeon pea	3,628 c	4,670 b	71 c	113 b
Means	3,538	5,062	71	118

ns, * and **: not significant at 5 % and significant at 5 % and 1 % of probability, respectively, by the F test. Within each year, means grouped by the same letter in the column do not differ by the Scott-Knott test, at 5 % of significance.

provided 5,171 kg ha^{-1} of dry matter, with 68, 49 and 8.2 kg ha^{-1} of N, Ca and S, respectively. These contents did not differ from those obtained in intercropping *U. ruziziensis* with *C. spectabilis*. This intercropping provided 10,283 kg ha^{-1} of dry matter in 2015, indicating its high potential for off-season phytomass production in the Cerrado.

The intercropping of *U. ruziziensis* with corn or with the leguminous plants *C. spectabilis*, *C. ochroleuca* and pigeon pea exhibited the highest dry matter and N values in 2015. The intercropping with the leguminous plants also presented the highest accumulations of P, K, Ca and S, especially K, whose maximum absolute value reached 213 kg ha^{-1} in the intercropping of *U. ruziziensis* with *C. ochroleuca* (Table 2).

The single cultivation of *U. ruziziensis* in 2015 produced 6,521 kg ha^{-1} of dry matter, lower than that observed in all intercroppings of this Poaceae. The P, K and S contents in the dry matter of *U. ruziziensis* intercropped with leguminous plants was higher than for the single *U. ruziziensis* (Table 2). According to Silva et al. (2021), the use of a mix of cover plants, especially with species that have contrasting characteristics, has been growing, because they can provide more benefits to the system than the cultivation of single species, such as a greater availability of nutrients for crops and improved soil protection.

In both years, the potential for biomass production of *U. ruziziensis* intercropped with corn was more evident than in its single cropping (Table 2). In 2015, the dry matter of the intercropping was approximately 20 and 190 % higher than those of *U. ruziziensis* and corn alone, respectively. In 2016, the intercropping performance was 52 and 540 % higher than for the single *U. ruziziensis* and single corn, respectively (Table 2). In intercropping corn with forage grasses, such as *U. ruziziensis*, these grasses continue to develop and accumulate dry matter after the corn harvest, with different potentials according to the region (Ceccon et al. 2013). It is worth noting that the corn was fertilized; however, it did not develop well due to the reduced rainfall amount, especially in the fall of 2016. This way, the nutrients applied and not absorbed by the corn may have been available to *U. ruziziensis*, thus favoring its growth.

The intercropping of pigeon pea with *U. ruziziensis* in 2015 produced 31.2 % more dry matter, in comparison to the single pigeon pea crop, which provided 6,414 kg ha^{-1} (Table 2). Ferreira et al. (2018) assessed the off-season pigeon pea cultivation in the Cerrado and found a dry matter yield ranging from 4,848 to 7,467 kg ha^{-1} for single pigeon pea and from 6,508 to 10,683 kg ha^{-1} for the combined dry matter of pigeon pea with *U. ruziziensis*. In 2016, the results of these two treatments did not differ significantly from each other, in terms of dry matter contribution, which was 11,908 kg ha^{-1} for pigeon pea without intercropping and 12,941 kg ha^{-1} with intercropping. The straw in these two treatments also had the highest contents of N and Ca, with more than 200 kg ha^{-1} of N and about 90 kg ha^{-1} of Ca.

Although in 2016 the dry matter yield values of the two treatments with pigeon pea were statistically together in the group with the highest average, the accumulated K in the phytomass of the pigeon pea intercropped with *U. ruziziensis* was 88 % higher than that of the single pigeon pea (Table 2). In the 2015 crop season, the accumulated K in the straw of this intercropping was about 200 % higher than in the pigeon pea grown alone (Table 2). This result indicates that, although the pigeon pea accumulates much dry matter in the shoots, it does not absorb nor store much K, since the concentrations in the single pigeon pea were 14.4 and 10.5 g kg^{-1}, respectively in 2015 and 2016. For the single *U. ruziziensis*, the K concentrations were 21.5 and 28.5 g kg^{-1}. The potassium concentrations in the pigeon pea were similar to those observed by Sousa et al. (2019), ranging from 9.9 to 12.3 g kg^{-1}, depending on the cultivar.

In the second crop after soybean, alone or intercropped with corn or leguminous plants, *U. ruziziensis* provided between 140 and 323 kg ha^{-1} of K (Table 2), indicating the high potential of this species for absorbing K. Sousa et al. (2019), who sowed *U. ruziziensis* in January, in soil with 25.6 g kg^{-1} of clay and 67.3 g kg^{-1} of sand, obtained 118 kg ha^{-1} of K in the shoots, with a concentration equivalent to 13.9 g kg^{-1}. Poaceae species generally have a higher capacity to absorb K from the soil (Volf et al. 2018) because of the action of exudates from their roots (Wang et al. 2011). The *U. ruziziensis* roots also explore deeper soil layers, extracting exchangeable (Rosolem et al. 2012b) and non-exchangeable K (Volf et al. 2018), thus improving the potassium fertilization on soils (Ferreira et al. 2022). These same authors observed that the cultivation of cotton in a no-tillage system, with *U. ruziziensis* as the cover crop, resulted in a greater availability of exchangeable K in the soil, twice as much as that observed in the conventional soil preparation system, in which *U. ruziziensis* had not been cultivated.

Even under low rainfall in the off-season, between June and September 2015, the intercropping of *U. ruziziensis* with *C. spectabilis*, *C. ochroleuca* and pigeon pea produced over 8,400 kg ha^{-1} of dry matter, with a minimum accumulation of 67, 195 and 51 kg ha^{-1} of N, K and Ca, respectively (Table 2). In the year two, N, K and Ca contents higher than 77, 162 and 31 kg ha^{-1} were observed in those same treatments. Pigeon pea in single cultivation or intercropped with *U. ruziziensis* resulted in a higher accumulation of N in the straw, especially in the year two, higher than 200 kg ha^{-1} of N. Although in some cover plants the amounts of dry matter and nutrient contents were not high, small straw contributions can improve the soil fertility and supply part of the nutritional requirements of crops in succession, as reported by Guan et al. (2020). However, after straw mineralization, the nutrient availability to plants varies with soil characteristics, especially those related to immobilization and leaching phenomena.

The highest absolute amounts of N and K were observed in the straw of the pigeon pea intercropped with *U. ruziziensis*, with 223 and 323 kg ha^{-1}, respectively, equivalent to 495 kg ha^{-1} of urea and 616 kg ha^{-1} of potassium chloride. It is worth mentioning that, except for K, whose release from the straw is fast, the availability of other nutrients to the plants may take longer, as it depends on the decomposition dynamics of the residues (Carvalho et al. 2013), which varies with the C-N ratio of the material (Wendling et al. 2016) and environmental conditions. The cultivation of cover plants, in the medium and long term, can improve the soil chemical and biological quality due to the recurrent contribution of straw (Carvalho et al. 2014), as well as the development of roots (Garcia et al. 2008, Wendling et al. 2016). The pearl millet and corn provided the lowest values for all the characteristics assessed in 2015, including the seed cotton yield (Table 3), which did not exceed 3,450 kg ha^{-1}.

Although the crotalarias did not produce a high amount of dry matter, the cotton yield in succession was higher in 2016-2017, the same occurring in 2015-2016 after *C. spectabilis*. In the first year, the highest average was for *C. spectabilis*, and, in the second year, for *C. spectabilis*, *C. ochroleuca* and pigeon pea cultivated alone or intercropped with *U. ruziziensis*, forming the cover plants cluster with the greatest cotton yields, statistically different from those of the other treatments or treatment group (Table 3). In both years, the cotton plants exhibited greater heights in succession to *C. spectabilis* (Table 3).

Despite the higher dry matter yield in 2015 (Table 2) in the intercropping of *C. spectabilis* with *U. ruziziensis*, the yield and height of the cotton plants in succession were in the intermediate group, probably because of the lower amount of N (85 kg ha^{-1}) in the higher dry matter contribution. Therefore, the soil N may have been immobilized, causing deficiency in the cotton plants, as reported by Rosolem et al. (2012a).

The cotton cultivated between December 17, 2015 and 31, 2016 had 707.6 mm of rainfall, and, between January 05, 2017 and August 10, 2017, 693.4 mm (Figure 2). Despite this similarity, the average cotton yield in the year one was 43 % lower. A possible explanation is that the rainfall was poorly distributed (Figure 2), raining 362 mm in January, in the cotton vegetative phase, whereas, between March 27 and May 12, 2016, it did not rain at all during 47 days in the reproductive phase, the period of greatest water demand of the plant. According to Hake & Grimes (2010), water deficit in this phase results in the shedding of fruiting structures in cotton plants. Between May 13 and 16, 2016 there was an accumulated rainfall of 14.4 mm, and then there was no more rain. This way, the cotton plants were short in height (Table 3) and ended the cycle earlier, with the harvest performed at 160 days after emergence.

Based on the high demand for K_2O by cotton (Borin et al. 2019) and its average yield in the year one (3,538 kg ha^{-1}), it was estimated that 205 kg ha^{-1} of K_2O would be required as maintenance fertilization, equivalent to 170 kg ha^{-1} of K, this amount being made available in the straw of leguminous plants intercropped with *U. ruziziensis*, whereas the general average was 89 kg ha^{-1} of K. In the year two, with an average seed cotton yield of 5,062 kg ha^{-1}, 294 kg ha^{-1} of K_2O with maintenance fertilization or 244 kg ha^{-1} of K would be necessary; however, the overall average K content was 136 kg ha^{-1}. Considering that there were no K losses by leaching or erosion, and that all the accumulated K was released, only the intercropping of pigeon pea with *U. ruziziensis* and corn with *U. ruziziensis* provided K via straw in amounts higher than that required by the cotton plant as a maintenance fertilizer. It is important to emphasize that, in the case of cotton, about 25 % of the variable production cost is related to fertilizers (Conab 2022), especially N and K.

CONCLUSIONS

1. Corn grown in the second crop after soybean provides little dry matter for cotton direct sowing and low amounts of macronutrients in the straw;
2. *Urochloa ruziziensis* + pigeon pea, cultivated after the soybean harvest, produce a higher amount of dry matter with high contents of N, P, K, Ca and S;
3. Straw from the single cultivation of *Urochloa ruziziensis* and its intercropping with corn, *Crotalaria spectabilis*, *C. ochroleuca* or pigeon pea show a higher K content;
4. The no-tillage system provides a higher cotton yield in succession to *C. spectabilis*.

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