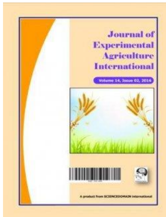

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Sorghum Intercropped with Piatã Grass in Eucalyptus Sub-forest

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Authors' contributions

This work was carried out in collaboration between all authors. The authors JGA and RGA designed and wrote the protocol for the experiment. The authors GMM conducted the experiment and wrote the first draft of the manuscript. The authors LVB, VHA, IMSN, CEAC, LDSH, WMP and DMH discussed the results, corrected and improved the writing of the manuscript in English version. All authors read and approved the final manuscript.

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ABSTRACT

The objective of this study was to evaluate the behavior of forage sorghum when intercropped with piatã grass and cultivated in eucalyptus sub-forest. The experiment was carried out at the Embrapa Gado de Corte, in Campo Grande - MS. The experimental design was a randomized complete block design with three replications. The main treatments were: monoculture (single sorghum); intercropping (simultaneous sowing of sorghum + piatã grass). The secondary treatments were composed by the sampling sites, with five sites equidistant between the rows of eucalyptus trees (CLFI), with full sun as a control (CLI). The percentage of shading was always higher than 30% in the sub-forest, and the overall average of the system with 63% shade, even after 50% thinning of

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eucalyptus trees. The intercropping with the grass, an interesting fact, did not affect sorghum grain yield, since it validates the potential of forage sorghum for use in intercropping with perennial grasses, with average grain yield of 2,404.63 kg ha^{-1}. Regarding the sampling sites, it was observed a higher yield in the full sun with 3,283 kg ha^{-1}. The weight of 100 grains was higher for sorghum in monoculture. On the other hand, the upper W1000 was observed at sites A and C. The weight of 1000 grains is considered stable, being affected only under conditions of stress during grain formation. The sorghum intercropped with the piatã grass did not influence the harvest index (HI), while in the shaded environment there was an increase in the harvest index in relation to the full sun.

Keywords: Eucalyptus urograndis; Sorghum bicolor; thinning; Uroclhoa brizantha.

1. INTRODUCTION

The crop-livestock-forest integration (CLFI) serves as an excellent alternative to the use of conventional agriculture and livestock, consisting of the combination of forest species with agricultural crops, livestock activities or both, these combinations being simultaneously or in a sequence of time and space [1]. These systems offer alternatives that are less impacting to the environment, which may help to reverse degradation processes and contribute to the improvement of the socioeconomic conditions of rural populations [2].

However, in the ILPF system, as the trees grow, there is a reduction in the radiation that occurs under the sub-forest, causing shading of the crop and/or pasture component, influencing the production of the system as a whole.

A potential crop for Integrated Agricultural and Livestock Production Systems is sorghum, because it presents tolerant characteristics to several environmental factors when compared to maize, such as tolerance to water deficit and excess moisture, and can be cultivated over a wide range of soil conditions [4].

Sorghum when intercropped with grass tend to improve soil quality and add value to land, resulting in higher income on the property. The sowing of the grass provides protection of the soil, improving the control of invasive plants, while the sorghum guarantees the economic return to the rural activity [5].

The objective of this study was to evaluate the behavior of forage sorghum when intercropped with piatã grass and cultivated in eucalyptus sub-forest.

2. MATERIAL AND METHODS

2.1 Location and Characterization of the Study Area

The experiment was carried out at the Brazilian Agricultural Research Corporation (EMBRAPA), Gado de Corte unit, located in the municipality of Campo Grande - MS (20º27'S, 54º37'W, 530 m altitude). The climate, according to Köppen-Geiger, is in the transition band between sub-type Cfa and sub-type Aw. The soil of the experimental area was classified as Red Latosol, with a clayey texture [6].

Table 1 shows the chemical attributes of the soil for the full sun and sub-forest (plots between eucalyptus trees).

Table 1. Chemical analysis of soil in the area under full sun and understory of eucalyptus, at a depth of 0-0.20 m

	[1]pH	[2]pH	[3]V	[4]m	[5]PM1	[6]C	[7]PM3	[8]Pres	[9]K
Site	**$CaCl_2$**	**SMP**	-------------------%----------------				---------mg dm^{-3}---------		
Full sun	5.36	6.40	46.46	0.25	2.89	1.75	4.91	8.78	87.52
Sub-forest	5.08	6.23	41.69	1.83	7.37	1.90	11.03	15.51	148.68
	[10]Ca	[11]Mg	[9]K	[12]Al	[13]H+Al	[14]S	[15]T	[16]t	
Site	-------------------------------$cmol_c$ dm^{-3}-----------------------------								
Full sun	2.33	1.49	0.22	0.01	4.60	4.05	8.76	4.06	
Sub-forest	2.05	1.19	0.38	0.07	5.14	3.72	8.76	3.77	

[1]Potential of Hydrogen in calcium chloride; [2]Potential of Hydrogen in Shoemaker, Mac lean and Pratt; [3]Base Saturation; [4]Aluminium Saturation; [5]Phosphorus in Mehlich1; [6]Carbon; [7]Phosphorus extracted in Mehlich3; [8] Phosphorus extracted in anion exchange resin; [9]Potassium; [10]Calcium; [11]Magnesium; [12]Aluminium; [13]Hydrogen + Aluminium; [14]Sulfur; [15]Cation exchange capacity to pH 7,0; [16]Effective cation exchange capacity

2.2 Experimental Design

The experimental design was a randomized block arrangement with three replications. The main treatments were composed of two types of cultivation: monoculture (single sorghum); intercropping (simultaneous sowing of sorghum + piatã grass). The secondary treatments were composed by the sampling sites, with five sites equidistant between the rows of eucalyptus trees - Agrosilvipastoril (CLFI), with full sun as a control - Agropastoril (CLI). These sites were marked on a transect perpendicular to the rows of trees (East-West direction). Sampling sites (North-South direction) were identified by the letters A; B; C; D and E, with the distances of rows of trees: 3 m; 7 m; 11 m; 7 m; 3 m, respectively.

2.3 Area Management

The sowing fertilization was 200 kg of the formulated 0-20-20, and 40 kg ha^{-1} of FTE BR16 (3.5% Zn, 3.5% Cu, 1.5% B and 0.1% - Mo).

The sorghum hybrid used was the Volumax, with a row spacing of 0.45 m. For the piatã grass, a sowing rate of 5.0 kg of viable pure seeds (VPS) per hectare was used. The sowing of the same occurred in the row and between rows of the sorghum, with spacing of 0.25 m between the grass rows, using mechanized seeder.

Simultaneous sowing of sorghum + piatã grass was carried out between March 7 and 9, 2017. The full emergence of 90% of sorghum and grass plants occurred on 03/16/2017. The harvest took place on July 10, 2017.

2.4 Field Evaluations

The evaluation of photosynthetically active radiation (PAR) occurred at 51; 61; 69; 83; 102 and 117 days after emergence (DAE) of sorghum. Data collection was performed between 9:00 am and 11:00 am (local time, GMT -04 hours) for each evaluation site. Subsequently, it proceeded in full sun, respecting the maximum interval of 10 minutes between the measurement in the shade and full sun, quantified with the aid of a datalogger.

The average shadow percentage of the system was calculated by the radiation absorption of the trees:

$$(A) = [(I0-I) / I0] * 100,$$

where:

I0 = radiation in full sun; I = radiation in the sub-forest.

The phytometric evaluations were performed at 15; 28; 45; 57; 75; 84; 98 and 116 DAE, and leaf height (LH; cm) was measured; stem diameter (SD; mm); total height of the plant (TH; cm).

The evaluation of forage production of sorghum and piatã grass occurred at 84 DAE, when sorghum plants had a dry matter content of 28 to 35%. From the material collected, a representative sample was collected for the morphological separation of the sorghum components: Green leaf, stem, dead material and panicle. The morphological separation of the grass was also performed in the following components: Leaf blade, pseudostem (stem + sheath) and dead material.

After separation, the material was taken to the laboratory and stored in an oven at 55°C until reaching a constant mass for determination of dry matter.

2.5 Graniferous Component

At the moment of physiological maturation, five panicles were collected per evaluation site. At that time, the number of plants in 2 linear meters was counted to obtain the final stand in number of plants ha^{-1} (FSP).

Panicle length (PL; cm) evaluations were performed with the aid of a graduated ruler. Then, all the grains were removed from the panicle in order to obtain the total grain weight and the weight of 1000 grains (W1000; g). With the data of the total grain weight, it was possible to estimate the grain yield (PROD), corrected for 13% of humidity and expressed in kg ha^{-1}.

The harvest index (HI,%) was obtained by collecting two plants per evaluation site at the physiological maturation stage, and these plants were taken directly to a forced ventilation oven at 55°C until reaching a constant mass. Subsequently, the grains and whole area of the sorghum plant were weighed. The HI was obtained through the dry matter ratio of total grains, total dry mass of the area (leaves, stem, sheath, panicle and grains) [7].

2.6 Statistical Analysis

The qualitative factors were submitted to analysis of variance and when the F test was significant, the Tukey test was applied, adopting the probability level of 5%. For the quantitative factors the polynomial regression analysis was performed, verifying the significance for the linear and quadratic effects. The analyze were performed using the SISVAR statistical software [8].

3. RESULTS AND DISCUSSION

3.1 Photosynthetically Active Radiation

The percentage of shading was higher than 30% in the sub-forest, with a general average of 63% of the shade, even after the thinning of 50% of eucalyptus trees (Table 2).

There was a decreasing shading in this direction E<B<C<D<A, showing that site A received the least amount of light, while site E presented higher values of PAR.

Solar radiation is indispensable to plant life as a primary source of energy, regulating photo-synthesis and all plant development, while temperature exerts a marked role in the biochemical phase of carboxylation and reduction of carbon dioxide in the process of photosynthesis [9].

[10] observed that global solar radiation was the most affected microclimatic variable within a silvopastoral system, influenced by the position of the sun and the orientation of the trees.

3.2 Phytometric Characterization of the Complete Cycle of Sorghum

There was a quadratic effect of age on stem diameter (SD) and height of insertion of the last expanded leaf (LH) for sorghum intercropped with piatã grass (Table 3). The plants in full sun reached maximum diameter at 77 DAE (15.13 mm). The C site was later, reaching its maximum diameter (8.23 mm) at 82 DAE. At 45; 58; 75; 84; 98 and 116 DAE, the sites in the eucalyptus sub-forest were not different from each other and were lower than the full sun.

The maximum height was obtaind in full sun at 93 DAE (162.63 cm). In the sites they were decreasing in the order D>C>B>A>E, with the latter site reaching its maximum increase in height at 94 DAE (118.99 cm).

There was a linear effect of age on the Total Plant Height (TH), in cm, for sorghum intercropped with piatã grass (Table 4). The full sun condition presented total plant height superior to the other sub-forest sites, with an average value of 176.79 cm.

[11] testing the establishment of sorghum under seven species of vegetal cover, concluded that from the 80 days after sowing (DAS), the height of the forage sorghum (BRS 601) stabilized for all treatments, based on the nonlinear regression model with logistic adjustment. Plant height is an important measure due to the good correlation with dry matter production and coefficients around 71% [12].

3.3 Sorghum Forage Components

There was interaction in the modalities and the cultivation sites (P = .05) for leaf dry mass (LDM), stem dry mass (SDM), stem proportion (SP) and panicle panicle (PP) (Table 5).

LDM was superior to monoculture sorghum. This lack of competition with piatã grass and trees tends to favor the accumulation of LDM. The sites B, C and E presented lower LDM than the other evaluated sites, even in full sun.

SDM was also superior for sorghum grown in full sun and monoculture. All sub-forest sites obtained SDM below full sun.

Table 2. Percentage of shading (%) in the eucalyptus sub-forest

Sites	Days after emergence (DAE)						Average
	51	61	69	83	102	117	
A	62.55	67.56	68.23	78.43	68.83	79.64	70.87
B	80.12	55.52	67.68	47.74	62.51	51.03	60.77
C	60.81	68.29	64.04	61.00	68.39	66.02	64.76
D	57.51	65.66	82.85	69.19	69.90	59.19	67.38
E	37.99	51.20	85.32	55.90	33.37	48.36	52.02
Average	59.80	61.65	73.63	62.45	60.60	60.84	63.16

Table 3. SD and LH of forage sorghum intercropped with piatã grass in eucalyptus sub-forest

Site	Days after emergence (DAE)								Regression equation	CV (%)	R^2
	15	28	45	57	75	84	98	116			
	Diameter (mm)										
A	4.13	7.93b	9.17b	9.21b	9.14b	9.01b	8.69b	8.72b	$\hat{y}$= 2.898206 + 0.171464x** – 0.001094x2**	8.7	0.80
B	4.51	7.96b	9.06b	8.70b	8.88b	8.25b	8.77b	8.38b	$\hat{y}$= 3.636865 + 0.142218x** – 0.000910x2**		0.73
C	3.52	6.12c	7.71b	7.70b	7.75b	7.69b	8.06b	7.46b	$\hat{y}$= 2.120360 + 0.149462x** – 0.000913x2**		0.89
D	3.54	6.46bc	7.93b	7.64b	8.14b	7.61b	7.54b	7.38b	$\hat{y}$= 2.248224 + 0.152621x** – 0.000971x2**		0.84
E	3.39	6.57bc	8.57b	8.73b	8.59b	8.30b	8.41b	7.67b	$\hat{y}$= 1.518913 + 0.194806x** – 0.001257x2**		0.89
Full sun	5.07	13.0a	15.19a	14.45a	13.84a	13.33a	13.90a	13.28a	$\hat{y}$= 3.530681 + 0.303295x** – 0.001981x2**		0.67
Site	**Leaf height (cm)**										
A	15.36	29.27	83.39bc	128.89b	121.72b	126.67b	127.95b	130.72b	$\hat{y}$= -43.841621 + 3.758937x** – 0.019808x2**	6.3	0.94
B	16.53	32.23	85.47b	126.22bc	117.17b	120.89b	123.00b	128.45b	$\hat{y}$= -37.325459 + 3.540754x** – 0.018693x2**		0.93
C	14.99	25.14	61.30d	113.28c	111.78b	114.28b	117.33b	113.50c	$\hat{y}$= -40.809738 + 3.323271x** – 0.017213x2**		0.93
D	15.25	26.63	70.67cd	113.72c	111.50b	114.61b	115.28b	119.22bc	$\hat{y}$= -37.425565 + 3.267688x** – 0.016809x2**		0.94
E	14.68	23.05	66.25d	112.78c	112.89b	114.17b	114.22b	112.39c	$\hat{y}$= -42.641646 + 3.423400x** – 0.018127x2**		0.94
Full sun	12.26	36.84	104.73a	151.33a	150.67a	151.47a	155.60a	155.20a	$\hat{y}$= -60.104835 + 4.788991x** – 0.025741x2**		0.96

*CV (%): Coefficient of variation; R^2: Determination coefficient. **, *: Significant at the 1 and 5% levels, respectively, by the F test. Means followed by the same letter in the column do not differ by Tukey test at the 5% probability level of error*

Table 4. TH of forage sorghum intercropping with piatã grass

Collect	Days after emergence (DAE)				Regression equation
	57	**75**	**84**	**98**	**116**	
	141.22	146.61	149.20	149.94	152.71	ŷ= 0.186103 + 0.03199352x**
CV (%)	4.11					
R^2	0.92					
Site	**A**	**B**	**C**	**D**	**E**	**Full sun**
	149.39 b	148.24 b	138.93 b	139.86 b	134.39 b	176.79 a
CV (%)	14.20					

*CV (%): Coefficient of variation; R^2: Determination coefficient. **, *: Significant at the 1 and 5% levels, respectively, by the F test. Means followed by the same letter do not differ by Tukey test at the 5% probability level of error.*

Table 5. DLM, SDM, SP e PR, at 84 DAE, of forage sorghum intercropped with piatã grass in eucalyptus sub-forest

Site	A	B	C	D	E	Full sun
LDM (g)						
Monoculture	4.16 Ba	4.25 Ba	4.22 Ba	3.73 Ba	4.13 Ba	9.04 Aa
Intercropping	3.65 Ba	3.03 Bb	2.77 Bb	3.44 Ba	3.06 Bb	6.81 Ab
CV (%)	7.81					
SDM (g)						
Monoculture	9.96 Ba	9.93 Ba	11.31 Ba	9.10 Ba	9.47 Ba	36.74 Aa
Intercropping	8.56 Ba	7.97 Ba	7.39 Bb	8.77 Ba	8.42 Ba	27.20 Ab
CV (%)	11,49					
SP (%)						
Monoculture	30.71 Ba	30.48 Ba	33.47 Ba	30.56 Ba	32.24 Ba	57.14 Aa
Intercropping	32.82 Ba	32.67 Ba	33.76 Ba	33.66 Ba	33.19 Ba	49.38 Ab
CV (%)	5,35					
PP (%)						
Monoculture	55.71 Aa	56.43 Aa	53.95 Aa	56.68 Aa	53.87 Aa	36.74 Ba
Intercropping	52.27 Aa	53.47 Aa	53.19 Aa	52.99 Aa	53.06 Aa	27.47 Bb
CV (%)	4.20					

CV (%): Coefficient of variation. Means followed by the same letter, uppercase in the row, and lowercase in the column, do not differ by Tukey's test (P = .05).

All SP values in the sub-forest were lower than the full sun. Sorghum monoculture in full sun was superior in relation to the intercropping.

PP follows the inverse pattern of the other variables, since it presented a higher proportion for sub-forest environments, not differing for cultivation modalities.

3.4 Grass Forage Components

There was interaction between the cultivation methods and sowing methods of the piatã grass (row spacing and between rows spacing) for leaf dry mass (LDM), stem dry mass (SDM), total dry mass of the aerial part (TDM), stem proportion (SP), Leaf/Stem (L/S) Ratio and Dry Matter yield (DMY) (Table 6).

Site B presented higher LDM, SDM, SP and DMY in the between rows spacing compared to the row. [13] evaluated the yield of *U. brizantha* cv. Marandu, in the different arrangements of the agroforestry system, and pointed out that the available forage was always larger in the between row than in the planting row, regardless of the eucalyptus plantation arrangement.

In shaded environments, to compensate for the lower luminosity in the basal portion of the canopy, plants can raise their leaves and stems in the search for light, a mechanism known as dewatering, and thus improve the distribution of radiation along the canopy [14,15]. These structural alterations of the canopy can, according to [16], influence the composition of the forage mass, as there is greater use of photo-assimilates for the elongation of stem, and greater shading of the bases of the tillers.

According to [17], Brachiaria, when sown in the between row of sorghum, does not interfere in the yield of the same, presenting itself as the most indicated sowing modality in order to minimize the competitive effect in an CLI system. In addition, the use of forages tends to suppress the emergence of weeds due to their aggressiveness [18].

Reverse behavior was observed in full sun, where higher LDM, MSC, SP and DMY were obtained in the line when compared to the between row. [19] found that, with a 32% shading in a silvopastoral system with eucalyptus (*E. urophylla*), Tanzania grass (*Panicum maximum* cv. Tanzania) recorded a decrease in dry mass accumulation rate when compared to open pastures due to the reduction of the amount of available light for the grass.

3.5 Post-harvest Componentes

Panicle length (LP) and final plant stand were not affected by cultivation modalities and sampling sites (Table 7). The average panicle length was 22.44 cm. The average plant stand was 158,000 ha^{-1} plants.

The final plant stand (FPS) and the number of panicles per hectare (NPha) were not influenced by sorghum cultivation (monoculture or intercropping) [20]. [21] stated that the ideal stand for sorghum is between 150 and 200 thousand plants per hectare.

The weight of 1000 grains (W1000) was higher for monoculture sorghum. While for the sites, higher W1000 was observed in sites A and C. According to [22], the weight of 1000 grains is considered stable, being affected only under conditions of stress during the formation of the grains.

The sorghum intercropping with the piatã grass did not influence the HI, whereas in the shaded environment there was an increase of the same in relation to the full sun. The HI represents the ratio between the biological yield and the grain yield, being indicative of the efficiency with which the plant converts the total production of phytomass above the soil into total production of part harvested and commercialized of the crop. As a result, higher harvest rates demonstrate a better targeting of the photo-assimilates from the plant to the grain.

Table 6. LDM, SDM, TDM, SP, L/S and DMY of the piatã grass intercropped with forage sorghum at 84 DAE in eucalyptus sub-forest

Site	A	B	C	D	E	Full sun
LDM (g)						
Row	9.68 Aa	9.44 Aa	14.57 Aa	10.59 Aa	11.76 Aa	14.48 Aa
Between row	8.24 Ba	18.46 Ab	7.91 Bb	12.46 ABa	7.53 Ba	7.37 Bb
CV (%)	28.29					
SDM (g)						
Row	11.65 Aa	11.16 Ab	17.24 Aa	12.09 Aa	13.77 Aa	20.46 Aa
Between row	9.95 Aa	29.36 Ba	8.46 Ab	14.56 Aa	7.77 Aa	6.93 Ab
CV (%)	29.03					
TDM (g)						
Row	22.69 Aa	22.24 Ab	34.15 Aa	24.72 Aa	27.02 Aa	38.00 Aa
Between row	19.78 Ba	50.33 Aa	19.44 Bb	30.29 ABa	17.73 Ba	18.43 Bb
CV (%)	26.16					
SP (%)						
Row	50.51 Aa	49.83 Ab	49.93 Aa	48.84 Aa	50.68 Aa	52.14 Aa
Between row	49.90 Aba	57.72 Aa	42.20 BCb	47.93 Ba	43.25 BCb	35.75 Cb
CV (%)	6.66					
L/S						
Row	0.85 Aa	0.85 Aa	0.85 Aa	0.88 Aa	0.86 Aa	0.73 Ab
Between row	0.83 Aba	0.64 Ba	0.99 Aba	0.86 ABa	1.02 Aa	1.07 Aa
CV (%)	14.42					
DMY (kg ha^{-1})						
Row	7,300 Aa	8,643 Aa	11,142 Aa	10,049 Aa	12,164 Aa	12,183 Aa
Between row	7,885 BCa	18,450 Ab	9,019 BCa	11,889 Ba	7,831 BCb	5,703 Cb
CV (%)	20.67					

CV (%): Coefficient of Variation; Means followed by the same letter, uppercase in the row, and lowercase in the column, do not differ by Tukey's test (P = .05).

Table 7. PL, W1000, Grain yield adjusted to 13% moisture (GY; kg ha^{-1}) and final plant stand (FPS; number of plants ha^{-1}), sorghum in monoculture and intercropped with piatã grass in eucalyptus sub-forest

Modality	PL (cm)	W1000 (g)	HI	GY	FPS
Monoculture	22.81	27.97 a	0.44	2,816.42	156,172.82
Intercropping	22.08	27.12 b	0.43	2,326.25	159,876.52
[1]CV (%)	4.07	0.38	6.31	28.27	7.32
Site					
A	24.02	25.63 b	0.43 ab	2,829.11 ab	157,407.39
B	20.98	30.25 a	0.43 bc	2,331.07 ab	144,444.43
C	22.28	31.36 a	0,47 a	2,496.81 ab	161,111.09
D	22.02	27.39 ab	0.44 ab	2,096.44 b	162,962.95
E	22.95	25.08 b	0.45 ab	2,391.41 ab	149,999.98
Full sun	22.40	25.45 b	0.39 c	3,283.11 a	172,222.20
CV (%)	9.54	8.03	4.32	22.53	11.25

CV (%): Coefficient of variation. Means followed by the same letter in the column do not differ by Tukey's test (P = .05)

HI varies among species and between cultivars within species. Studies have shown that the HI of a crop is highly influenced by sowing density, water availability, nutrients and temperature [23].

Grain yield did not differ among cultivation methods, an interesting fact, since it validates the potential of forage sorghum in an intercropping with forage species, obtaining an average yield of 2,404.63 kg ha^{-1}. Regarding the sampling sites, it is observed a higher yield in the full sun with 3,283 kg ha^{-1}, being 10.6% higher than the national average, and this is due to the greater availability of radiation, which ensures that the plant reaches productive potential.

[24] indicates six characters explaining 51% of the variation in grain yield of sorghum, presenting the following percentages of participation: height of the plant (+ 1.09%), stem diameter (+ 3.28%), thousand grain weight (+ 0.33%), number of spikelets (+ 0.15%), number of grains per panicle (+ 1.17%) and harvest index (+ 55.14%), stating that the HI variable is the main determinant of grain yield. However, the present work does not demonstrate a direct relationship between HI and GY, where, full sun presented a higher productivity in relation to the other sites and a lower HI.

4. CONCLUSION

Sorghum competition with piatã grass affects its morphological components, but does not reflect losses of grain yield or forage mass.

Cultivation of sorghum in the eucalyptus sub-forest abruptly affects the production of its morphological components, reflecting lower grain yield and forage yield.

The piatã grass is harmed when cultivated in the sorghum row, affecting its productive potential.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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