Francieli Fátima de Camargo 99817845168
CNPJ 22.986.804/0001-44
Rua Paulo João Ramos, 1727, Casa 1, Cep 88.334-560,
Estaleirinho, Balneário Camboriú, SC

Declaração

Eu, **CRISTIANO SANTOS,** CPF 944.030.159-72, RG 7.679.194-5, Engenheiro Agrônomo (CREA MT026195), com formação em Língua Inglesa pela Stanton School of English (Londres, Inglaterra, Reino Unido), Tradutor e Revisor Final da empresa **CANAL PAGE**, inscrita no CNPJ sob o número 22.986.804/0001-44, localizada na Rua Paulo João Ramos, 1727, Casa 1, Cep 88.334-560, Estaleirinho, Balneário Camboriú, SC, **DECLARO** para todos os fins que o artigo que segue abaixo, intitulado ***"SEEDING SYSTEM AND DENSITY FOR WINTER Urochloa ruziziensis INTERCROPPED WITH SORGHUM BETWEEN SOYBEAN CROPS"***, foi traduzido por esta empresa, para o idioma inglês (norte-americano), contemplando revisão textual, observando as normas gramaticais e ortográficas, assim como a adequação de estilo e de expressões características da área de estudo.

Por ser expressão da verdade, firmamos a presente declaração.

Balneário Camboriú, SC, 17 de julho de 2018

Cristiano Santos
Tradutor e Revisor Final

Francieli Fátima de Camargo
Proprietária/Gerente Administrativo

SEEDING SYSTEM AND DENSITY FOR WINTER *Urochloa ruziziensis* INTERCROPPED WITH SORGHUM BETWEEN SOYBEAN CROPS

Abstract

The intercrop of sorghum with *Urochloa ruziziensis* allows the production of grains and biomass in the winter. The objective of this study was to identify the more adequate seeding system and seed density for *Urochloa ruziziensis* intercropped with sorghum between soybean crops to obtain high grain and biomass yields with these species and evaluate the performance of the subsequent soybean crop. The experiments were carried out in the winter of 2015 and in the 2015-2016 crop season in Rio Verde GO, and Santa Helena de Goiás GO, Brazil. The treatments consisted of three seeding systems (in-row, inter-row, and broadcast), and five seed densities (2, 4, 6, 8, and 10 viable seeds m^{-2}) of *U. ruziziensis* intercropped with sorghum, using monocultures of sorghum and *U. ruziziensis* as controls. The seeding density of 8 viable seeds m^{-2} of *U. ruziziensis* using in-row seeding, and up to 10 viable seeds m^{-2} using inter-row, and broadcast seeding do not decrease sorghum grain yield. Increasing seeding density of *U. ruziziensis* increases its dry matter yield, and the total dry matter yield when intercropped with sorghum. The intercrop of sorghum with *U. ruziziensis* increases the soil plant coverage. The dry matter of the intercrop of sorghum with *U. ruziziensis* does not affect soybean grain yield.

Keywords: biomass, *Brachiaria* spp., dry matter, *Sorghum bicolor*

Introduction

Winter sorghum has been a promising crop for grain production between soybean crops in the Center-West region of Brazil because it has similar nutritional value to maize, lower production costs, and good adaptation to different environments (Baumhardt et al., 2005; Dan et al., 2010), including those with water deficits (Cysne & Pitombeira, 2012).

The state of Goiás in Brazil has been a major producer of sorghum in the country, with sorghum crops covering areas of high (>600 m) and low (<600 m) altitudes. However, in the last decade, sorghum grains have been increasingly produced for the agro-industries of the Southwest region of the State, denoting the need of alternatives for the maintenance of straw production for the no-tillage system. Winter grasses are important for the implementation and feasibility of the no-tillage system because they have low decomposition rate, and present longer maintenance of straws on the soil surface (Torres et al., 2008).

The intercrop of sorghum with grass species is a promising system that allows the production of grains and biomass in the winter (Mateus et al., 2011; Horvathy Neto et al., 2012; Silva et al., 2013; 2015). Moreover, this biomass can be used as forage (Horvathy Neto et al., 2014; Silva et al., 2014).

This system generates abundant root system due to the grass species, contributing to water infiltration and soil aggregation and aeration (Kluthcouski et al., 2004; Silva et al., 2007). However, the intercropping of winter grass species with sorghum must consider a grass seed density that avoids its competition with the cereal, regardless of the altitude of the area.

The objective of this study was to identify the more adequate seeding system and seed density for *Urochloa ruziziensis* intercropped with sorghum between soybean crops to obtain high grain and biomass yields with these species and evaluate the performance of the subsequent soybean crop.

Material and Methods

Field experiments were conducted in the winter of 2015, in areas with high and low altitudes, Rio Verde GO (17°47'23.9"S; 50°57'41.5"W; and 758 m of altitude) and Santa Helena de Goiás GO (17°50'41.1"S; 50°36'51.0"W; and 580 m of altitude), respectively, in Brazil. The soils of the experimental areas were classified as dystrophic Red Latossolo (Oxisol), which were cultivated with summer soybean crops in no-tillage system for 11 (Rio Verde) and 18 (Santa Helena de Goiás) years.

The chemical analysis of the soil of the experiment area in Rio Verde showed pH ($CaCl_2$) of 4.7, 1.50 $cmol_c$ dm^{-3} of Ca, 0.16 $cmol_c$ dm^{-3} of K, 1.01 $cmol_c$ dm^{-3} of Mg, 0.30 $cmol_c$ dm^{-3} of Al, 5.7 $cmol_c$ dm^{-3} of H+Al, CEC of 8.4 $cmol_c$ dm^{-3}, sum of bases of 2.7 $cmol_c$ dm^{-3}, 7.7 mg dm^{-3} of P, base saturation of 32.3%, and Al saturation of 8.5%.

The chemical analysis of the soil of the experiment area in Santa Helena de Goiás showed pH ($CaCl_2$) of 4.8, 1.60 $cmol_c$ dm^{-3} of Ca, 0.22 $cmol_c$ dm^{-3} of K, 0.50 $cmol_c$ dm^{-3} of Mg, 0.15 $cmol_c$ dm^{-3}

of Al, 3.6 $cmol_c$ dm^{-3} of H+Al, CEC of 6.0 $cmol_c$ dm^{-3}, sum of bases of 2.4 $cmol_c$ dm^{-3}, 36 mg dm^{-3} of P, base saturation of 39.1%, and Al saturation of 6.1%.

The mean air temperature and precipitation during the experiment, and the periods of implementation and harvest of the crops are shown in Figure 1.

Figure 1. Mean air temperature and precipitation from January 2015 to March 2016 in Rio Verde GO (RV) (Source: Comigo Cooperative meteorological station), and from January to November 2015 in Santa Helena de Goiás GO (SHG) (Source: Monsanto meteorological station), Brazil.

The experiment was conducted in a randomized block design with four replications, consisted of three seeding systems (in-row, inter-row, and broadcast), and five seed densities (2, 4, 6, 8, and 10 viable seeds m^{-2}) of *U. ruziziensis* intercropped with sorghum, using monocultures of sorghum and *U. ruziziensis* as control.

The sorghum cultivar used was the BRS330, a hybrid of early cycle, red grains, and without tannin. The grass species used was *Urochloa ruziziensis* because it is widely used in the Cerrado biome. The plots consisted of seven 6.0-meter rows spaced 0.5 m apart. The evaluation area consisted of the central 12.5 m², considering 0.5 m of each row end, and the end rows as borders.

Weeds were controlled after soybean harvest at seven days before the implementation of the treatments with application of 1,189 g a.e. ha^{-1} of glyphosate, and 1,500 g a.i. ha^{-1} of atrazine, with flow rate of 150 L ha^{-1}. Seedings were carried out in March 13 in Rio Verde, and March 18 in Santa Helena de Goiás, using a seven-row seeder to make the furrows in all seeding systems. The intercrop with inter-row seeding had, in addition, two-centimeters deep furrows made with hoes.

Sorghum seeds were mechanically sown, and *U. ruziziensis* seeds were manually sown at 2 cm deep in all monocrop systems, except in the broadcast seeding, in which the *U. ruziziensis* seeds were broadcasted on the soil surface, followed by the sowing of sorghum seeds, with subsequent covering of the seeds. The amount of seeds used to reach the seeding densities of each plot were calculated considering the seed quality (SQ) (purity, and germination index), seed weight (SW), total plot size (TPS), and number of viable seeds per m^{-2} (NVS), using the formula $SW \times NVS \times$

TPS × 100 / SQ. The seed weight of the *U. ruziziensis* was determined using the weight of one-thousand seeds.

Soil fertilization in the intercrop and monoculture systems followed the recommendations for the sorghum crop (Sousa & Lobato, 2004), using 300 kg ha^{-1} of the 02-20-18 N-P-K fertilizer. Topdressing was performed manually with application of 100 kg ha^{-1} of nitrogen (urea) next to the sorghum plant row at 25 days after emergence (DAE), when the sorghum crop was thinned to a population of 180,000 plants ha^{-1}.

Post-emergence weed control was carried out using two manual weeding at 20 DAE, and 35 DAE, since the sorghum crop has no selective herbicide to control grasses. Pests, especially *Spodoptera frugiperda,* were controlled with application of 50 g a.i ha^{-1} of cypermethrin, with flow rate 150 L ha^{-1}.

Sorghum was harvested in July, at 125 DAE. Panicle samples were collected, threshed, and their grains were weighted to evaluate grain yield, and 1000-grain weight, considering a grain moisture of 13%. Plant height from the stem base to the top of the panicle was measured considering five random plants of each plot; and plant population was determined considering the total number of panicles collected.

U. ruziziensis plants remained in the field up to 101 days after the sorghum harvest, when five plants were randomly chosen in the plots to determine the plant height from the stem base to the top of the last fully expanded leave, and the number of tillers.

Total dry matter yields of both crops were evaluated. The biomasses of sorghum, and *U. ruziziensis* in 1 m^2 areas randomly chosen using a square frame were collected separately, packed in paper bags and placed in a forced-air circulation oven at 65 °C to obtain their dry weights.

The percentage of soil coverage by the plants was quantified considering the biomass present on the soil surface at the sorghum harvest, and at 101 days after harvesting, using areas of 0.25 m^2 randomly chosen using a graduated square frame with ten equidistant points in two places of each plot, considering the points that coincided with the presence of plant cover.

The soybean seeds used were from the early-maturing NS7000IPRO cultivar, which has an indeterminate growth habit, and presents maturation group 7.0 for the region of the experiment. The soybean seeds were sown on November 10, 2015**,** using the same seeder used for the furrowing of the area for the intercrop, and same spacing between rows. Soil fertilization consisted of application of 300 kg ha^{-1} of the 02-20-20 N-P-K fertilizer, following the recommendations for the crop (Sousa & Lobato, 2004).

Initial plant height of soybean from the stem base to the top of the third fully developed trifoliate leaf was determined using five random plants. Soybean was harvested at 115 days after sowing (March 4, 2016). The pods of the plants were sampled and threshed and their grains were weighted to evaluate the grain yield, and 1000-grain weight, considering a grain moisture of 13%.

Individual and combined analysis of variance of the intercrop and monocrop systems were carried out. Significant means were compared by the Tukey's test at 5% probability for the intercrop system, and by regression analysis for the seeding densities of *U. ruziziensis*. The means of the intercrop treatments were compared with those of the respective monocrops (controls) by the Dunnett's test at 5% probability.

Results and Discussion

The intercrop of sorghum with *U. ruziziensis* using inter-row seeding resulted in a higher sorghum grain yield than that using in-row seeding (Table 1). This was probably due to the lower competition between species for water, light, nutrients, and physical space in the initial development stage of the sorghum plants. Moreover, *U. ruziziensis* plants had slower emergence compared to sorghum, delaying the possible competition between these species. Similar results for grain production with this seeding system have been reported using grass species intercropped with sorghum (Silva et al., 2014) and maize (Borghi & Crusciol, 2007).

In the experimental area of Rio Verde GO, only the highest seed density of *U. ruziziensis* in the intercrop using in-row seeding reduced sorghum grain yield compared to the control (Table 1).

The highest seeding densities of *U. ruziziensis* using inter-row and broadcast seedings had no effect on sorghum grain yield. A greater number of plants of grass species can result in greater biomass production in the winter.

Table 1. Grain yield, 1000-grain weight, plant height, and dry matter yield of winter sorghum intercropped with five seeding densities of *Urochloa ruziziensis* in Rio Verde GO, and Santa Helena de Goiás GO, Brazil, 2015.

Seeding systems	Density (viable seeds m^{-2})					Means*[2]
	2	4	6	8	10	
--- Grain yield (Kg ha^{-1}) ---						
Rio Verde						
In-row	5,068	5,107	4,981	4,894	4,746*[1]	4,959 b
Inter-row	5,475	5,056	5,128	5,094	5,241	5,198 a
Broadcast	5,397	5,241	5,113	5,094	5,113	5,191 a
Means	5,313	5,134	5,074	5,027	5,033	
Monocrop (control)						5,404
Santa Helena de Goiás						
In-row	6,220	5,913	5,956	6,164	6,111	6,072 b
Inter-row	6,570	6,511	6,799	6,492	6,520	6,578 a
Broadcast	6,356	5,892	6,294	6,313	6,568	6,284 ab
Means	6,382	6,105	6,349	6,323	6,399	
Monocrop (control)						6,610
--- 1000-grain weight (g) ---						
Rio Verde						
In-row	18.0	17.7	18.1	18.2	16.9	17.8
Inter-row	18.1	16.7	17.8	16.8	17.4	17.3
Broadcast	17.9	17.4	17.8	17.7	17.6	17.7
Means	18.0	17.3	17.9	17.6	17.3	
Monocrop (control)						17.3
Santa Helena de Goiás						
In-row	18.1	17.3	17.5	16.8	17.8	17.5
Inter-row	18.1	18.2	17.5	16.9	18.0	17.8
Broadcast	17.6	17.4	16.7	18.2	18.0	17.6
Means	18.0	17.6	17.2	17.3	17.9	
Monocrop (control)						17,4
--- Plant height (m) ---						
Rio Verde						
In-row	1.41	1.42	1.41 b	1.40*	1.39 b*	1,41 b
Inter-row	1.45	1.43	1.42 ab	1.41	1.47 a	1,44 a
Broadcast	1.41	1.46	1.47 a	1.41	1.41 b	1,43 a
Means	1.43	1.44	1.43	1.41	1.42	
Monocrop (control)						1,48
Santa Helena de Goiás						
In-row	1.49	1.50	1.47	1.45	1.46	1.47 b
Inter-row	1.49	1.49	1.44	1.49	1.47	1.48 ab
Broadcast	1.49	1.50	1.52	1.50	1.49	1.51 a
Means	1.49	1.50	1.48	1.48	1.47	
Monocrop (control)						1.50
--- Dry matter yield (Kg ha^{-1}) ---						
Rio Verde						
In-row	2,070	1,995	2,047	1,880*	1,862*	1,970 a
Inter-row	1,907	1,982	1,965	1,900	1,787*	1,908 a
Broadcast	1,985	1,975	1,902	1,832*	1,870*	1,912 a
Means	1,987	1,984	1,971	1,870	1,839	
Monocrop (control)						2,220
Santa Helena de Goiás						
In-row	2,088	2,049	2,000	2,374	2,375	2,177 a

Inter-row	2,131	1,894	1,980	2,151	2,426	2,116 a
Broadcast	1,981	2,260	2,077	2,340	2,277	2,187 a
Means	2,067	2,068	2,019	2,288	2,359	
Monocrop (control)						2,270

*[1] Means differ significantly by the Dunnett's test at 5% probability from the control treatments.
*[2] Means followed by the same letters in the column do not differ by the Tukey's test at 5% probability.

The other treatments presented similar sorghum grain yields to the control (Table 1). This confirms the feasibility of the winter sorghum intercropped with *U. ruziziensis* in the Cerrado biome, even using a high seeding density for the grass species. Similar result was found in other studies using lower seeding density for the grass species (Mateus et al., 2011; Horvathy Neto et al., 2012; Silva et al., 2013; 2015).

The competition between the species used affected the plant height when using in-row seeding; the densities of 8 and 10 viable seeds m^{-2} resulted in lower plant height of sorghum when compared to the control (Table 1). In general, the broadcast seeding of *U. ruziziensis* resulted in higher heights of sorghum plants, regardless of the experimental area, because of the more regular distribution of plants throughout the areas and, consequently, lower competition pressure.

U. ruziziensis were expected to suppress sorghum plants at the vegetative stage of both crops, affecting the population of sorghum plants. However, this was not observed because the intercrop was conducted in the winter season and the grass species presented a slower emergence than the sorghum. This made the sorghum to emerge and develop faster, establishing a plant population of 194,000 plants ha^{-1} in both experimental areas, with similar results to those found in the monocrops in both experimental areas (Rio Verde, and Santa Helena de Goiás).

Moreover, the plant competition generated a lower dry matter yield of sorghum crops in Rio Verde, compared to the control (Table 1), when using the highest seeding densities of *U. ruziziensis*—with in-row, and broadcast seeding when using 8 viable seeds m^{-2}, and with all sowing systems when using 10 viable seeds m^{-2}. The Santa Helena de Goiás area presented no significant differences in dry matter yield of sorghum due to its higher soil fertility (higher P content) and the better rainfall distribution during the sorghum development in that area when compared to Rio

Verde (Figure 1), which favored the development and accumulation of shoot biomass of the intercropped plants, which presented similar results to the monocrops.

The inter-row seeding in Rio Verde increased the height of the *U. ruziziensis* plants compared to the broadcast seeding (Table 2), improving the *U. ruziziensis* development, especially at the early stages due to the lower competition between species and greater solar radiation interception (Taiz et al., 2017). The broadcast seeding resulted in suppression of the *U. ruziziensis* growth, except when using the density of 4 seeds m^{-2}, and in all seeding systems with the highest density, presenting lower plant height than the controls.

The sorghum plants reduced the *U. ruziziensis* growth, as observed in other studies on intercrops of these plant species (Horvathy Neto, 2012; Silva et al., 2013; 2015). Thus, the number of tillers, and dry matter yield of the grass species were lower in all treatments of both experimental areas when compared to the controls. The sowing season (winter) and the slower establishment of the *U. ruziziensis* plants compared to the sorghum made the sorghum plants to suppress the growth of the grass species, regardless of the sowing system, even with the higher rainfall volume in the region, compared to previous years.

Table 2. Plant height, number of tillers, and dry matter yield of winter *U. ruziziensis* intercropped with sorghum, with five seeding densities of the grass species, in Rio Verde GO, and Santa Helena de Goiás GO, Brazil, 2015.

Seeding systems	Density (viable seeds m^{-2})					Means*[2]
	2	4	6	8	10	
--- Plant height (m) ---						
Rio Verde						
In-row	0.54*[1]	0.68	0.65	0.62	0.60*	0.62 ab
Inter-row	0.67	0.66	0.72	0.63	0.65*	0.67 a
Broadcast	0.59*	0.58	0.53*	0.59*	0.66*	0.59 b
Means	0.60	0.64	0.63	0.61	0.63	
Monocrop (control)	0.80	0.76	0.80	0.80	0.85	
Santa Helena de Goiás						
In-row	0.60*	0.75	0.65	0.68	0.67	0.67 a
Inter-row	0.71	0.68	0.69	0.63	0.68	0.68 a
Broadcast	0.63*	0.58	0.59	0.61	0.72	0.63 a
Means	0.65	0.67	0.64	0.64	0.69	
Monocrop (control)	0.83	0.75	0.72	0.72	0.79	
--- Number of tillers ---						
Rio Verde						
In-row	20.4*	20.6*	24.8*	28.5*	22.1*	23.3 a
Inter-row	30.9*	31.9*	26.8*	21.9*	43.5*	31.0 a
Broadcast	27.4*	21.7*	22.6*	29.8*	36.8*	27.7 a

Means	26.2	24.7	24.7	26.7	34.1	
Monocrop (control)	119.7	118.6	116.9	136.8	134.9	
			Santa Helena de Goiás			
In-row	21.1*	22.5*	22.4*	30.1*	24.7*	24.2 a
Inter-row	33.2*	33.3*	27.8*	27.3*	39.2*	32.2 a
Broadcast	29.1*	22.6*	25.1*	31.2*	40.4*	29.7 a
Means	27.8	26.1	25.1	29.5	34.7	
Monocrop (control)	115.2	122.4	132.6	132.2	133.1	
			--- Dry matter yield (Kg ha^{-1}) ---			
			Rio Verde			
In-row	970*	774*	1,300*	1,508*	1,744*	1,259 a
Inter-row	1,040*	1,313*	1,415*	1,822*	1,590*	1,436 a
Broadcast	856*	1,102*	904*	1,173*	1,590*	1,125 a
Means	955	1,063	1,206	1,501	1,641	
Monocrop (control)	4,326	4,823	5,810	6,790	8,505	
			Santa Helena de Goiás			
In-row	973*	1,365*	1,749*	2,068*	2,289*	1,688 a
Inter-row	1,154*	1,371*	1,665*	2,324*	2,444*	1,791 a
Broadcast	834*	1,108*	1,256*	1,506*	2,068*	1,354 b
Means	987	1,281	1,556	1,966	2,267	
Monocrop (control)	5,924	6,926	7,399	7,595	9,476	

*[1] Means differ significantly by the Dunnett's test at 5% probability from the control treatments.
*[2] Means followed by the same letters in the column do not differ by the Tukey's test at 5% probability.

The dry matter yield of *U. ruziziensis* increased linearly in the intercrop (Figure 2A) and monocrop (Figure 2B) systems in both experimental areas with increasing seeding density, as observed by Ceccon et al. (2009) in intercrops of maize with grass species**.** The absence of sorghum plants in the monocrops of *U. ruziziensis* resulted in a higher dry matter yield of this grass species.

Figure 2. Regression analysis of dry matter yields of winter *Urochloa ruziziensis* intercropped with sorghum (DMYI) (A) and as monocrop (DMYM) (B) with five seeding densities at 101 days after the sorghum harvest in Rio Verde GO, and Santa Helena de Goiás GO, Brazil, 2015.

Pariz et al. (2011) evaluated an intercrop of maize with *U. ruziziensis* and found lower competition between the species when using broadcast seeding for the grass species, compared to the in-row seeding, resulting in a higher dry matter yield for the grass species. The dry matter yields of *U. ruziziensis* using in-row and inter-row seeding were lower than that using broadcast seeding in Santa Helena de Goiás. Similar result was found by Chioderoli et al. (2010). Most *U. ruziziensis* seeds were not incorporated into the soil when using broadcast seeding; it may have hindered the establishment of the plants. This affected negatively the dry matter yield of this species, since seeding density is related to shoot biomass accumulation, regardless of the seeding system used.

The production of biomass in the intercrop areas differed from that of control areas. The total dry matter yields of the intercrops were lower than those of the respective *U. ruziziensis* monocrops and higher than that of the sorghum monocrops, in both experimental areas (Table 3). The greater rainfall volume in the first months of the experiment, especially in Santa Helena de Goiás, resulted in a greater development of the monoculture of *U. ruziziensis*; it was even greater with the increases in seeding density. This explains the better performance of *U. ruziziensis* in all treatments when compared to the sorghum monocrop.

The highest total dry matter yields were found when using the density of 10 viable seeds m^{-2} of *U. ruziziensis* in monocrop (Table 3) and intercrop with sorghum in Santa Helena de Goiás (Figure 3A), resulting in greater soil plant coverage (Figure 3B). Therefore, increasing winter *U. ruziziensis* seeding density in intercrop with sorghum increases the dry matter yields, in the Cerrado biome, region that presents less precipitation during winter. These increases increase the biomass production and soil plant coverage, which may favor the maintenance of the no-tillage system (Silva et al., 2013; 2015; Borges, et al., 2016).

Table 3. Total dry matter yield, and soil plant coverage at sorghum harvest, and soil plant coverage at soybean seeding (SCSS), using intercrops of winter sorghum with five seeding densities of *Urochloa ruziziensis*, in Rio Verde GO, and Santa Helena de Goiás GO, Brazil, 2015.

Seeding system	Density (viable seeds m^{-2}) 2	4	6	8	10	Means*[3]
			--- Total dry matter yield (kg ha^{-1}) ---			
			Rio Verde			
In-row	3.040*[1, 2]	2.769*[1, 2]	3.347*[1, 2]	3.388*[1, 2]	3.606*[1, 2]	3.230 a
Inter-row	2.947*[1, 2]	3.295*[1, 2]	3.380*[1, 2]	3.722*[1, 2]	3.337*[1, 2]	3.344 a
Broadcast	2.841*[1, 2]	3.077*[1, 2]	2.806*[1, 2]	3.005*[1, 2]	3.460*[1, 2]	3.038 a
Means	2.943	3.047	3.178	3.372	3.481	
			U. ruziziensis			Sorghum
Monocrop (control)	4.326 E	4.823 D	5.810 C	6.790 B	8.505 A	2.220 F
			Santa Helena de Goiás			
In-row	3.061*[2]	3.414*[2]	3.749*[1, 2]	4.442*[1, 2]	4.664*[1, 2]	3.866 a
Inter-row	3.285*[2]	3.265*[2]	3.645*[1, 2]	4.475*[1, 2]	4.870*[1, 2]	3.908 a
Broadcast	2.815*[2]	3.368*[2]	3.333*[2]	3.846*[1, 2]	4.345*[1, 2]	3.541 a
Means	3.053	3.349	3.575	4.254	4.626	
			U. ruziziensis			Sorghum
Monocrop (control)	5.924 C	6.926 BC	7.399 B	7.595 B	9.476 A	2.265 D
			--- Soil plant coverage at sorghum harvest (%) ---			
			Rio Verde			
In-row	72	76	76*[2]	80*[2]	80*[2]	76 a
Inter-row	73	76	78*[2]	80*[2]	87	79 a
Broadcast	77	75	80	81	88*[1]	80 a

Means	74	75	78	80	85	
			U. ruziziensis			Sorghum
Monocrop (control)	81 D	93 C	98 B	100 A	100 A	63 E
		Santa Helena de Goiás				
In-row	76	77*[2]	81	76*[2]	80*[2]	78 a
Inter-row	80	73*[2]	83	67*[2]	88	78 a
Broadcast	80	78	75*[2]	72*[2]	73*[2]	75 a
Means	78	76	79	71	80	
			U. ruziziensis			Sorghum
Monocrop (control)	83 AB	97 A	98 A	100 A	100 A	72 B
		--- Soil plant coverage at soybean seeding (%) ---				
		Rio Verde				
In-row	78	80*[2]	77*[2]	82*[2]	88	81 a
Inter-row	75*[2]	81*[2]	85*[2]	86	90*[1]	83 a
Broadcast	80	83*[2]	83*[2]	82*[2]	83	82 a
Means	77	81	81	83	87	
			U. ruziziensis			Sorghum
Monocrop (control)	95 B	100 A	100 A	100 A	100 A	72 C
		Santa Helena de Goiás				
In-row	80*[2]	86	88*[1]	90*[1]	96*[1]	88 a
Inter-row	82	81*[2]	95*[1]	91*[1]	92*[1]	88 a
Broadcast	81	88*[1]	87*[1]	85	92*[1]	86 a
Means	81	85	90	88	93	
			U. ruziziensis			Sorghum
Monocrop (control)	96 A	100 A	100 A	100 A	100 A	71 B

*[1,2] Means differ significantly by the Dunnett's test at 5% probability from the control treatments of *U. ruziziensis* and sorghum, respectively.
*[3] Means followed by the same lowercase letters in the column and uppercase letters in the row do not differ by the Tukey's test at 5% probability.

Figure 3. Regression analysis of total dry matter yield of intercrops (TDMI) (A) and soil plant coverage at soybean seeding (SCSS) (B), using winter sorghum intercropped with five seeding densities of *Urochloa ruziziensis*, in Santa Helena de Goiás GO, Brazil, 2015.

The occurrence of precipitation during the cycle of the crops, and lower precipitation after sorghum harvest increased the biomass production. Thus, the soil plant coverage of most areas with intercrop was greater than those with sorghum monocrop (Table 3) at soybean seeding. However, soil plant coverage with monocrop of sorghum at harvest, and at soybean seeding were lower in both experimental areas, compared to the *U. ruziziensis* monocrop. Therefore, sorghum monocrops do not produce enough biomass for soil plant coverage as the intercrops, even with favorable soil moisture and temperature for their regrowth after harvest. This confirms the importance the grass species in increasing the biomass in winter intercrops. However, the soil plant coverage by the sorghum monocrop in Rio Verde was higher at soybean seeding than at sorghum harvest due to the regrowth of the sorghum plants. The broadcast seeding of *U. ruziziensis* at density of 10 viable seeds m^{-2} in the Rio Verde experimental area was the only treatment that resulted in higher soil plant coverage at soybean seeding than those of sorghum monocrops.

Therefore, increasing seeding density of winter *U. ruziziensis* in intercrop systems can increase the production of biomass of plants. However, the choice for these systems must consider whether grass seeding densities above the rates evaluated in the present work increase dry matter yields without decreasing sorghum grain yield.

The results found in the present work showed that the intercrop of winter sorghum with *U. ruziziensis* is promising for increasing grain yield and dry matter yield in regions of high (Rio Verde) and low (Santa Helena de Goiás) altitudes when using the seeding density of 10 viable seeds m^{-2} for the grass species, regardless of the seeding system used. The increase in biomass production in the winter by using this intercrop is important because this period presents significant decreased precipitation in the Cerrado biome. The use of this grass as forage is another advantage of this system.

Increasing seeding density in the monocrop of *U. ruziziensis* increased its biomass production, and the plant height of the soybean plants at initial stage; however, this did not occur with sorghum monocrops (Table 4). The plant height is dependent on the stem elongation towards light (Benicasa, 2004). This explains the higher biomass production of treatments with higher seeding density, and with inter-row seeding of the grass species in the intercrop with sorghum, when compared to the controls.

Table 4. Plant height at initial stage, grain yield, and 1000-grain weight of soybean plants grown after the intercrop of winter sorghum with five seeding densities of *Urochloa ruziziensis*, in Rio Verde GO, Brazil, 2015-2016.

Seeding systems	Density (viable seeds ha^{-1})					Means*[3]
	2	4	6	8	10	
	--- Plant height at initial growth stage (cm) ---					
In-row	26	26	26	27	28	27 a
Inter-row	25	26	26	27	27*[1]	26 a
Broadcast	28	26	27	27	28	27 a
Means	26	26	27	27	28	
	U. ruziziensis					Sorghum
Monocrop (control)	28 AB	30 AB	31 AB	31 AB	34 B	24 A
	--- Grain yield (kg ha^{-1}) ---					

In-row	2,258	2,181*[1]	2,432	2,520	2,480	2,422 a
Inter-row	2,369	2,495	2,575	2,373	2,275	2,417 a
Broadcast	2,230	2,295	2,463	2,285	2,375	2,330 a
Means	2,286	2,395	2,490	2,393	2,377	
			U. ruziziensis			Sorghum
Monocrop (control)	2,532 A	2,587 A	2,423 A	2,408 A	2,476 A	2,460 A
			--- 1000-grain weight (g) ---			
In-row	172	167	168	175	172	171 a
Inter-row	169	170	172	169	175	171 a
Broadcast	165*[1]	167	170	165	169	168 a
Means	170	168	170	170	172	
			U. ruziziensis			Sorghum
Monocrop (control)	181 A	177 A	174 A	171 A	171 A	172 A

*[1,2] Means differ significantly by the Dunnett's test at 5% probability from the control treatments of *U. ruziziensis* and sorghum, respectively.
*[3] Means followed by the same lowercase letters in the column and uppercase letters in the row do not differ by the Tukey's test at 5% probability.

The intercrops with seeding densities of 4 viable seeds m^{-2} of the grass species using in-row seeding decreased the grain yield of soybean plants; and the intercrop with seeding densities of 2 viable seeds m^{-2} using broadcast seeding decreased the 1000-grain weight of soybean plants when compared to the controls (Table 4). The higher dry matter yield of the monocrop probably improved the soybean grain yield but did not affect the 1000-grain weight.

The similar dry matter contents produced in the intercrop and monocrop systems denote their suitability for the maintenance of no-tillage systems. Great biomass productions also allow better control of weeds, soil moisture maintenance, and soil erosion protection. Thus, increasing seeding density of *U. ruziziensis* for intercrop with sorghum is a sustainable practice for agricultural systems in the Cerrado biome.

Conclusions

The intercrop of sorghum with *U. ruziziensis* does not decrease sorghum grain yield when using seeding densities of up to 8 viable seeds m^{-2} for the grass species for in-row seeding, and up to 10 viable seeds m^{-2} for broadcast seeding, regardless of the altitude of the area.

Increasing the seeding density of *U. ruziziensis* for the intercropping with sorghum increases the dry matter yield of the grass species, and total dry matter yield (sorghum and *U. ruziziensis*).

The intercrop of sorghum with *U. ruziziensis* increases the soil plant coverage for the implementation of soybean crops in no-tillage system.

The dry matter of the intercrop of sorghum with *U. ruziziensis* does not affect soybean grain yield.

References

Baumhardt, R.L., Tolk, J.A., Winter, S.R. 2005. Seeding practices and cultivar maturity effects on simulated dryland grain sorghum yield. *Agronomy Journal* 97: 935-942.

Benicasa, M.M.P. 2004. *Análise de Crescimento de Plantas (noções básicas).* FUNEP, Jaboticabal, Brasil. 42p.

Borges, L.P., Silva, A.G., Goulart, M.M.P., Teixeira, R.I., Simon, G.A., Costa, K.A.P. 2016. Seeding density of *Brachiaria ruziziensis* intercropped with grain sorghum and effects on soybean in succession. African Journal of Agricultural Research 11:4343-4353.

Borghi, E., Crusciol, C.A.C. 2007. Produtividade de milho, espaçamento e modalidade de consorciação com *Brachiaria brizantha* em sistema plantio direto. *Pesquisa Agropecuária Brasileira* 42:163-171.

Ceccon, G., Staut, L.A., Kurihara, C.H. 2009. Cerrado: Manejo de *Brachiaria ruziziensis* em consórcio com milho safrinha e rendimento de soja em sucessão. *Revista Plantio Direto* 113: 4-8.

Chioderoli, C.A., Mello, L.M.M., Grigolli, P.J., Silva, J.O.R., Cesarin, A.L. 2010. Consorciação de braquiárias com milho outonal em plantio direto sob pivô central. *Engenharia Agrícola* 30:1101-1109.

Cysne, J.R.B., Pitombeira, J.B. 2012. Adaptabilidade e estabilidade de genótipos de sorgo granífero em diferentes ambientes do estado do Ceará. *Revista Ciência Agronômica* 43: 273-278.

Dan, H.A., Carrijo, M.S., Carneiro, D.F., Costa, K.A.P., Silva, A.G. 2010. Desempenho de plantas sorgo granífero sobre condições de sombreamento. *Acta Scientiarum-Agronomy* 32: 675-679.

Horvathy Neto, A., Silva, A.G., Teixeira, I.R., Simon, G. A., Assis, R.L., Rocha, V.S. 2012. Consórcio sorgo e braquiária para produção de grãos e biomassa na entressafra. *Revista Brasileira de Ciências Agrárias* 7: 743-749.

Horvathy Neto, A., Silva, A.G., Teixeira, I.R., Costa, K. A. P., Assis, R.L. 2014. Consórcio de sorgo granífero e braquiária na safrinha para produção de grãos e forragem. *Revista Caatinga* 27: 132-141.

Kluthcouski, J., Aidar, H., Stone, L.F., Cobucci, T. 2004. Integração lavoura-pecuária e o manejo de plantas daninhas. *Informações Agronômicas* 106: 1-20.

Mateus, G.P., Crusciol, C.A.C., Borghi, É., Pariz, C.M., Costa, C., Silveira, J.P.F. 2011. Adubação nitrogenada de sorgo granífero consorciado com capim em sistema de plantio direto. *Pesquisa Agropecuária Brasileira* 46: 1161-1169.

Pariz, C.M., Andreotti, M., Azenha, M.V., Bergamaschine, A.F., Mello, L.M.M., Lima, R.C. 2011. Produtividade de grãos de milho e massa seca de braquiárias em consórcio no sistema de integração lavoura-pecuária. *Ciência Rural* 41: 875-882.

Silva, M.B., Kliemann, H.J., Silveira, P.M., Lanna, A.C. 2007. Atributos biológicos do solo sob influência da cobertura vegetal e do sistema de manejo. *Pesquisa Agropecuária Brasileira* 42: 1755-1761.

Silva, A.G., Moraes, L.E., Horvathy Neto, A., Teixeira, I.R., Simon, G.A. 2013. Consórcio na entrelinha de sorgo com braquiária na safrinha para produção de grãos e forragem. *Semina-Ciências Agrárias* 34:3475-3488.

Silva, A.G., Moraes, L.E., Horvathy Neto, A., Teixeira, I.R., Simon, G.A. 2014. Consórcio sorgo e braquiária na entrelinha para produção de grãos, forragem e palhada na entressafra. *Revista Ceres* 61: 697-705.

Silva, A.G., Horvathy Neto, A., Teixeira, I.R., Costa, K.A.P., Braccini, A.L. 2015. Seleção de cultivares de sorgo e braquiária em consórcio para produção de grãos e palhada. *Semina-Ciências Agrárias* 36: 2951-2964.

Sousa, D.M. G., Lobato, E. 2004. *Cerrado: correção do solo e adubação*. EMBRAPA Informação Tecnológica, Brasília, Brasil. 416p.

Tais, l., Zeiger, E., Moller, I.M., Murphy, A. 2017. Fisiologia e desenvolvimento vegetal. Porto Alegre: Artmed. 858 p.

Torres, J.L.R., Pereira, M.G., Fabian, A.J. 2008. Produção de fitomassa por plantas de cobertura e mineralização de seus resíduos em plantio direto. *Pesquisa Agropecuária Brasileira* 43: 421-428.