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Grain sorghum intercropping with *Brachiaria brizantha* cultivars in two sowing systems as a double crop

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The intercropping of grain sorghum with forage grasses is a promising cultivation technique for the production of grains and forage in the Midwest region of Brazil. However, few studies have been performed with the goal of evaluating the development of the two species when cultivated simultaneously in the same area. The goal of the present study was to evaluate agronomic characteristics and grain yield of grain sorghum intercropped with *Brachiaria brizantha* cultivars under two sowing systems (row and inter-row) as a double crop in the midwest region of Brazil. The experiment was conducted at the Federal Institute of Goiás (*Instituto Federal Goiano*), Rio Verde Campus. A randomized block design was used, with a 3x2+1 factorial scheme, with three replicates. Three cultivars of *B. brizantha* (*Marandu palisadegrass*, *Xaraes palisadegrass* and *Piata palisadegrass*) were row or inter-row (sowing systems) intercropped with grain sorghum. In addition, there was one treatment of sorghum monoculture. The inter-row intercropping of grain sorghum with *B. brizantha* cultivars had no effect on sorghum agronomic characteristics and grain yield. However, row intercropping with *X. palisadegrass* affected the sorghum stem diameter, dry mass production and grain yield. The *M. palisadegrass* and *P. palisadegrass* cultivars are therefore better recommended for intercropping with sorghum. The intercropping of sorghum with the tested *B. brizantha* cultivars was shown to be a viable cultivation practice for grain production as a double crop in the Midwest region of Brazil.

Key words: *Marandu palisadegrass, Piata palisadegrass, Xaraes palisadegrass*, integrated crop-livestock farming systems, *Sorghum bicolor*, grain yield.

INTRODUCTION

Over the last few years, the intercropping of annual crops with tropical forage grasses, used in integrated crop-livestock farming systems, has been increasingly adopted by farmers from the Cerrado region (Pacheco et al., 2008; Petter et al., 2011). This system allows the cultivation of crops for grain production and the stocking of cattle, for either meat or milk production, in the same area. The integrated crop-livestock farming system

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creates an increase in production and a decrease in the risk of pasture degradation, while improving chemical, physical and biological soil characteristics and the grain, forage grasses and silage yield potential (Silva et al., 2010).

Grain sorghum has been used as an alternative crop in integrated crop-livestock farming systems in the off season (Horvathy et al., 2012, Silva et al., 2013). From the agronomical point of view, the use of sorghum intercropped with forage grasses, especially those belonging to the genus *Brachiaria*, is mainly justified by the potential for the production of sorghum grain and for the production of dry mass of both of the crops. Thus, sorghum has been found to be an excellent option for the production of grain, forage and silage when water deficit and low soil fertility result in higher risk for the cultivation of other crops, such as corn (Embrapa Milho and Sorgo, 2012).Of the forage grasses used in crop rotation, succession or intercropping systems in the Cerrado (tropical savanna) region, grasses of the genus *Brachiaria* should be highlighted. The use of species of this genus in integrated systems is advantageous due to their abundant root system, which contributes to water infiltration as well as higher soil aggregation and aeration (Kluthcouski et al., 2004). In addition, these forage grasses present good adaptation, tolerance and resistance to biotic factors and high production of dry mass that has good nutritional value and is able to meet animal demands, especially during the dry season (Brighenti et al., 2008).

The previous studies of integrated crop-livestock farming systems have used *Brachiaria brizantha* cv. Marandu, *Brachiaria decumbens* and *Brachiaria ruziziensis* (Paris et al., 2010, Horvathy Neto et al., 2012, Silva et al., 2013; Maia et al., 2014). With the emergence of new *B. brizantha* cultivars, new studies of the intercropping of sorghum with the cultivars *Xaraes palisadegrass* and *Piata palisadegrass* are needed to identify the associations that result into in higher sorghum grain yields. Given that the association of sorghum with *Brachiaria* cultivars is largely unexplored, especially as a double crop, there is a need for more information, especially in terms of the recommendations for implementation methods as alternatives for diversification of crops in farms.The goal of the present study was to evaluate agronomic and grain yield characteristics of grain sorghum intercropped with *B. brizantha* cultivars according to two sowing systems (row and inter-row) cultivated as a double crop in the midwestern region of Brazil.

MATERIALS AND METHODS

The experiment was conducted in the field (17° 48' S, 50° 55' W, and 748 m altitude), at the Federal Institute of Goiás (*Instituto Federal Goiano*), Rio Verde Campus, in an area of dystroferric Red Latosol (Embrapa, 2013). The soil of the experimental area, in the 0 to 20 cm depth instead, before the setting of the experiment had the following chemical and physical characteristics: 510 g kg^{-1} clay; 160 g kg^{-1} silt; 330 g kg^{-1} sand; pH in $CaCl_2$: 5.10; Ca: 2.88 cmol$_c$ dm^{-3}; Mg: 1.27 cmol$_c$ dm^{-3}; Al: 0.01 cmol$_c$ dm^{-3}; Al+H: 4.0 cmol$_c$ dm^{-3}; K: 0.39 cmol$_c$ dm^{-3}; CEC: 8.54 cmol$_c$ dm^{-3}; P: 6.72 mg dm^{-3}; Cu: 3.4 mg dm^{-3}; Zn: 1.5 mg dm^{-3}; Fe: 43.0 mg^{-3}; O.M.: 26.76 g dm^{-3}.

The area was prepared by clearing the weeds by applying 3 L ha^{-1} glyphosate. Thirty days after desiccation, harrowing was performed using a disk plough, followed by a disk harrow. One week before sowing, a second harrowing was performed, and sowing furrows were opened using a seeder.

The experimental design was of randomized blocks, with three replicates, in a 3x2+1 factorial scheme, with three *B. brizantha* cultivars (*Marandu palisadegrass, X. palisadegrass* and *P. palisadegrass*) row and inter-row intercropped with grain sorghum Buster (an early hybrid with grains without tannin and with reddish color). An additional treatment of sorghum in monoculture was included in the study. 50 cm spacing between rows was used for all the treatments. The plots with monoculture and with row intercropping were composed of eight three-meter-long lines. For the inter-rowintercropping, fifteen rows were used (eight with sorghum and seven with *Brachiaria*) for a total of 12 m². A usable plot area of 6 m² was considered by excluding one row on each side of each plot and 0.5 m at the ends of each row.

Sowing was performed in February 2013, with 80 kg ha^{-1} P_2O_5 and 20 kg ha^{-1} FTE BR 12 fertilization, using single superphosphate and silicon dioxide as sources, respectively. At 20 and 40 days after seedling emergence (DAE), 50 kg ha^{-1} nitrogen and 40 kg ha^{-1} K_2O in the form of urea and potassium chloride, respectively, were applied by broadcasting.

For the row intercropping, *B. brizantha* cultivars were sown at a depth of 6cm, in combination with the fertilizers, and sorghum was sown at 2cm depth. For the inter-rowintercropping and for the sorghum monoculture, all the seeds were sown at 2cm depth.The Buster sorghum was thinned two weeks after seedling emergence, leaving 240.000 plants ha^{-1}, in accordance with the recommended density for this cultivar for the region of study. For the forage grasses, 5 kg of pure viable seeds were used per hectare. Weeding was performed during the experiment to avoid problems with weeds and pests that could compromise production. The daily rainfall and monthly average temperature were monitored (Figure 1).

For sorghum, both intercropped and as a monoculture, the plant height (measured from the stem base to the tip of the last expanded leaf, for the first measurement, and to the tip of the panicle for measurements at 60 and 90 days after sowing (DAS) for one plant per row in the usable plot area), stem diameter and number of fully expanded leaves were measured at 30, 60 and 90 DAS.Grain was harvested 148 days after seedling emergence, and the following characteristics were evaluated: plant stand (counting of the number of plants and extrapolating to plants per hectare), panicle index (ratio between the number of harvested panicles and the initial plant population), dry mass production, thousand grain weight (weight of one thousand grains, in grams, corrected for 13% moisture) and grain yield (panicle threshing, grain weighing and conversion of the data into kg ha^{-1} corrected for 13% moisture).

An analysis of variance followed by a Tukey's test, at $p<0.05$, was performed. Two analyses were performed: one using only the data for intercropping (sorghum intercropped with the *B. brizantha* cultivars and the two sowing systems), and one using the data for both of the plants in association and in monoculture. The Dunnett test, at $p<0.05$, was also used to compare data for intercropped plants with the sorghum in monoculture. All the analyses were performed using the ASSISTAT 7.6 beta software

RESULTS AND DISCUSSION

No significant differences were observed in plant height

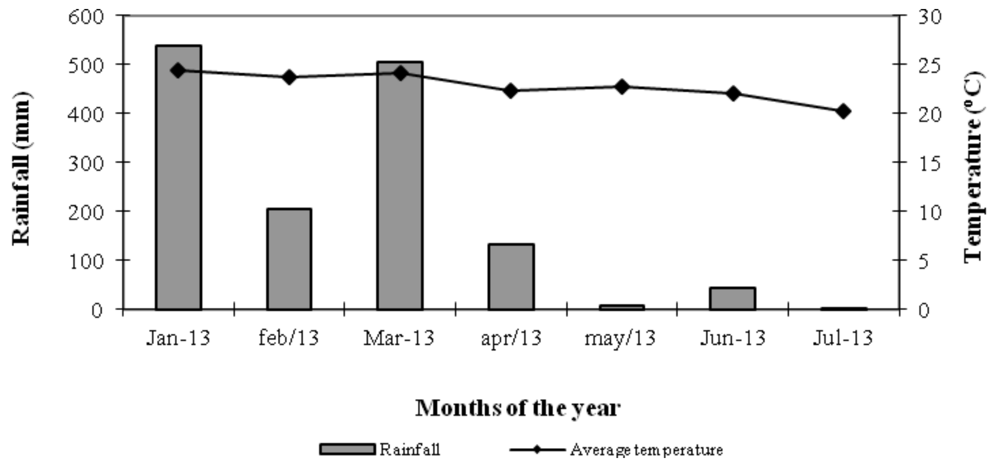

Figure 1. Rainfall and average temperature from January to July 2013 in Rio Verde-GO, Brazil.

Table 1. Plant height at 30, 60 and 90 DAS of sorghum in monoculture and intercropped with *B. brizantha* cultivars under two different sowing systems.

Integrated systems	Sowing Systems		Average
	Row	Inter-row	
	Plant height at 30 DAS (m)		
Sorghum x *Marandu palisadegrass*	0.41	0.42	0.41[a]
Sorghum x *Xaraes palisadegrass*	0.40	0.44	0.42[a]
Sorghum x *Piata palisadegrass*	0.42	0.47	0.44[a]
Average	0.41[a]	0.44[a]	
Sorghum in monoculture	0.41		
CV (%)	10.52		
	Plant height at 60 DAS (m)		
Sorghum x *Marandu palisadegrass*	0.92	0.82	0.87[a]
Sorghum x *Xaraes palisadegrass*	0.88	0.89	0.88[a]
Sorghum x *Piata palisadegrass*	0.89	0.79	0.83[a]
Average	0.89[a]	0.83[a]	
Sorghum in monoculture	0.98		
CV (%)	8.52		
	Plant height at 90 DAS (m)		
Sorghum x *Marandu palisadegrass*	1.35	1.28	1.32[a]
Sorghum x *Xaraes palisadegrass*	1.39	1.26	1.33[a]
Sorghum x *Piata palisadegrass*	1.31	1.28	1.29[a]
Average	1.35[a]	1.27[a]	
Sorghum in monoculture	1.33		
CV (%)	8.28		

Means followed by the same lowercase letters within the same column, and uppercase letters within the same row, were not significantly different according to Tukey's and F tests, at $p<0.05$. Averages followed by (*) were significantly different from the sorghum monoculture according to the Dunnett test, at $p<0.05$.

at 30, 60 and 90 DAS between the different integrated systems (sorghum intercropped with *B. brizantha* cultivars) and sowing systems (row and inter-row), nor were there significant interactions between factors ($p>0.05$) (Table 1). This finding indicates that *B. brizantha* did not affect sorghum development, which is in

Table 2. Stem diameter at 30, 60 and 90 DAS of sorghum plants in monoculture and intercropped with *Brachiaria brizantha* cultivars under two different sowing systems.

Integrated systems	Sowing Systems		Average
	Row	Row	
	Stem diameter at 30 DAS (mm)		
Sorghum x *Marandu palisadegrass*	10.09	10.77	10.38[a]
Sorghum x *Xaraes palisadegrass*	9.57 *	11.26	10.42[a]
Sorghum x *Piata palisadegrass*	10.48	11.66	11.07[a]
Average	10.01[a]	11.23[a]	
Sorghum in monoculture	12.47		
CV (%)	...................12.09		
	Stem diameter at 60 DAS (mm)		
Sorghum x *Marandu palisadegrass*	15.93	17.06	16.50[a]
Sorghum x *Xaraes palisadegrass*	15.11 *	16.32	15.71[a]
Sorghum x *Piata palisadegrass*	16.27	16.21	16.24[a]
Average	15.77[a]	16.53[a]	
Sorghum in monoculture	19.50		
CV (%)	.... 11.60		
	Stem diameter at 90 DAS (mm)		
Sorghum x *Marandu palisadegrass*	16.73	17.57	17.15[a]
Sorghum x *Xaraes palisadegrass*	15.67 *	17.01	16.34[a]
Sorghum x *Piata palisadegrass*	17.37	16.74	17.0[6a]
Average	16.59[a]	17.11 [a]	
Sorghum in monoculture	19.97		
CV (%)	.... 10.71		

Means followed by the same lowercase letters within the same column, and uppercase letters within the same row, were not significantly different according to Tukey's and F tests, at p<0.05. Averages followed by (*) were significantly different from the sorghum monoculture according to the Dunnett test, at p<0.05.

accordance with Almeida et al.(2012) and Horvathy et al. (2012). At 90 DAS, the average sorghum height was 1.31 m in monoculture and 1.33 m intercropped (Table 1). These values were higher than those reported by Silva et al. (2013), who evaluated sorghum inter-row intercropped with *Brachiaria*, as a double crop, and obtained 1.14 and 1.15 m plant height. This difference may be due to the different hybrids used in the two studies and the sowing time, which affects plant development.

The sorghum row intercropped with *X. palisadegrass* exhibited lower stem diameters at 30, 60 and 90 DAS (Table 2). This difference was likely due to greater competition for water, light, nutrients and physical space because both of the species were sown in the same row. In addition, *X. palisadegrass* may have affected sorghum development because it possesses wider leaves and greater height (Costa et al., 2009), resulting in more competition for light. These findings differ from those of Crusciol et al. (2011), who observed that sorghum hybrids row intercropped with *M. palisadegrass* exhibited greater stem diameters than sorghum grown in monoculture. In turn, when *B. brizantha* cultivars were inter-row intercropped with sorghum, the association had no effect on stem diameter compared to sorghum grown in monoculture (p>0.05) (Table 2). These findings confirm the viability of inter-rowintercropping because it results in less competition with the sorghum plants.

The number of leaves at 30 DAS was not significantly different between the different integrated and sowing systems tested (p>0.05) (Table 3). However, sorghum exhibited a lower number of leaves when intercropped with *Marandu palisadegrass* than in monoculture at 60 DAS (p>0.05). This difference may be attributed to the fact that plants with fewer leaves develop greater leaf area to maintain the photosynthesis levels necessary for development. No significant differences were observed in plant populations between the sorghum intercropped with *B. brizantha* cultivars and the sorghum in monoculture, thus confirming the absence of competition between species under different forage systems and indicating that the association with *Brachiaria* was not detrimental for the sorghum plant stand (p>0.05) (Table 3).

However, the sowing system influenced (p>0.05) the sorghum population. Sowing *B. brizantha* as an inter-row

Table 3. Number of leaves, plant population and panicle index at 30 and 60 DAS for sorghum grown in monoculture and intercropped with *Brachiaria brizantha* cultivars under two different sowing systems.

Integrated systems	Sowing Systems		
	Row	**Inter-row**	**Average**
	Number of leavesat 30 DAS		
Sorghum x *Marandu palisadegrass*	4.17	4.41	4.29 [a]
Sorghum x *Xaraes palisadegrass*	3.83	4.50	4.17 [a]
Sorghum x *Piata palisadegrass*	4.08	4.58	4.33 [a]
Average	4.03 [a]	4.50 [a]	
Sorghum in monoculture	4.92		
CV (%)	.... 16.28		
	Number of leavesat 60 DAS		
Sorghum x *Marandu palisadegrass*	7.42 *	7.91	7.67 [a]
Sorghum x *Xaraes palisadegrass*	7.58	7.50	7.54 [a]
Sorghum x *Piata palisadegrass*	7.63	7.67	7.63 [a]
Average	7.53 [a]	7.69 [a]	
Sorghum in monoculture	8.50		
CV (%)	.... 6.25		
	Plant population		
Sorghum x *Marandu palisadegrass*	243.333	185.000	214.117 [a]
Sorghum x *Xaraes palisadegrass*	236.667	205.000	220.833 [a]
Sorghum x *Piata palisadegrass*	233.889	198.333	216.111 [a]
Average	237.963 [a]	196.111 [b]	
Sorghum in monoculture	216.667		
CV (%)	.... 17.08		
	Panicle index (%)		
Sorghum x *Marandu palisadegrass*	94.50	94.89	94.70 [a]
Sorghum x *Xaraes palisadegrass*	87.11	91.45	89.28 [a]
Sorghum x *Piata palisadegrass*	85.92	93.38	89.65 [a]
Average	89.18 [a]	93.24 [a]	
Sorghum in monoculture	94.65		
CV (%)	.... 4.98.............................		

Means followed by the same lowercase letters within the same column, and uppercase letters within the same row, were not significantly different according to Tukey's and F tests, at$p$<0.05. Averages followed by (*) were significantly different from the sorghum monoculture according to the Dunnett test, at$p$<0.05.

crop resulted in a smaller sorghum population. This result is in contrast with previous studies of the intercropping of grain sorghum with *Brachiaria*, in which no differences in population were observed either for intercropping at the row (Horvathy et al., 2012) or inter-row (Lara, 2011; Silva et al., 2013).

The forage and sowing systems did not affect (p>0.05) the panicle index (Table 4). It should be noted that this variable represents the tillering capacity of sorghum. Even with differences in plant population between the tested sowing systems, the panicle indexes were similar between treatments, which indicates that the tillering index did not change with the decrease in plant population observed with inter-row intercropping (approximately 18%). This lack of change in the tillering index was most likely due to the high plant density recommended for the Buster hybrid. Therefore, even with high plant populations, the values obtained in intercropping and in monoculture were similar to those reported by Borghi et al. (2013) for sorghum grown in monoculture (91%) and intercropped with *M. palisadegrass* (99%).

No differences were observed in dry mass production among the sorghum crops grown in association with the different *B. brizantha* cultivars and under different sowing systems (p>0.05) (Table 4). However, there was a 45%

Table 4. Dry mass production, total dry mass production, thousand-grain weight and grain yield of sorghum in monoculture and in association with *Brachiaria brizantha* cultivars under two different sowing systems.

Integrated systems	Sowing Systems		
	Row	Inter-row	Average
	Dry mass production of sorghum (kg ha^{-1})		
Sorghum x *Marandu palisadegrass*	4.964	4.615	4.964
Sorghum x *Xaraes palisadegrass*	3.850*	4.385	3.850*
Sorghum x *Piata palisadegrass*	4.979	4.068	4.979
Average	4.598 [a]	4.356 [a]	4.598 [a]
Sorghum in monoculture	5.618		
CV (%)	16.12		
	Total dry mass production (kg ha^{-1})		
Sorghum x *Marandu palisadegrass*	8.568*	8.474*	8.568*
Sorghum x *Xaraes palisadegrass*	8.507*	9.647*	8.507*
Sorghum x *Piata palisadegrass*	8.755*	9.061*	8.755*
Average	8.610 [a]	9.060 [a]	8.610 [a]
Sorghum in monoculture	5.618		
CV (%)	18.11		
	Thousand-grain weight (g)		
Sorghum x *Marandu palisadegrass*	29.41	30.74	29.41
Sorghum x *Xaraes palisadegrass*	30.74	31.99	30.74
Sorghum x *Piata palisadegrass*	27.62	31.87	27.62
Average	29.26 [a]	31.53 [a]	29.26 [a]
Sorghum in monoculture	31.52		
CV (%)	6.25		
	Grain yield (kg ha^{-1})		
Sorghum x *Marandu palisadegrass*	5.872	4.940	5.872
Sorghum x *Xaraes palisadegrass*	3.729 *	4.075	3.729*
Sorghum x *Piata palisadegrass*	4.622	4.035	4.622
Average	4.741 [a]	4.350 [a]	4.741 [a]
Sorghum in monoculture	6.953		
CV (%)	14.63		

Means followed by the same lowercase letters within the same column, and uppercase letters within the same row, were not significantly different according to Tukey's and F tests, at p<0.05. Averages followed by (*) were significantly different from the sorghum monoculture according to the Dunnett test, at p<0.05.

decrease in dry mass production of the sorghum row intercropped with *X. palisadegrass* compared to sorghum grown in monoculture. This finding may be due to greater competition between plants in this treatment. In addition to being in the same sowing row as the sorghum, using the same resources (water, light and nutrients), the *X. palisadegrass* has wider leaves and is taller than the remaining cultivars (Costa et al., 2009); therefore, there may have been more competition between the *X. palisadegrass* and sorghum plants.

One of the great advantages of intercropping is the complementation of the production of both of the species without resulting in decreases in the yield of the main crop. The absence of significant differences in dry mass production of the sorghum intercropped with *M. palisadegrass* and *P. palisadegrass,* compared to the sorghum in monoculture, indicates that there was no competition with these cultivars to the point of decreasing production.

For the total dry mass production (sorghum + *B. brizantha* cultivars) (Table 4), all the intercropping systems and both of the sowing systems exhibited higher values (p>0.05) than the sorghum in monoculture. The intercropping of sorghum with *B. brizantha* cultivars contributed to increase the total dry mass production by 53 and 61% for the row and inter-row sowing systems, respectively, which shows the efficiency of *B. brizantha* cultivars in supplementing the dry mass production in integrated systems.

These results confirm the viability of using grain sorghum intercropped with *B. brizantha* cultivars. This system allows the straw from sorghum and *B. brizantha* to remain in the area following the grain harvest. The straw can then be grazed by animals during the off-season period (Maia et al., 2014) or used for desiccation for the establishment of the summer crop (Silva et al., 2013).No significant differences were observed in the thousand-grain weight between the sowing systems (p>0.05) (Table 4). This pattern is explained by the absence of competition of sorghum with *B. brizantha* at the maturation stage, that is, following sorghum flowering. In addition, the results of the thousand-grain weight were similar to the remaining parameters, especially the plant height. This result indicates that the association with *B. brizantha* cultivars did not influence the formation of sorghum panicles and consequently the thousand-grain weight, which were determined at the reproductive (30 to 60 DAS) and maturation (after 60 DAS) stages of sorghum (Vanderlip, 1993).

Grain yield was only affected by the sorghum rowintercropping with *X. palisadegrass* for consistency, which resulted in decreased sorghum grain yield compared to the monoculture (p>0.05), similar to what was observed for the stem diameter and dry mass production (Table 4). The stem is one of the structures that stores reserve substances in plants; wider stem diameters provide the plant with greater capacity for storage. A larger diameter considerably contributes to grain filling (Gimenes et al., 2008).

The sorghum grain yield was similar when it was intercropped with *M. palisadegrass* and *P. palisadegrass* and in monoculture, for the two tested sowing systems (Table 4). This result indicates that the association of the Buster hybrid with these cultivars is viable for cultivation as a double crop because intercropping did not result in grain yield decrease. This finding is in accordance with a previous study of the inter-row intercropping of grain sorghum with *M. palisadegrass* (Silva et al., 2013).

Due to the different region of study and genetic differences between sorghum cultivars, the present grain yields were lower than those reported by Borghi et al. (2013) and higher than those reported by Horvathy et al. (2012) and Silva et al. (2013). The higher yields obtained in the present study are most likely due to the earlier time of sorghum sowing (February) together with the early onset of the Buster hybrid. Because of this relation, the crop reached the flowering stage at the time of rainfall occurrence (Figure 1), which is desirable to obtain higher grain yields (Baumhardt et al., 2005; Fornazieri Filho and Fornasieri, 2009).

Conclusion

The inter-row intercropping of grain sorghum with *B. brizantha* cultivars did not interfere with the sorghum agronomic characteristics and grain yield. However, the association of sorghum with *X. palisadegrass* in the rows affected the stem diameter, sorghum dry mass production and grain yield. Intercropping with *M. palisadegrass* and *P. palisadegrass* is therefore recommended more. The intercropping of sorghum with *B. brizantha* cultivars was a viable cultivation system for grain production as a double crop in the midwest region of Brazil.

Conflict of Interest

The authors have not declared any conflict of interest.

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