Australian Journal of Crop Science

AJCS

AJCS 16(08):997-1009 (2022) ISSN:1835-2707
doi: 10.21475/ajcs.22.16.08.p2078

Intercropping of sorghum with congo grass (*Brachiaria ruziziensis*) on soybean succession at the rainy season

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Abstract

Sorghum intercropping with *Brachiaria* has the potential to improve grain yield and dry matter in the Cerrado region, but there are no studies on the ideal density of *Brachiaria* seeds for adoption in intercropping when the system is deployed at the beginning of the rainy season. Thus, the objective of this study was to determine the intercropping of sorghum with *Brachiaria ruziziensis* that may provide higher yield of grain sorghum and dry mass of both crops. We also evaluated the performance of soybeans in succession after intercropping. The test was conducted in 2013/14 and 2014/15 in tropical climate region with wet and dry seasons. The experimental design followed a randomized complete block in a factor 3 x 5 + 1 + 5, corresponding to three intercropping *Brachiaria ruziziensis* seeding systems (row, inter-row and broadcast sowing) associated with five densities of *Brachiaria* (2, 4, 6, 8 and 10 pure viable seeds m^{-2}) plus the additional treatments related to monocultures of the grain sorghum and the five densities of the *Brachiaria*. The *Brachiaria ruziziensis* association with sorghum cultivation proved to be a promising technique for improving grain yield and dry matter at different times of the year without affecting the development and yield of the soybean crop culture. The best results were achieved with planting of *Brachiaria ruziziensis* in the line at the sowing density of 8 viable pure m^{-2} seeds and the inter-row sowing density of 6 viable pure m^{-2} seeds.

Keywords: crop succession; dry matter; *Glycine max*; *Sorghum bicolor*; yield.

Introduction

The search for sustainability in Brazilian agricultural systems has led to diversification and integration of activities on rural property (Bonaudo et al., 2014; Lemaire et al., 2014; Paula et al., 2017). In this context, intercropping of annual crops with tropical forage grasses, being used in crop-livestock integration systems has been increasingly adopted by farmers in the Cerrado region (Loss et al., 2012; Oliveira et al., 2015; Paula et al., 2017).

The system in question allows the cultivation of crops for grain and straw production, aiming to cover the soil or the formation of grazing pastures (Moraes et al., 2014). Furthermore, biomass production provides reciprocal benefits for crops and livestock farming, reducing problems with soil's physical, chemical and biological degradation (Bell et al., 2014). This allows the consolidation of no-tillage systems for agricultural cropping in the Cerrado region, with positive effects on crops grown in succession, such as soybeans.

However, one of the difficulties being faced during the maintenance of no-tillage systems in the Brazilian Midwest is the limitation of straw production (Borghi and Crusciol, 2007). In this region, the climate is characterized by high temperatures during the year and a prolonged dry season in winter, which makes it difficult to plant cover crops and especially the permanence of straw on the soil surface (Loss et al., 2012). In this situation, succession cultivation of summer crops such as millet, sorghum and forage grasses such as *Brachiaria* is essential to increase the biomass input for soil coverage (Loss et al., 2012; Silva et al., 2014a, Simão et al., 2015).

The straw produced from grass species has a high C / N ratio, which causes a lower rate of decomposition (Lal, 2004). The straw also makes it possible to dissipate the energy from rainfall impact on the soil surface, which provides less surface erosion, reduces evaporation of soil water, promotes the cycling of nutrients, and helps with weed control (Entz et al., 2002; Franzluebbers, 2007). The advantage of using *Brachiaria* in no-tillage systems is that these species present an abundant root system, contributing to the soil water infiltration and soil aggregation and aeration (Kluthcouski et al., 2004).

Furthermore, forage grasses have good adaptability, tolerance and resistance to biotic factors and high production of dry matter, having a good nutritional value to meet the demands of animal husbandry, especially during the dry season (Entz et al., 2002). Therefore, forage grasses stand out as an alternative for adoption in intercropping systems with annual crops in the Cerrado region.

Sorghum has been used as an alternative crop in intercropping systems (Horvathy Neto et al., 2012; Silva et al., 2014a; Ribeiro et al., 2015). The use of sorghum as a intercropping with forage crops, especially *Brachiaria,* is mainly justified by the potential for grain yield and dry matter (Borghi et al., 2013). Furthermore, the *Brachiaria* in question have been found to accumulate large amounts of biomass, even under adverse edaphic climatic conditions (Silva et al., 2015). Studies of grain and straw production systems are based on the use of *B. brizantha, B. decumbens* and *B. ruziziensis* (Horvathy Neto et al., 2012; Maia et al., 2014; Silva et al., 2015). *Brachiaria ruziziensis* is a species that exhibits easy desiccation compared to other forage species and is suitable for the mass production of ground coverings (Franchini et al., 2014).

The limitation of dry mass production in the intercropping of sorghum and *Brachiaria* under Cerrado conditions (tropical climate region) has been far from ideal for no-tillage systems. Therefore, there is a need to look for options to increase dry mass production in the intercropping season, without affecting the yield of sorghum grains.

Thus, the objectives of this study were to evaluate the intercropping of grain sorghum with *Brachiaria ruziziensis* to provide a higher yield of grain sorghum and dry weight of both crops to forage different seeding densities located on the row, inter-row and broadcast sowing, and to evaluate the performance of the culture of the soybean cultivated in succession to intercropping systems.

Results and discussion

Sorghum culture crop

The analysed sources of variation significantly influenced the characteristics of sorghum (Supplementary Table 1). The sorghum yield ranged from 6,235 kg ha^{-1} (consortium in row in the density of 8 viable pure seeds m^{-2}) at 9,913 kg ha^{-1} (broadcast in seeding density of 2 pure viable seeds m^{-2}) (Table 2). In the monoculture, sorghum BRS 330 achieved 7,902 kg ha^{-1} of grain yield. The lack of significance in the results with the consortium of sorghum monoculture demonstrates the advantage of adopting the system in tropical climate region.

It should be noted that in the consortium no graminicide (herbicide) was used to suppress the growth of *Brachiaria* plants. This is because the sorghum crop is not tolerant to these herbicides, commonly used at post-emergence in maize (Archangelo et al., 2002). Furthermore, *B. ruziziensis* shows slow initial growth and prostate (Valle and Pagliarini, 2009), allowing sorghum plants to develop without interference at the initial stage of development.

The yield results demonstrate the feasibility of the consortium with *B. ruziziensis* for grain production, regardless of the *Brachiaria* deployment system. A similar fact was observed by Silva et al. (2015), by which the combination of BRS 310 with the same forage species did not cause a reduction in grain yield in relation to sorghum monoculture. However, the authors could verify significant reductions in the sorghum grain yield, when intercropped with other *Brachiaria* species.

It is noteworthy that only the combination in the row caused a lower yield of sorghum grains in relation to broadcast sowing at the lowest density, with no differences in other densities (Table 2). This fact is attributed to greater competition from plant pasture with the sorghum for water, light, nutrients and physical space, as the *Brachiaria* was sown in the same row of sorghum, increasing the intensity of competition between species (Horvathy Neto et al., 2012; Silva et al., 2015; Ribeiro et al., 2015).

The sowing density of the *Brachiaria* influenced the grain yield of sorghum as a function of the intercropping system. The highest value at broadcast sowing was obtained with 3.40 viable pure seeds m^{-2}. Quadratic adjustment was also observed in the overall average of the densities used, where the peak was found approximately 3.75 seeds m^{-2} (Fig 2A). In general, the increase in the *Brachiaria* seed density in combination resulted in a reduction in sorghum grain yield, with a difference of 20% between the lowest and the highest sowing density.

The highest yield of grains at the lowest density in the broadcast sowing system may be correlated with the highest 1000-grain weight under these conditions (Fig 2B). In the inter-row, the lowest 1000-grain sorghum weight was observed in the densities of 4 and 8 seeds m^{-2} in relation to the combination in the row (Table 2). Greater competition among the species in the combination in the row is expected. However, the greater development of *Brachiaria* in the broadcast sowing intercropping system occurred in the summer, due to the presence of humidity, high temperatures (Fig 1) and the incidence of light in the initial phase of development. These conditions allowed greater development of the plants, and consequently greater competition with sorghum.

The height and population of sorghum plants were not influenced by the treatments (Table 2). Furthermore, there was no difference between treatment combinations to a monoculture of sorghum, leading to the belief that this system did not interfere with the *B. ruziziensis* variables in question.

In the first cut, sorghum dry matter yield varied among sowing systems (Table 3). In the inter-row, the highest values were obtained at densities of 2, 6 and 10 m^{-2} seeds, unlike the broadcast system. In the system of *Brachiaria* densities of 2 and 6 seeds m^{-2}, the dry mass yield of sorghum was significantly reduced compared to a monoculture. The combination in the inter-row may have promoted less competition in the early stages of development of the plants, allowing sorghum plants to accumulate more dry mass in the shoot.

In the second cut, no effects from sowing systems were verified for sorghum dry matter yield only at the lowest sowing density (Table 3). The intercropping in the inter-row continued was observed to provide higher sorghum dry mass yield in relation to the others, as observed for the first cut. Due to the presence of *Brachiaria* in the consortium, the dry mass values of all treatments were inferior to the sorghum monoculture. A linear reduction in the accumulation of dry mass of sorghum was observed from the increase in the sowing density of *Brachiaria* (Fig 3A), intensifying the competition in the regrowth of the plants of both species.

In the third cut, the observed densities of 2 and 4 viable pure seeds m^{-2} did not provide significant differences between sowing systems. The sorghum dry mass production was inferior to the sorghum monoculture due to the suppression of the *Brachiaria* plants in the regrowth in most of the treatments of the consortium (Table 3). We observed a reduction in sorghum dry mass values with increased seeding density of the *Brachiaria*, only in the inter-row consortium (Fig 3B).

A comparison of sorghum dry matter yield of the three cuts, both in the intercropping system and in the monoculture, indicated higher values in the first cut. This is due to the

accumulation of dry mass in the aerial part of the plants during the 104 days of development of sorghum associated with conditions of higher temperature and precipitation, which favoured the growth of the *Brachiaria* plants, in relation to the conditions of regrowth in the second and third cuts (Fig 1). Water deficiency in the off-season, characteristic of the Cerrado region, limited the achievement of higher yields of dry mass in the last cut.
Therefore, the dry mass yield of the sorghum was affected in the intercropping system, decreasing significantly with the increase of seeding density of the *Brachiaria*. After grain harvest, the regrowth of sorghum plants tended to be more sensitive to competition with the *Brachiaria* plants, due to the forage already established in the area. This resulted in a decrease in the dry mass yield of the cereal.

Brachiaria crop
The analysed sources of variation significantly influenced the characteristics of *Brachiaria* (Supplementary Table 2). The plant height was influenced only by the intercropping system (Table 5). A significant difference was only observed at a density of 8 seeds m^{-2} in the broadcast system and was lower when compared with monoculture *Brachiaria*. The increase in sowing density of the inter-row and average cropping systems exhibited a quadratic behaviour in the plant population, whereas they presented a linear increase in the broadcast system and in the row system (Fig 4A). A greater establishment of plants was observed when the intercropping system was used with the inter-row method, whereas the smallest population was observed in the broadcast system.
At the first and second cuts, the dry matter yields of *Brachiaria* were inferior to the respective monocultures in most of the treatments of the consortium (Table 5). This may have occurred due to the interception of solar radiation by the canopy of sorghum plants reducing the incidence of direct radiation on the basal part of the *Brachiaria* plants. Consequently, there was suppression of the induction of tiller emergence from axillary forage buds (Larcher, 2003). The reduction in tillering caused a decrease in dry mass yield, a fact that also observed by Silva et al. (2014a) in sorghum intercropping with forage species *B. brizantha* cv. Xaraés and cv. Marandu and *B. ruziziensis* in cerrado conditions.
It is important to note that in the broadcast system, there was a linear increase in the yield of dry matter of *Brachiaria* of the first cut, with an increase in seeding density (Fig 4B). This was already expected because the system in question demands a greater quantity of seeds due to the smaller establishment of seedlings in relation to the other systems, because it does not cover the seeds.
In the second cut, it important to observe that the yields of dry mass in the monoculture were smaller in relation to the first cut, since the second cut was higher than the values obtained in the intercropped systems (Table 5). The viability of obtaining dry matter from *Brachiaria* to establish the regrowth of the plants was also found by Silva et al. (2014a) with *B. brizantha* and *B. ruziziensis*. Furthermore, in the second cut, a reduction and a linear increase in the dry mass yield can be observed with the increase of the seeding density for the consortia in the row and in the broadcast system, respectively (Fig 4C). In the inter-row, the quadratic adjustment allowed for observation of a higher yield, with 7.0 viable pure seeds m^{-2}. It is interesting to note that the production of dry mass of the forage in the off season (cut of May 18) is fundamental for the production of vegetation cover on the soil surface, aimed at the maintenance of no-tillage systems under Cerrado conditions (Saraiva et al., 2013, Silva et al., 2015).
In the third cut, most of the treatments of intercropping presented a dry mass yield similar to the respective monocultures of *Brachiaria* (Table 5). It is known that sowing with the broadcast system provides a better distribution of *Brachiaria* plants, which could have helped to obtain higher dry mass yields. The sowing of *Brachiaria* in rows had the same spacing of sorghum, which could have caused the use of the residual fertilizer. Therefore, *Brachiaria* have better absorbed the fertilizer nutrients during regrowth, resulting in higher dry matter yield in the density of 8 viable pure seeds m^{-2} relative to the broadcast system. Therefore, the results demonstrate the potential of the forage biomass production and adaptation to cultivation in Cerrado soils (Paula et al., 2017).

Sorghum and Brachiaria crops
The sum of the dry matter yield of both crops and the soil coverage of sorghum crop in July were influenced by a variety of sources (Supplementary Table 3). The advantages of *Brachiaria* cultivation with sorghum in the straw production for each tillage system can be proven by obtaining values of higher total dry matter yield in relation to their monocultures of *Brachiaria* and sorghum, especially in the first and third cuts (Table 7).
The superior performance of intercropping demonstrates that the substantial increase in dry mass of Brachiaria maximized the production of straw for tillage. The dry weight increase in intercropping with sorghum was also observed in other researches in row systems (Horvath Neto et al., 2012; Silva et al., 2015) and leading (Silva et al., 2014a).
The excellent capacity of plant regrowth from *B. ruziziensis* was possible because the intercropping plants were installed at the start of the rainy season (Fig 1). The regrowth of the plants after harvesting sorghum, with log mean temperatures above 25°C and the occurrence of precipitation during plant development, made it possible to obtain high dry matter yield values. The intercropping values came from three cuts of *Brachiaria* plants (on sorghum harvest and after 78 and 176 days after harvesting the grain). This biomass production makes it possible to use forage production in the form of grazing in the off-season, during which time, the pastures in tropical climate region are weakened for cattle production.
In the second cut, the lower precipitation in relation to the previous months (Fig 1) limited the accumulations of dry mass by the *Brachiaria* plants. Also in this cut, there was a linear increase of dry matter yield with increased sowing density of *Brachiaria* for the broadcast system (Fig 5B). In the sum of the values obtained from the three cuts, it can be observed that intercropping in the inter-row system at densities of 6 and 10 seeds m^{-2}, rows with 4, 8 and 10 seeds m^{-2} and broadcast systems with 6 seeds m^{-2} enabled higher dry matter in relation to sorghum monocultures and *Brachiaria* (Table 7).
At the start of the rainy season in the region, increased precipitation from September coupled with increases in temperature values compared to previous months favoured the sprouting of *Brachiaria* plants, thus allowing the dry

matter to increase in the intercropping systems. Therefore, it is possible to use the forage for grazing before the start of the rainy season, since the regrowth of the plants allowed a third biomass, wherein it may be desiccated to soybean in succession.

Regardless of seeding density (evaluation carried out in July), the dry matter production of *B. ruziziensis* in the intercropping during winter contributed to increases in ground cover in relation to the sorghum monoculture (Table 7). However, the values are lower than those of the same *Brachiaria* cultivation system due to shading of sorghum forage, suppressing their growth. In this system, at the time of this evaluation, the entire surface of the ground was covered in the area cultivated with *Brachiaria*, which did not occur with sorghum.

The increased quantity of seeds in rows increased the soil cover in the intercropping of inter-row systems (Fig 5D). In the intercropping of row and broadcast systems, quadratic effects occurred in soil coverage, whereas the ground cover increased with increases in density of *Brachiaria* seeds to 7.3 and 6.0 viable pure seeds m^{-2}, respectively. Thereafter, a competition may have already occurred between species and consequently decreased soil coverage. The advantage of vegetation cover by Brachiaria has also been found in other research papers (Horvath Neto et al., 2012; Silva et al., 2014a; Silva et al., 2015; Paula et al., 2017).

The onset of the rainy season in October contributed to increases in land cover compared to July. Although the values were higher in the intercropping planted treatments, there were no significant differences between the two culture systems (Table 7). It is worth mentioning that the straw on the soil surface in the early stage of soybean development, implemented at the beginning of the rainy season in tropical climate region, provides protection against soil erosion and weed suppression. In the early days of development, soybean does not provide an effective ground cover and the presence of biomass on the soil surface for a tillage system (Silva et al., 2014, Ribeiro et al., 2015; Simão et al., 2015). In the dry mass production in intercropping, the system also allows for production of sorghum grains, providing additional income to farmers for marketing with agricultural industries located in the region.

Soybean crop

The systems and *Brachiaria* seeding densities intercropping planted with sorghum, influenced some variables of soybean (Supplementary Table 4). When the culture was planted in monocultures of straw *B. ruziziensis*, a reduction in yield was found with increasing forage-seeding densities (Table 9). The consortium to broadcast system 8 viable pure seeds m^{-2} gave higher yields of soybeans in relation to the respective monoculture. This result is justified by the greater weight of the oleaginous grains, whose variables were correlated significantly and positively with the grain yield (0.27*), whereas the first variable values varied depending on the intercropping systems and seeding density (Fig 6A). For the other intercropping associations, they found no differences in performance compared to soybeans grown in monocultures of *Brachiaria* and sorghum.

Therefore, intercropping with *Brachiaria* sorghum provided no limitation on the soybean crops in succession. In other research papers, increases were recorded in yields when the culture was planted in succession with the intercropping system (Borges et al., 2016; Moraes et al., 2014).

The benefits of the integration of grasses have been observed in the soil structure with the use of plants such as sorghum and *Brachiaria*, which have deep root systems and are bulky and aggressive (Kluthcouski et al., 2004). The decomposition of the root system occurs with the drying of the culture, where the roots of subsequent crops grow in addition to the formation of residues with different amounts of nutrients to be recycled (Entz et al., 2002). This can have benefits for soybeans, providing greater grain weight and higher yield.

Furthermore, from the second half of December 2014 to the end of January 2015 (Fig 1), water drought occurred in the region, which limited the achievement of higher yields of soybean grains. During this period, the culture was in the pod formation stage and the start of the grain-filling phase, which resulted in a high demand for water (Norman, 2012; Beutler et al., 2014). The higher dry matter yield in the intercropping, mainly obtained from the third cut, was positively correlated with the soybean yield (0.23*). The total sorghum biomass and pasture soil provided better coverage, which may have achieved moisture retention in the soil, which is essential for water stress mitigation (Silva et al., 2014b).

Unlike the initial plant population, there is an influence from the systems on the final population (Table 9). At lower densities (2 and 4 viable pure seeds m^{-2}) of the intercropping in inter-rows, there was a lower population of plants in relation to the other systems as observed in the density of 8 seeds m^{-2} in the broadcast system. The increase in seeding density in the intercropping planted row and in the broadcast system caused significant linear reductions in final population (Fig 6B). The fact was similar to that observed in the monoculture. In the consortium of inter-rows, the final population density decreased to 4.9 seeds m^{-2}.

The lowest population of plants at the highest sowing densities influenced the yield of soybean grains in the monoculture. In the analysis of the relationship among these variables, it the population of plants was found to be positively correlated with grain yield (0.24*), which means that any factor that reduced the population of soybean negatively affected the yield.

The initial height of the plants and pod insertion were not influenced by the intercropping systems and *Brachiaria* seeding density in both culture systems (Tables 9 and 10 respectively). However, the final plant heights of the soybeans cultivated in succession with the intercropping in the interline with 4 and 8 viable pure m^{-2} seeds, as well as sowing in the line and the haul with 6 and 8 m^{-2} seeds were higher in relation to the respective monocultures of *Brachiaria* (Table 10). For other densities, no significant differences were observed for plant heights between the intercropping and the monoculture.

In the monoculture, soybean grown in succession with sorghum showed higher plant heights relative to the densities from 6 to 10 inbred viable seeds m^{-2} (Table 10), which demonstrated the positive and significant correlation with grain yield (0.29**). One of the factors that could influence plant height is the amount of dry matter produced on the soil surface.

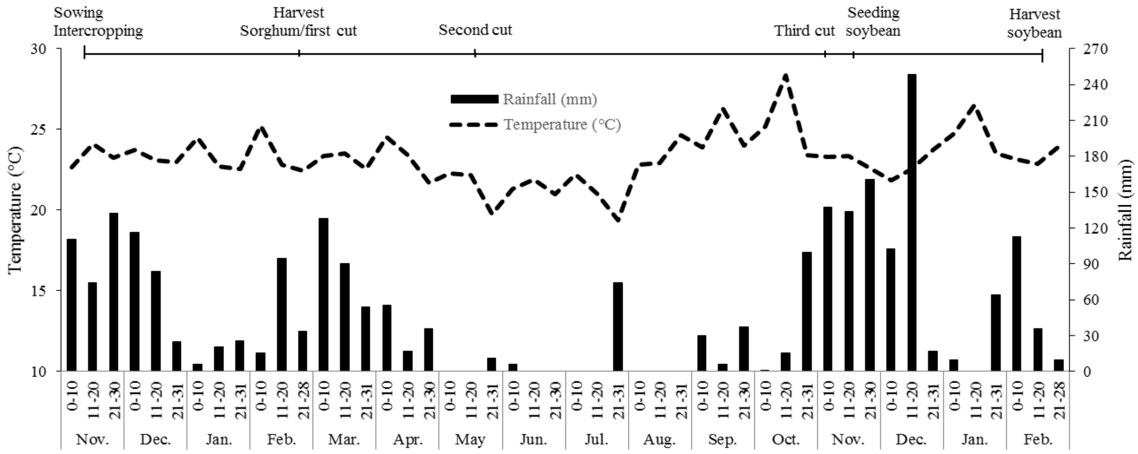

Fig 1. Monthly variation in the average air temperature and rainfall from November 2013 to February 2015, Rio Verde/GO, Brazil (Source: weather station at the University of Rio Verde, Rio Verde).

Table 2. Mean values of grain yield (GY), thousand grain weight (TGW), plant height (SPH), plant population (POP) of grain sorghum crop intercropped with *B. ruziziensis* in the densities of 2, 4, 6, 8 and 10 viable pure seeds m^{-2}, Rio Verde.

Intercropping systems	Seeding density (viable pure seeds m^{-2})					Mean values
	2	4	6	8	10	
	GY (Kg ha^{-1})					
Row	6,708 b	7,949 a	9,357 a	6,235 a	7,426 a	7,535 a
Inter-row	7,985 ab	7,915 a	7,385 a	8,169 a	6,338 a	7,558 a
Broadcast	9,913 a	7,767 a	7,752 a	6,992 a	5,840 a	7,653 a
Mean values	8,202	7,877	8,165	7,132	6,535	7,582
Monocultures	7,902					
TGW (g)						
Row	16.94 ab	18.12 a	14.63 a	19.62 a	17.77 a	17.42 a
Inter-row	14.86 b	14.46 b	15.59 a	14.87 b	15.07 ab	14.97 b
Broadcast	19.87 a	15.08 ab	16.23 a	16.69 a	14.56 b	16.49 a
Mean values	17.22	15.89	15.48	17.06	15.80	16.30
Monocultures	17.31					
SPH (m)						
Row	1.26 a	1.26 a	1.28 a	1.22 a	1.28 a	1.26 a
Inter-row	1.27 a	1.31 a	1.31 a	1.28 a	1.30 a	1.29 a
Broadcast	1.29 a	1.28 a	1.27 a	1.28 a	1.27 a	1.27 a
Mean values	1.27	1.28	1.28	1.26	1.28	1.27
Monocultures	1.27					
POP (x 10.000 plants ha^{-1})						
Row	22.88 a	21.10 a	22.76 a	18.60 a	21.56 a	21.38 a
Inter-row	21.96 a	21.43 a	21.83 a	22.43 a	21.24 a	21.78 a
Broadcast	20.57 a	21.53 a	22.10 a	21.03 a	20.53 a	21.52 a
Mean values	21.80	21.35	22.23	20.69	21.11	21.56
Monocultures	20.90					

Means followed by the same lowercase letter in the column do not differ from each other by the Tukey test at 5% probability.
* Averages differ significantly by the Dunnett test at 5% probability being higher $^{(+)}$ or lower $^{(-)}$ in relation to sorghum monoculture.

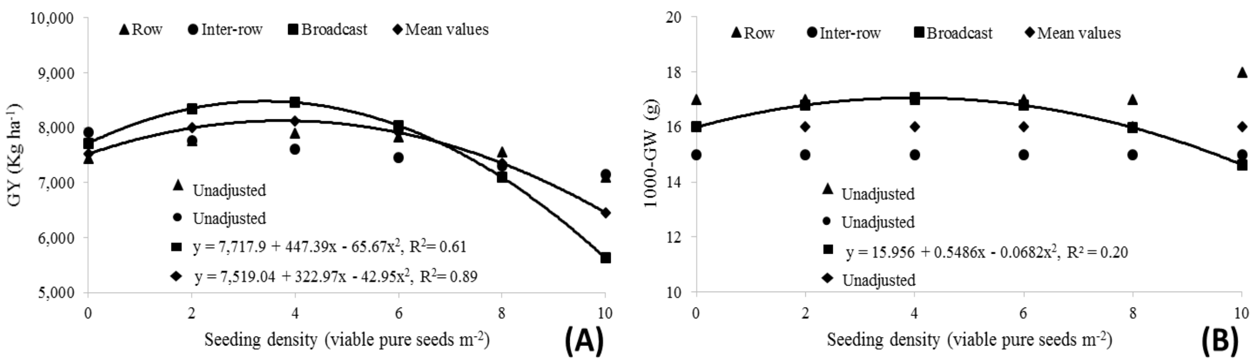

Fig 2. Regression adjusted to the characteristics of grain yield (GY) and thousand grain weight (TGW) of sorghum (Figs 2A and 2B, respectively) combined with *B. ruziziensis* densities of 2, 4, 6, 8 and 10 seeds viable pure $m^{-2,}$ Rio Verde.

Table 3. Mean values for dry matter yield of sorghum in the first (SDMY1C), second (SDMY2C) and third cuts (SDMY3C) of sorghum crop intercropped with *B. ruziziensis* in densities of 2, 4, 6, 8 and 10 viable pure seeds m^{-2}, Rio Verde.

Intercropping systems	Seeding density (viable pure seeds m^{-2})					Mean values
	2	4	6	8	10	
SDMY1C (kg ha^{-1})						
Row	2,905 b	3,546 a	3,733 a	3,060 b	4,409 a	3,531 a
Inter-row	5,014 a*(+)	3,093 a	4,666 a	3,194 ab	4,422 a	4,078 a
Broadcast	1,932 b*(-)	2,614 a	2,010 b*(-)	4,245 a	2,965 b	2,753 b
Mean values	3,284	3,084	3,470	3,499	3,932	3,454
Monocultures	3,407					
SDMY2C (kg ha^{-1})						
Row	2,045 a*(-)	2,049 a*(-)	866 c*(-)	1,175 b*(-)	1,133 b*(-)	1,454 b
Inter-row	1,700 a*(-)	1,468 ab*(-)	2,977 a	1,596 ab*(-)	1,850 a*(-)	1,918 a
Broadcast	1,620 a*(-)	808 b*(-)	1,612 b*(-)	2,256 a	1,254 ab*(-)	1,510 b
Mean values	1,788	1,442	1,818	1,676	1,412	1,627
Monocultures	3,057					
SDMY3C (kg ha^{-1})						
Row	1,338 a*(-)	2,082 a*(-)	1,608 b*(-)	2,721 a	2,713 a	2,092 a
Inter-row	2,082 a*(-)	1,878 a*(-)	2,770 a	1,596 b*(-)	1,570 b*(-)	1,979 a
Broadcast	1,698 a*(-)	1,826 a*(-)	1,656 b*(-)	1,940 b*(-)	1,624 b*(-)	1,749 b
Mean values	1,706	1,929	2,011	2,086	1,969	1,940
Monocultures	3,113					

Means followed by the same lowercase letter in the column do not differ from each other by the Tukey test at 5% probability. * Averages differ significantly by the Dunnett test at 5% probability being higher (+) or lower (-) in relation to sorghum monoculture.

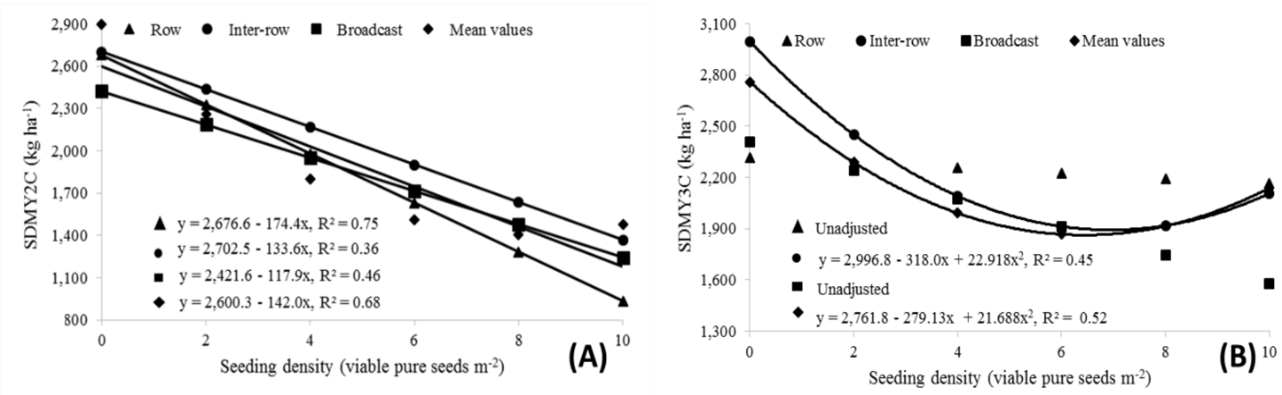

Fig 3. Regression adjusted to the characteristics of dry matter yield in the second sorghum (SDMY2C) and third sections (SDMY3C) of sorghum (Figs 3A and 3B, respectively) intercropping in *B. ruziziensis* densities of 2, 4, 6, 8 pure and viable seeds 10^{-2} m, Rio Verde.

Table 5. Mean height values (BPH), plant population (POP), dry matter yield of *Brachiaria* in the first (BDMY1C), second (BDMY2C) and third cuts (BDMY3C) of sorghum intercropped with *B. ruziziensis* in the densities of 2, 4, 6, 8 and 10 viable pure seeds m^{-2}, Rio Verde.

Intercropping systems	Seeding density (viable pure seeds m^{-2})					Mean values
	2	4	6	8	10	
BPH (m)						
Row	1.09 a	1.22 a	1.24 a	1.11 ab	1.27 a	1.18 a
Inter-row	1.20 a	1.25 a	1.33 a	1.26 a	1.11 a	1.23 a
Broadcast	0.96 a	1.10 a	1.08 a	0.84 b*(-)	1.31 a	1.05 b
Mean values	1.08	1.19	1.21	1.07	1.23	1.15
Monocultures	1.31 A	1.36 A	1.30 A	1.30 A	1.33 A	
POP (x 10.000 plants ha^{-1})						
Row	37.3 b	38.0 a	39.9 a	46.8 a	52.0 a	42.8 ab
Inter-row	47.3 a	38.8 a	46.5 a	44.2 a	54.3 a	46.2 a
Broadcast	41.1 ab	40.3 a	41.1 a	43.7 a	46.0 a	42.4 b
Mean values	41.9	39.0	42.5	44.9	50.8	43.8
Monocultures	44.1 A	35.2 A	43.7 A	50.3 A	50.0 A	
BDMY1C (kg ha^{-1})						
Row	2,299 a*(-)	3,081 a	2,025 ab*(-)	2,583 a*(-)	2,380 a*(-)	2,474 a
Inter-row	1,792 ab*(-)	2,004 b*(-)	2,280 a*(-)	1,516 b*(-)	1,681 a*(-)	1,855 b
Broadcast	1,163 b*(-)	1,999 b*(-)	1,490 b*(-)	1,929 ab*(-)	2,139 a*(-)	1,744 b
Mean values	1,751	2,361	1,932	2,008	2,067	2,024
Monocultures	4,494 A	3,782 A	4,060 A	4,530 A	3,679 A	

BDMY2C (kg ha^{-1})						
Row	2,672 a	2,277 a	1,514 b*$^{(-)}$	2,493 a	1,594 b*$^{(-)}$	2,110 a
Inter-row	1,628 b*$^{(-)}$	1,790 a*$^{(-)}$	2,347 a	2,567 a	1,914 b*$^{(-)}$	2,049 a
Broadcast	1,654 b*$^{(-)}$	2,084 a*$^{(-)}$	2,075 ab*$^{(-)}$	1,681 b*$^{(-)}$	2,957 a	2,090 a
Mean values	1,985	2,050	1,979	2,247	2,155	2,083
Monocultures	3,096 A	2,645 A	3,115 A	3,049 A	3,367 A	
BDMY3C (kg ha^{-1})						
Row	2,607 a	3,274 a	3,756 a	3,534 a	3,427 a	3,320 a
Inter-row	2,370 a	2,132 a	3,164 a	2,544 ab*$^{(-)}$	3,357 a	2,713 b
Broadcast	1,925 a*$^{(-)}$	3,208 a	4,998 a	2,293 b*$^{(-)}$	2,611 a	3,007 a
Mean values	2,301	2,871	3,973	2,790	3,132	3,013
Monocultures	3,486 A	3,577 A	3,453 A	4,413 A	3,199 A	

Means followed by the same lowercase letter in columns and upper case letter in lines do not differ by Tukey test at 5% probability. *1; 2: * Averages differ significantly by the Dunnett test at 5% probability being higher $^{(+)}$ or lower $^{(-)}$ in relation to sorghum monoculture.

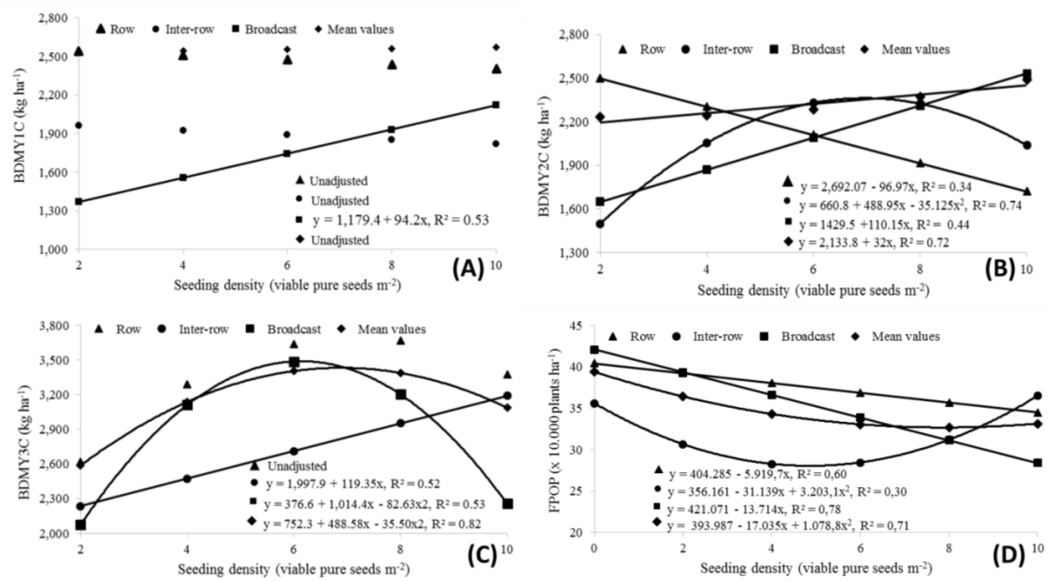

Fig 4. Regression adjusted to the characteristic plant population (POP), dry matter yield of *Brachiaria* in the first (BDMY1C), second (BDMY2C) and third cuts (BDMY3C) (Figs 4A, 4B, 4C and 4D, respectively) of sorghum intercropped with *B. ruziziensis* in densities of 2, 4, 6, 8 and 10 viable pure seeds m^{-2}, Rio Verde.

Table 7. Total dry matter yield in the first (TDMY1C), second (TDMY2C) and third sections (TDMY3C) and total (TDMY1 + 2 + 3); and soil cover in July (SCJ) and October (SCO) of sorghum intercropped with *B. ruziziensis* in the densities of 2, 4, 6, 8 and 10 viable pure seeds m^{-2}, Rio Verde.

Intercropping systems	Seeding density (viable pure seeds m^{-2})					Mean values
	2	4	6	8	10	
TDMY1C (kg ha^{-1})						
Row	5,204 a	6,627 a*$^{1.2}$	5,758 ab*^{2}	5,643 ab	6,789 a*$^{1.2}$	6,004 a
Inter-row	6,806 a*$^{1.2}$	5,097 a*$^{1.2}$	6,946 a*$^{1.2}$	4,710 b	6,103 a*$^{1.2}$	5,932 a
Broadcast	3,095 b	4,613 b	3,500 b	6,174 a*$^{1.2}$	5,104 b*^{1}	4,497 b
Mean values	5,035	5,446	5,401	5,509	5,999	Sorghum
Monocultures	4,494 A	3,782 A	4,050 A	4,530 A	3,679 A	3,407 A
TDMY2C (kg ha^{-1})						
Row	4,717 a*$^{1.2}$	4,326 a*^{1}	2,380 c	4,709 a	2,727 a	3,652 a
Inter-row	3,328 ab	3,258 b	5,324 a*$^{1.2}$	4,163 a	3,764 a	3,967 a
Broadcast	3,274 b	2,892 b	3,687 b	3,937 a	4,211 a	3,600 a
Mean values	3,773	3,492	3,797	4,270	3,567	Sorghum
Monocultures	3,096 A	2,645 A	3,115 A	3,049 A	3,367 A	3,057 A
TDMY3C (kg ha^{-1})						
Row	3,945 a	5,356 a*^{2}	5,364 a*$^{1.2}$	6,251 a*$^{1.2}$	6,140 a*$^{1.2}$	5,411 a
Inter-row	4,452 a	4,010 a	5,934 a*^{2}	4,140 b	4,927 a*^{2}	4,693 b
Broadcast	3,623 a	5,034 a *^{2}	6,654 a*$^{1.2}$	4,233 ab*^{2}	4,235 a	4,756 ab
Mean values	4,007	4,803	5,984	4,874	5,101	Sorghum
Monocultures	3,486 A	3,577 A	3,453 A	4,413 A	3,199 A	3,113 A
TDMY1+2+3C (kg ha^{-1})						
Row	13,866 a	16,309 a*$^{1.2}$	13,502 a	16,603 a*$^{1.2}$	15,656 a*$^{1.2}$	15,187 a
Inter-row	14,586 a	12,365 a	18,204 a*$^{1.2}$	13,013 a	14,794 a*$^{1.2}$	14,592 a

Broadcast	9,992 a	12,539 a	13,841 a	10,344 a	13,550 a	12,053 a
Mean values	12,815	13,738	15,182	13,320	14,667	Sorghum
Monocultures	11,076 A	10,004 A	11,224 A	11,692 A	10,245 A	9,577 A
SCJ (%)						
Row	73.7 a*[1]	87.5 a*[1.2]	87.5 a*[1.2]	86.5 a*[1.2]	85.0 a*[1.2]	84.0 a
Inter-row	78.7 a*[1.2]	81.2 a*[1.2]	88.7 a*[2]	86.2 a*[1.2]	87.5 a*[1.2]	84.5 a
Broadcast	75.0 a*[1]	81.2 a*[1.2]	87.5 a*[1.2]	82.5 a*[1.2]	83.7 a*[1.2]	82.0 a
Mean values	75.8	83.3	87.9	85.1	85.4	Sorghum
Monocultures	100.0 A	100.0 A	100.0 A	100.0 A	100.0 A	63.7 B
SCO (%)						
Row	90.0 a	91.2 a	96.2 a	92.5 a	92.5 a	92.5 a
Inter-row	95.0 a	96.0 a	91.2 a	92.5 a	96.2 a	94.2 a
Broadcast	83.7 a	91.2 a	95.0 a	95.0 a	97.5 a	92.5 a
Mean values	89.6	92.8	94.2	93.3	95.4	Sorghum
Monocultures	100.0 A	100.0 A	100.0 A	100.0 A	100.0 A	77.5 A

Means followed by the same lowercase letter in columns and upper case letter in lines do not differ by Tukey test at 5% probability. *[1; 2]: Averages differ significantly by the Dunnett test at 5% probability being [(1)] monoculture of brachiaria and [(2)] monoculture of sorghum.

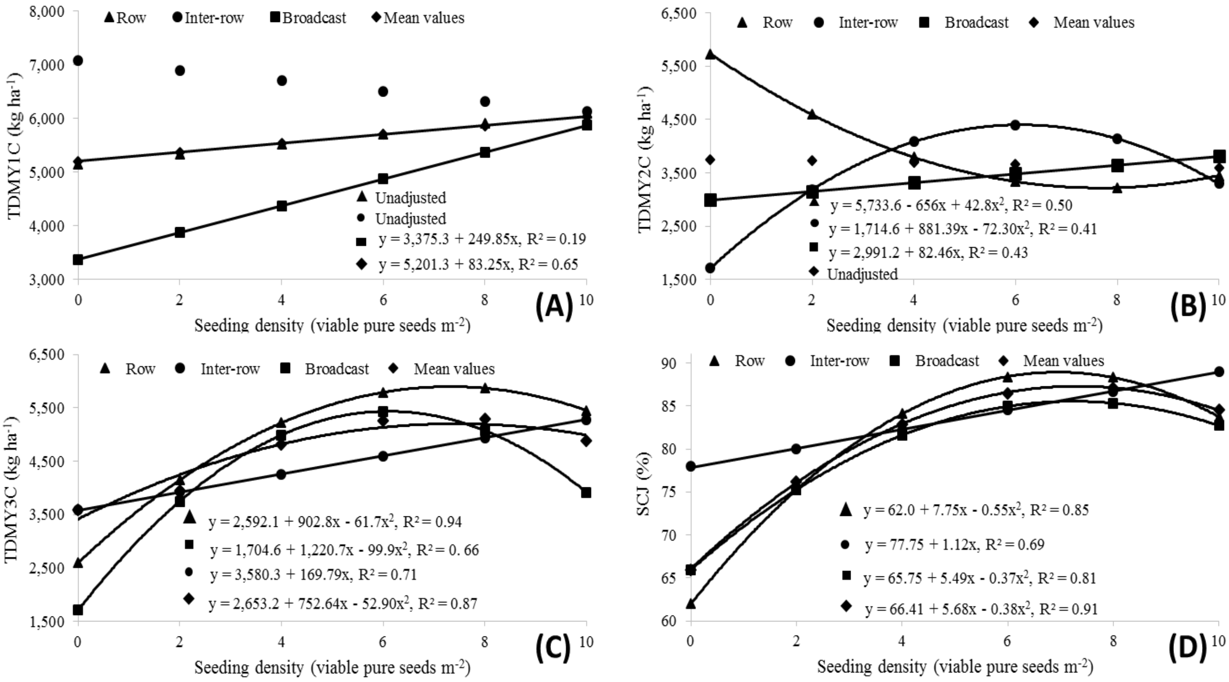

Fig 5. Regression adjusted to the total dry matter yield in the first (TDMY1C), second (TDMY2C) and third sections (TDMY3C), as well as soil cover in July (SCJ) (Figures 5A, 5B, 5C and 5D, respectively) of sorghum intercropped with *B. ruziziensis* in densities of 2, 4, 6, 8 and 10 viable pure seeds m^{-2}, Rio Verde.

Table 9. Average values of grain yield (GY), thousand grain weight (TGW), initial (IPOP) and final populations (FPOP) and initial plant height (IPH) of soybean crops in succession to grain sorghum intercropped with *B. ruziziensis* in densities of 2, 4, 6, 8 and 10 viable pure seeds m^{-2}, Rio Verde.

Intercropping systems	Seeding density (viable pure seeds m^{-2})					Mean values
	2	4	6	8	10	
GY (kg ha^{-1})						
Row	2,673 a	2,762 a	2,703 a	2,581 a	2,068 a	2,557 a
Inter-row	2,416 a	2,315 a	2,283 a	2,677 a	2,457 a	2,429 a
Broadcast	2,615 a	2,762 a	2,722 a	2,943 a*[1]	2,340 a	2,676 a
Mean values	2,568	2,613	2,569	2,733	2,288	Sorghum
Monocultures	2,391 AB	2,285 AB	2,187 AB	1,981 AB	1,673 B	2,499 A
TGW (g)						
Row	120 a	102 a*[2]	132 a	129 a	140 a	125 ab
Inter-row	108 b	122 a	104 a	127 a	123 a	117 b
Broadcast	138 a	131 a	131 a	137 a*[1]	122 a	132 a
Mean values	122	118	122	131	128	Sorghum
Monocultures	124 A	110 A	108 A	106 A	120 A	133 A
IPOP (x 10,000 plants ha^{-1})						
Row	41.75 a	40.50 a	35.87 a	43.00 a	41.00 a	40.40 a

Inter-row	36.00 a	34.50 a	35.68 a	38.00 a	39.62 a	36.76 a
Broadcast	44.81 a	43.62 a	39.87 a	37.00 a	33.37 a	39.73 a
Mean values	40.85	39.54	37.14	39.33	38.00	Sorghum
Monocultures	38.50 A	41.12 A	41.12 A	37.00 A	33.50 A	39.61 A
FPOP (x 10,000 plants ha^{-1})						
Row	39.87 a	36.50 a	34.56 a	38.37 a	34.25 a	36.71 a
Inter-row	28.87 b	20.37 b	35.37 a	34.50 a	33.25 a	30.47 b
Broadcast	39.75 a	38.25 a	36.75 a	26.37 b	29.75 a	34.17 a
Mean values	36.16	31.70	35.56	33.08	32.41	Sorghum
Monocultures	32.50 AB	35.25 A	37.25 A	28.87 AB	20.62 B	35.34 A
IPH (cm)						
Row	13.6 a	13.9 a	15.2 a	13.8 a	16.7 a	14.7 a
Inter-row	14.9 a	15.8 a	14.9 a	14.7 a	14.3 a	14.9 a
Broadcast	15.8 a	15.1 a	14.2 a	14.9 a	14.8 a	15.0 a
Mean values	14.8	15.0	14.8	14.5	15.3	Sorghum
Monocultures	17.5 A	16.1 A	17.1 A	15.9 A	16.5 A	15.6 A

Means followed by the same lowercase letter in columns and upper case letter in lines do not differ by Tukey test at 5% probability. *1; 2: Averages differ significantly by the Dunnett test at 5% probability being (1) monoculture of brachiaria and (2) monoculture of sorghum.

Table 10. Average values of final plant height (FPH), insertion height of the first pod (FPIH), number of pods on the main stem with one (NPMS1G), two (NPMS2G), three (NPMS3G) and four grains (NPMS4G) of soybean crops grown in succession with sorghum intercropped with *B. ruziziensis* in densities of 2, 4, 6, 8 and 10 viable pure seeds m^{-2}, Rio Verde.

Intercropping systems	Seeding density (viable pure seeds m^{-2})					Mean values
	2	4	6	8	10	
FPIH (cm)						
Row	14.8 a	15.7 a	16.2 a	15.8 a	16.5 a	15.8 a
Inter-row	14.5 a	15.5 a	15.2 a	14.7 a	14.8 a	14.9 a
Broadcast	15.7 a	16.8 a	16.4 a	17.4 a	15.0 a	16.3 a
Mean values	15.0	16.0	16.0	16.0	15.5	Sorghum
Monocultures	15.4 A	14.8 A	14.9 A	15.8 A	15.3 A	15.5 A
FPH (cm)						
Row	64.1 a	61.7 a	66.8 a*1	66.6 a*1	64.4 a	64.7 a
Inter-row	64.5 a	68.7 a*1	62.8 a	62.1 a*1	59.8 a	63.6 a
Broadcast	63.2 a	63.0 a	66.1 a*1	65.4 a*1	62.8 a	64.0 a
Mean values	64.0	64.4	65.2	64.7	62.3	Sorghum
Monocultures	59.6 AB	60.9 AB	56.1 B	55.1 B	59.0 B	65.6 A
NPMS1G						
Row	1.8 a	0.8 a	1.0 a	1.6 a	1.5 a	1.3 a
Inter-row	0.8 a	1.3 a	1.2 a	1.4 a	1.7 a	1.3 a
Broadcast	1.1 a	1.1 a	0.8 a	1.7 a	0.3 a	1.0 a
Mean values	1.2	1.1	1.0	1.5	1.2	Sorghum
Monocultures	0.8 A	0.7 A	0.6 A	1.8 A	1.4 A	0.6 A
NPMS2G						
Row	5.9 a	4.6 a	5.1 a	5.2 a	5.8 a	5.3 a
Inter-row	5.4 a	4.4 a	3.6 a	4.5 a	4.5 a	4.5 a
Broadcast	4.7 a	4.0 a	4.7 a	4.6 a	3.4 a	4.3 a
Mean values	5.3	4.3	4.5	4.8	4.5	Sorghum
Monocultures	3.6 A	5.9 A	3.2 A	5.4 A	7.0 A	4.0 A
NPMS3G						
Row	9.6 a	12.7 a	11.4 a	10.1 a	11.1 a	11.0 a
Inter-row	14.1 a	12.1 a	12.4 a	9.7 a	10.1 a	11.7 a
Broadcast	10.2 a	10.7 a	11.3 a	9.5 a	13.1 a	20.0 a
Mean values	11.3	11.8	11.7	9.8	11.4	Sorghum
Monocultures	9.3 A	13.5 A	10.4 A	12.8 A	11.4 A	12.1 A
NPMS4G						
Row	2.4 a	2.5 a	2.2 a	2.0 a	2.5 a	2.3 a
Inter-row	2.7 a	1.7 a	2.0 a	1.9 a	2.0 a	2.1 a
Broadcast	1.7 a	2.9 a	1.8 a	2.7 a	2.4 a	2.3 a
Mean values	2.3	2.4	2.0	2.2	2.3	Sorghum
Monocultures	2.3 A	2.8 A	1.5 A	1.5 A	2.5 A	2.3 A

Means followed by the same lowercase letter in columns and upper case letter in lines do not differ by Tukey test at 5% probability. *1; 2: Averages differ significantly by the Dunnett test at 5% probability being (1) monoculture of brachiaria and (2) monoculture of sorghum.

Table 11. Average values of the number of pods on the secondary stem with one (NPSS1G), two (NPSS2G), three (NPSS3G) and four grains (NPSS4G) of soybean crops grown in succession with sorghum intercropped with *B. ruziziensis* in densities of 2, 4, 6, 8 and 10 viable pure seeds m^{-2}, Rio Verde.

Intercropping systems	Seeding density (viable pure seeds m^{-2})					Mean values
	2	4	6	8	10	
NPSS1G						
Row	0.3 a	0.1 a	0.4 a	0.7 a	0.5 a	0.4 a
Inter-row	1.1 a	0.1 a	0.5 a	1.0 a	1.2 a	0.8 a
Broadcast	0.3 a	0.4 a	0.4 a	1.6 a	0.4 a	0.6 a
Mean values	0.6	0.2	0.4	1.1	0.7	Sorghum
Monocultures	0.7 A	0.5 A	0.4 A	1.6 A	1.2 A	0.2 A
NPSS2G						
Row	2.4 a	3.8 a	3.1 a	1.9 a	1.7 a	2.6 a
Inter-row	5.0 a	1.2 a	3.1 a	4.7 a	3.4 a	3.5 a
Broadcast	1.8 a	1.8 a	1.8 a	4.3 a	2.0 a	2.4 a
Mean values	3.1	2.3	2.7	3.6	2.4	Sorghum
Monocultures	2.8 A	1.8 A	1.3 A	3.9 A	5.6 A	2.1 A
NPSS3G						
Row	3.1 a	6.7 a	7.5 a	3.9 a	2.9 a	4.8 a
Inter-row	6.2 a	7.2 a	5.7 a	6.6 a	4.7 a	6.1 a
Broadcast	3.1 a	4.2 a	5.1 a	4.9 a	4.6 a	4.4 a
Mean values	4.1	6.1	6.1	5.1	4.1	Sorghum
Monocultures	5.0 A	4.7 A	4.7 A	8.4 A	6.2 A	4.1 A
NPSS4G						
Row	0.5 a	0.8 a	0.9 a	0.2 a	0.3 a	0.5 a
Inter-row	1.0 a	0.8 a	0.3 a	0.8 a	0.3 a	0.7 a
Broadcast	0.3 a	0.1 a	0.7 a	0.1 a	0.3 a	0.3 a
Mean values	0.6	0.6	0.6	0.9	0.3	Sorghum
Monocultures	0.7 A	0.7 A	0.1 A	0.3 A	0.4 A	0.4 A
NSS						
Row	2.2 a	2.7 a	3.4 a	1.9 a	1.9 a	2.4 a
Inter-row	4.1 a	2.4 a	3.3 a	3.4 a	2.8 a	3.2 a
Broadcast	1.3 a	2.1 a	2.2 a	2.9 a	2.4 a	2.2 a
Mean values	2.6	2.4	3.0	2.7	2.4	Sorghum
Monocultures	1.9 A	2.7 A	1.7 A	3.4 A	2.7 A	2.3 A
NPT						
Row	26.1 a	32.1 a	31.5 a	25.5 a	26.4 a	28.3 a
Inter-row	44.5 a	28.9 a	28.9 a	30.8 a	27.9 a	32.2 a
Broadcast	23.4 a	25.3 a	26.8 a	29.5 a	26.7 a	26.3 a
Mean values	31.3	28.7	29.1	28.6	27.0	Sorghum
Monocultures	25.3 A	30.8 A	19.5 A	35.8 A	35.8 A	25.9 A

Means followed by the same lowercase letter in columns and upper case letter in lines do not differ by Tukey test at 5% probability.
*1; 2: Averages differ significantly by the Dunnett test at 5% probability being (1) monoculture of brachiaria and (2) monoculture of sorghum.

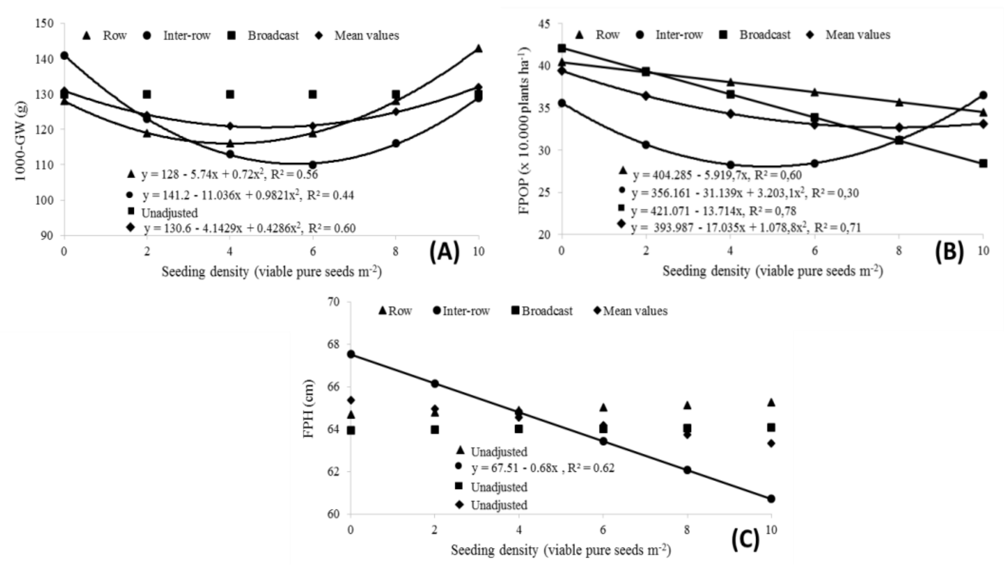

Fig 6. Regression adjusted to the characteristics of 1000-grain weight (1000-GW), final populations (FPOP) and final plant height (FPH) (Figs 6A, 6B and 6C, respectively) of soybean crops grown in succession with sorghum intercropped with *B. ruziziensis* in densities of 2, 4, 6, 8 and 10 viable pure seeds m^{-2}, Rio Verde.

However, this variable did not show differences between the monoculture of sorghum and *Brachiaria* at different sowing densities, as discussed previously. For the other components of soybean yield (the number of pods on the main and secondary stems, regardless of the number of grains), there was no influence from the tested sources of variation (Tables 10 and 11).

For all presented treatments, it is possible to observe that the increase in seeding density of *B. ruziziensis* in the intercropping allowed for increases in biomass yield, without causing a reduction in the yield of grain sorghum and soybeans grown in succession. From these results, we suggest assessing the feasibility of increasing the density of seeding *B. ruziziensis* above 10 pure viable seeds m^{-2} in a intercropping system to identify the conditions that do not cause interference with the development and grain yield of sorghum when the consortium is deployed at the beginning of the rainy season in the mid-western region of Brazil.

The increase in dry mass production at the soil surface can minimize the risk of agricultural losses under water stress conditions, common in years of "El Niño" occurrence in South America. Furthermore, greater mass production of dry matter on the soil surface contributes to the maintenance of no-tillage systems in the Cerrado region, to the detriment of a higher rate of decomposition of straw according to the environmental conditions of the region. Therefore, sorghum intercropping planted with *B. ruziziensis*, independent of the sowing system, was shown to be a promising cultivation technique for the no-tillage system, combining improvements in grain yield and dry mass (straw).

Materials and methods

Conduction of study

The experiment was conducted in the Brazilian Cerrado in Rio Verde-Goiás, Brazil (17°47'21.2 "S, 50°57'40.8" W and 766 m altitude) in soil classified as a dystrophic red Latosol cultivated in a no-tillage system in the 2013/14 and 2014/15 crop seasons. The results of a chemical analysis of soil samples of the experimental area were characterized by the following: pH in $CaCl_2$: 5.7; Ca, Mg, K, Al, H+Al, CTC and SB: 1.20; 0.93; 0.32; 0.40; 5.7; 8.14 e 2.45 in $cmol_c\ dm^{-3}$, respectively; P: 2.85 mg dm^{-3}; base and aluminium saturations: 30 and 14%, respectively; organic matter: 24.20 g dm^{-3}; and clay, silt and sand: 530; 150 and 320 g kg^{-1}, respectively. The average air temperature and rainfall during the experiment are shown in Fig 1.

Experimental design

The experimental design was a randomized complete block factorial 3x5+1+5, with four replications, corresponding to three *Brachiaria ruziziensis* consortium seeding systems (row, inter-row and broadcast sowing) with five seeding densities *Brachiaria* (2, 4, 6, 8 and 10 inbred viable seeds m^{-2}) beyond the corresponding additional treatments to grain sorghum monocultures (0 density of viable pure seeds m^{-2}) and the five *Brachiaria* seeding densities.

Plant materials and treatments

The grain sorghum was BRS 330 (medium cycle with semi-open panicles, red grains and without tannin). The forage was *B. ruziziensis,* characterized by decumbent stems, racemes short and intense hairiness, which is suitable for dry mass production for soil coverage (Kluthcouski et al., 2004). The plots consisted of seven sorghum-sowing rows that were 5.0 m long and spaced 0.50 m apart. The useful area was obtained disregarding the two side rows and eliminating 0.50 m at each end.

One week prior to implantation assay, the desiccation of weeds was performed by mechanically applying the equivalent to 1,440 g ha^{-1} glyphosate and 0.5 L ha^{-1} 2.4 D in a spray volume of 150 L $ha^{-1.}$ Fertilization was performed with a seeder in seven rows of grooves 10 cm deep and with application equivalent to 370 kg ha^{-1} of 02-20-18 fertilizer. Subsequently, both crops were sown, manually, on November 13th, 2013.

In the intercropping of the row, the *Brachiaria* was sown to 10 cm depth, with the aid of a graduated template, which was placed along with the fertilizer. Afterwards, the seeds were covered with 8 cm of soil, and the sorghum was then sown, covering the seeds with 2 cm of soil. In the intercropping of the inter-row, sowing grooves of the *Brachiaria* were made between the rows of sorghum to depths of 10 cm, using hoes and a graduated template. For this system, the same depth of sorghum seeding from the row intercropping was adopted. In the third seeding system, the *B. ruziziensis* was seeded by spreading (broadcast sowing system). Then, the monocultures of sorghum and *B. ruziziensis* were sown at 2 and 10 cm of depth, respectively.

The quantity of *Brachiaria* seeds was defined on the basis of test results in a germinating bed of sand to obtain the amount of viable pure seeds $m^{-2.}$ At 15 days after emergence (DAE) of sorghum, the seedlings were thinned, leaving a population equivalent to 180,000 plants ha^{-1}. After 30 DAE, 100 kg ha^{-1} of urea nitrogen was applied manually to the side of the sorghum-planting row to the source.

The management of *Spodoptera frugiperda* and *Helicoverpa armigera* in sorghum was carried out in a mechanized manner and depended on the occurrence of the species, application of insecticide acephate (0.50 L ha^{-1}) at 28 DAE, chlorantraniliprole and teflubenzuron (both 0.05 L ha^{-1}) at 29 DAE, [lambadacialotrina + thiamethoxam] (0.30 L ha^{-1}) and abamectin (0.50 L ha^{-1}) at 41 DAE, teflubenzuron (0.05 L ha^{-1}) at 50 DAE [lufenuron + profenofos] (0.50 L ha^{-1}) and teflubenzuron (0.50 L ha^{-1}) at 62 DAE, chlorantraniliprole (0.10 L ha^{-1}) and teflubenzuron (0.50 L h^{-1}) at 76 DAE. To avoid damage from anthracnose *(Colletotrichum sublineolum),* the fungicides carbendazim (0.40 L ha^{-1}) and [pyraclostrobin + epoxiconazole] (0.50 L ha^{-1}) were applied at 50 DAE.

Sorghum was harvested at 104 DAE (02-28/2014). In the experimental area of the plots, the grain yield (harvest of panicles, with threshing and grain weighing, with moisture correction of 13%) was evaluated. The weight of one thousand grains (weighing one thousand grains, randomly selected in the yield sample, with moisture correction to 13%) was determined and the plant height (measurement of the collar to the end of the panicle in five randomly chosen plants) and the final population (counting the total number of plants harvested) were obtained.

After the sorghum harvest, the *Brachiaria* remained in the field, together with the remaining biomass of sorghum, and three cuts were made. The first one was carried out on the same day as the sorghum harvest, 30 cm high, to allow for efficient regrowth of the *Brachiaria* and sorghum plants. Afterwards, the border plants were cut to standardize the plant height. At 79 days after the first cut (05/18/2014), the second cut of *Brachiaria* and sorghum was also performed at 30 cm height. Cultures remained for another 176 days in the field after sorghum harvest for the third cut (10/11/2014), which was made close to the soil.

During the last cut of the forage, five plants were chosen randomly in the experimental area of the plots and evaluated along with the height of the plants (measurement of the colon to the end of the last fully expanded leaf) and the population of plants (count of plants).

The sorghum and the *Brachiaria* were evaluated for the following: the dry mass yield of each crop as well as their sum for quantification of the yield of the total dry mass (straw). In this evaluation, the sorghum and *Brachiaria* biomass was collected on 1 m^2 using an iron square of 1.0 x 1.0 m, with a section taken at ground level. The samples were separately packed in paper bags and taken to dry in an air circulating oven at 65°C to determine the dry weight and the dry matter yield.

After the sorghum harvest, the percentage of vegetation cover was quantified on the soil by evaluating two points randomly chosen in the useful area of the plots. In this evaluation, an iron square with dimensions of 0.50 x 0.50 m was used, containing a row with ten equidistant separated points. A determination of the percentage of soil surface cover was computed when these points coincided with the presence of vegetation cover.

The desiccation of the sorghum and *Brachiaria* biomass was evaluated in the third section using the equivalent of 1,440 g ha^{-1} glyphosate and 0.50 L ha^{-1} of 2.4 D, in a spray volume of 150 L ha^{-1}, with use of a trailed sprayer. Five days after the third cut (11/15/2014), the soybean planting was carried out to evaluate the performance of the crop in succession with the sorghum and *Brachiaria* sorghum intercropping treatments. For the implantation of the culture, we used the equivalent of 408 kg ha^{-1} of fertilizer 08-20-18 using a seeder of seven rows composed of cut discs.

For the management of weeds, pests and diseases, we applied glyphosate (960 g ha^{-1}) + bifenthrin + zeta-cypermethrin (0.25 L ha^{-1}) and [carbendazim + kresoxim-methyl + tebuconazole] (10 L ha^{-1}) at 20 DAE, [carbendazim + kresoxim-methyl + tebuconazole] (1.0 L ha^{-1}) and [bifenthrin + carbosulfan] (0.6 L ha^{-1}) at 52 DAE [carbendazim + kresoxim-methyl + tebuconazole] (1.0 L ha^{-1}) and acephate (1.0 kg ha^{-1}) at 86 DAE, each with a trailer sprayer with 150 L ha^{-1} syrup.

Traits measured

For the soybean crop, the following measurements were taken: the grain yield (harvesting the pods, with subsequent threshing and weighing of the grains, with correction for humidity to 13%); 1000-grain weight grains (weighing one thousand grains with correction for humidity 13%); initial population (counting the number of plants) when the plants were fully developed with two trefoil (growth stage $_{V2)}$; a final population (counting the number of plants at harvest) plant heights initial and final (measured from ground level to the insertion of the second trifoliate, $V_{2,}$ and the last node with the pod insertion harvest, respectively); height of insertion of the first pod (measurement of the surface of the soil until the insertion of the first pod in the harvest); number of pods on the main and secondary stems with one, two, three, and four grains and total pods; and the number of secondary stems (counting the number of pods and secondary stems at harvest).

Statistical analysis

First, the analysis of individual variance was performed on all variables, and then the combined analysis between the data obtained in the intercropping with the monoculture data was performed. For a comparison of the means of the intercroppings, a Tukey's test was used at 5% probability for a comparison of the intercropping systems and regression analysis for the means of *Brachiaria* densities. Among the results obtained in the intercropping with those of the monoculture (control), a comparison was performed using the means of contrasts with a Dunnett test at 5% probability.

Conclusion

The cultivation of *Brachiaria ruziziensis* with the BRS 330 grain sorghum did not cause a reduction in sorghum grain yield in the intercropped systems in relation to the monoculture, but the consortium caused a decrease in the dry mass yield of the sorghum with an increase in the sowing density of the *Brachiaria*. The intercropping systems and sowing densities of *Brachiaria ruziziensis* did not influence the performance and yield of soybeans grown in succession with the intercropping.

The best results were the planting of *Brachiaria ruziziensis* in the line at the sowing density of 8 viable pure m^{-2} seeds and the inter-row sowing density of 6 viable pure m^{-2} seeds.

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