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SOWING ARRANGEMENTS OF SORGHUM WITH BRACHIARIA FOR FORAGE PRODUCTION AND SOIL COVER

Abstract – The objective of this study was to evaluate the dry matter content and morphological parameters of sorghum and brachiaria (signalgrass, specifically palisade grass) grown simultaneously for forage production, along with soil cover formation outside of the primary crop season. The treatments were in a randomized block design consisting of three different sowing arrangements: sorghum + two rows of brachiaria between sorghum rows, sorghum + two rows of brachiaria (one in the row + another between the sorghum rows), and sorghum with brachiaria broadcast; as well as sorghum and brachiaria in monoculture. In the first cycle, the dry matter yield of sorghum was higher, approximately 12.01 t ha^{-1}, in the arrangement of sorghum alone. However, the highest total dry matter yield was obtained in the arrangement of sorghum with broadcast brachiaria, with 11.01 t ha^{-1} for sorghum and 3.75 t ha^{-1} for the brachiaria. In the second cycle, soil cover was greatest in the brachiaria monoculture and the arrangement of sorghum with broadcast brachiaria, at 95% and 86%, respectively. Therefore, intending to produce forage sorghum and form adequate soil cover by brachiaria, the sorghum intercropping with brachiaria in broadcast sowing is a promising strategy.

Keywords: off-season, regrowth, *Urochloa brizantha, Sorghum bicolor.*

ARRANJOS DE SEMEADURA DE SORGO COM BRAQUIÁRIA PARA PRODUÇÃO DE FORRAGEM E COBERTURA DO SOLO

Resumo – O estudo objetivou avaliar a produção de matéria seca e parâmetros morfológicos de sorgo e braquiária em cultivo simultâneo, visando a produção de forragem concomitantemente à formação da cobertura de solo na entressafra. Os tratamentos foram dispostos em delineamento de blocos ao acaso e foram constituídos de três diferentes arranjos de semeadura: sorgo + duas linhas de braquiária (na entrelinha do sorgo); sorgo + duas linhas de braquiária (uma na linha + outra na entrelinha de sorgo); e sorgo com braquiária semeada a lanço, além dos respectivos monocultivos de sorgo e braquiária. A produtividade de matéria seca de sorgo no 1º ciclo foi superior no arranjo sorgo solteiro com obtenção de cerca de 12,01 t ha^{-1}. No arranjo sorgo com braquiária a lanço obteve-se o maior rendimento de matéria seca total com 11,01 t ha^{-1} para o sorgo e 3,75 t ha^{-1} para a braquiária. No segundo ciclo, a cobertura do solo foi maior no monocultivo de braquiária e no arranjo de sorgo com braquiária semeada a lanço, com cerca de 95% e 86%, respectivamente. Visando a produção de forragem de sorgo concomitantemente à formação de cobertura adequada do solo por braquiária, o arranjo sorgo com braquiária a lanço é promissor.

Palavras-chave: Entressafra, rebrota, *Urochloa brizantha, Sorghum bicolor.*

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Brazil ranks ninth among sorghum (*Sorghum bicolor* L. Moench) producing countries. Traditionally, the forage sorghum is grown in the fall-winter and spring-summer seasons. However, most of its production is in the fall-winter and represents approximately 70% of the total sorghum produced in Brazil. The greater concentration of sorghum production in the fall-winter period results from the lower market value of sorghum compared to primary crops like maize and the greater hardiness of sorghum.

These features allow satisfactory yields even under adverse conditions. However, silage production systems involve considerable extraction of nutrients and soil exhaustion because the whole plant is harvested. Also, soil turnover and machine movement lead to high losses of soil and fertility (Freitas et al, 2005). The adoption of no-till planting (Moraes et al., 2016) may minimize this problem by reducing the eutrophication and water pollution besides improving the chemical-physical parameters of the soil through soil cover, crop rotation, nutrient cycling, organic matter preservation, and efficient use of inputs and machinery.

However, the no-till system implies the maintenance of soil cover as long as possible to delay the plant desiccation and to form the straw cover on the soil surface. Menezes et al. (2015) and Pascoaloto et al. (2017) claimed that the use of sorghum, maize, oats, and brachiaria grasses (fall-winter crops) integrated with a planned rotation system provides high potential for plant biomass production with a high C / N ratio, thus ensuring the minimum quantity to keep the soil covered longer. Therefore, aiming to produce the maximum amount of pasture biomass or a no-till system, the simultaneous growth of two or more fall-winter crops may be most appropriate. Supporting this assertion, several authors have found a high plant biomass production in simultaneous growth of sorghum and brachiaria grasses (Borghi et al., 2013; Neto et al., 2014; Ribeiro et al., 2015). Furthermore, Neto et al. (2014) stated that the plant regrowth of brachiaria growing simultaneously with sorghum proved to be a viable technique for forage production and soil cover in the off-season in the Brazilian cerrado (tropical savanna) conditions. Various studies have discussed the advantages of simultaneous cultivation of sorghum and brachiaria grasses.

However, according to Neto et al. (2014), few studies have considered the most suitable sowing arrangement to prevent competition between both species, especially the reduction of sorghum yield. Furthermore, there are no graminicides to stall the growth of brachiaria competing with the sorghum crop. In addition, another gap observed in this area is the absence of studies monitoring the pasture formation and vegetative matter production of regrowth followed by straw cover after sorghum harvest. In addition, no studies address the sorghum growing with broadcast sowing of brachiaria. Thus, this study aimed to evaluate arrangements of sowing forage sorghum with brachiaria aiming at sorghum silage production and the formation of soil cover for no-till planting.

Materials and Methods

The experiment was set up considering the fall-winter growing of forage sorghum intercropped with brachiaria (*Urochloa brizantha*) under the sorghum harvest and pasture formation and straw cover soil after sorghum harvest.

Sorghum was sown together with brachiaria on February 27, 2019, at the “Airport” Teaching, Research, and Extension Unit (UEPE - Aeroporto) of the Department of Agronomy (DAA) of the Universidade Federal de Viçosa (UFV), Viçosa, MG, Brazil. The final evaluation of the soil cover experiment was performed on November 12, 2019, approximately nine months after the experiment implementation. According to the Köppen climate classification, the region climate type is Cwa: hot temperate climate with more rain in summer than winter. A summary of the monthly mean values for maximum and minimum temperatures and monthly rainfall accumulated during the experiment is shown in Figure 1.

The soil is classified as *Argissolo Vermelho Amarelo* (Santos et al, 2018). The soil chemical analyses were performed in the laboratory of the soil department of the Universidade Federal de Viçosa and the results consisted of pH 5.4, phosphorus (P) 5.9 mg dm^{-3}, potassium (K) 44 mg dm^{-3}, calcium (Ca^{2+}) 2.61 $cmol_c dm^{-3}$, magnesium (Mg^{2+}) 0.97 cmolc dm^{-3}, aluminum (Al^{3+}) 0 $cmol_c dm^{-3}$, hydrogen + aluminum (H+Al) 3 $cmol_c dm^{-3}$, sum of bases 3.69 $cmol_c dm^3$, base saturation 55.2%, aluminum saturation 0%, organic matter (OM) 2.15 $dagkg^{-1}$, and residual phosphorus (P-res) 31.2 mg L^{-1}. The analyses were conducted according to the following methodologies: Mehlich-1 extractant for P and K; 1 mol/L KCl extractants for Ca^{2+}, Mg^{2+}, and Al^{3+}; 0.5 mol L^{-1} calcium acetate extractant at pH 7.0 for H + Al; for the soil organic matter (OM) determination. The Walkley-Black method was used for soil organic carbon (SOC) determination, and then OM = Org. C. × 1.724; and S – extractant: monocalcium phosphate in acetic acid for P-res.

A randomized block experimental design was used with five treatments and four replicates. The treatments consisted of five sorghum sowing

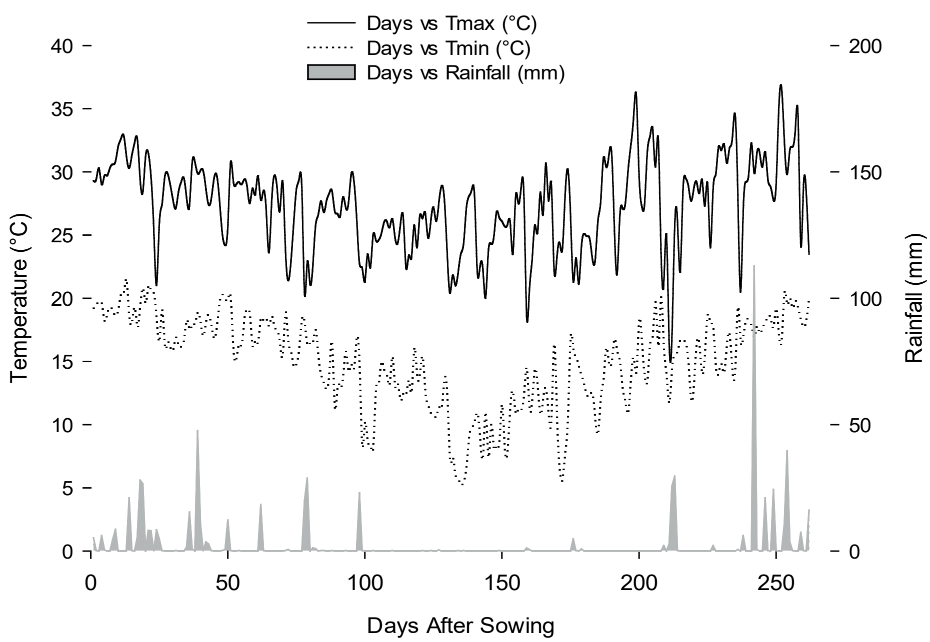

Figure 1. Daily maximum and minimum temperatures (ºC) and daily accumulated rainfall (mm) during the period from 27 February to 15 November 2019 (Source: INMET).

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arrangements using the cultivar SHS 570 Astral and brachiaria (*Urochloa brizantha*) cultivar Marandu.

Three arrangements corresponding to different sowing strategies of brachiaria and sorghum were used. First, sorghum + two rows of brachiaria between the rows of sorghum (SBB); second, sorghum with one row of brachiaria between the rows of sorghum, and third, the row of brachiaria in the sorghum row (SBBR), and sorghum with brachiaria broadcast (SBBc). Two control treatments corresponded to the respective monocultures sorghum (Control 1 – MS) and brachiaria (Control 2 – MB). The area was prepared by desiccation with glyphosate herbicide at the dose of 1.8 kg ha¹ ten days before sowing. The soil was then plowed and disked. Sorghum and brachiaria were sown simultaneously on February 27, 2019. In all the plots with sorghum, 14 seeds per linear meter of the row were sown with the sorghum SHS 570 Astral, a hybrid intended for silage production, with an early cycle.

The brachiaria sown was *Urochloa brizantha* cv Marandu, a perennial vegetative cycle cultivar that grows in clumps. After germination tests made in pots, the pelletized seeds with high purity (around 95%) were used. In the MB, SBB, and SBBR plots, the seeds of brachiaria were sown at a density of 32 g. In the SBBc plots, the sowing density was 48 g to minimize germination and emergence failure due to greater seed exposure to biotic and abiotic factors. Fertilization at planting was performed using 300 kg ha^{-1} of the formulation 8-28-18 of N-P-K, following the soil analysis results.

The fertilizer was applied only in the sorghum rows. The sorghum and brachiaria seeds were sown at a depth of 2 cm, as recommended by Freitas et al. (2005), except in the plots where brachiaria was broadcast. Fertilizer was broadcast in top dressing 25 days after sorghum emergence using 140 kg ha^{-1} of ammonium sulfate (Mateus et al., 2011). Supplemental irrigation was provided up to the beginning of flowering. The weeds were controlled by applying atrazine at the dose of 1.5 kg de a.i. ha^{-1} at 20 days after sorghum emergence using a CO_2 pressurized backpack sprayer maintaining a constant pressure of 200 kPa, equipped with two TT 110.02 nozzles, spaced at 1.0 m and calibrated to apply the equivalent of 100 L ha^{-1} of the spray mixture. At the time of application, the climate conditions were the following: clear sky, moist soil, wind speed less than 5 km h^{-1}, air temperature of around 25°C, and relative humidity greater than 80%.

Plant health control was performed in all plots, maintaining the disease vector pest and organism populations below the Economic Threshold (ET) level. The evaluations were performed regarding shoot biomass of the two forage species, and detailed morphological evaluations were performed on sorghum in the first cycle, between the sowing and first cutting. On July 5, 2019, after harvesting sorghum and brachiaria samples for evaluation, all the plots were cut with a mechanical brush cutter, and the cut plant material was removed from the area to simulate a mechanical silage harvest. In the second cycle, shoot biomass production and soil cover for the different sowing arrangements were studied from regrowth to the second cutting.

For the first evaluation cycle, the stem diameter and plant height variables were measured only for sorghum and consisted of 10 plants chosen randomly at the harvest time. Plant density was determined for the two forage crops. In sorghum, the plant density was done by counting the total number of plants in 3m² (data collection area) through a non-destructive sampling method. A digital caliper rule determined

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the stem diameter, and plant height was determined using a wooden ruler. Sorghum plants were manually cut 5cm above the soil in the data collection area 105 days after sowing. For the dry matter determination, stems, panicles, and leaves were collected separately and weighed for fresh matter determination. Then, the samples were placed in a forced air circulation oven at 70ºC until reaching constant weight, and the dry matter was determined.

At the sorghum harvest, plants of brachiaria were sampled to determine the brachiaria population in the sorghum field. Two random 0.25 m^2 were taken in each plot (Freitas et al., 2005). The plants were cut at soil level, and the tillers were counted to determine the number of brachiaria tillers. Brachiaria plants were also collected for dry matter evaluation by collecting two random samples of $0.25m^2$. The samples were placed in a forced-air circulation oven between 60º and 70 ºC until reaching constant weight. The plots were irrigated twice a day with a water level of 6 mm day^{-1}, since the beginning of the experiment on August 15, aiming to stimulate the regrowth (Alencar et al., 2009).

The fertilization procedure was performed with 144.4 kg ha^{-1} of urea according to soil analysis and the recommended levels for the culture (Ribeiro et al., 1999). The second evaluation cycle began 105 days after the first sorghum harvest (DASH), and from that date, the dry matter of sorghum and brachiaria were evaluated every 15 days. The last evaluation of the dry matter for the two forage species was performed at harvest on 12 November. During the experiments, the plants of sorghum and brachiaria were sampled in an area of 0.25 m2 to determine plant matter. After that, the samples were weighed and maintained separately to determine the fresh matter. Finally, the samples were placed in a forced-air circulation oven at 65ºC until reaching constant weight for the dry matter determination.

In addition, at the time of harvest, the plant density and soil cover were evaluated. Soil cover was estimated visually by randomly casting a $1m^2$ metallic square. Soil cover was determined by attributing scores in terms of percentage of soil cover, where 0 corresponded to the soil without any cover and 100 to total soil coverage. The plant samples for density determination were performed by twice randomly casting a 0.5-m-sided metallic square, and then the plants sampled were cut at soil level and collected. Sorghum and brachiaria were separated in the laboratory, and the tillers were counted. The Shapiro-Wilk normality test was performed on the data obtained for the variables under study. The data of normality were processed without transformation. The Tukey test at 5% probability ($p < 0.05$) was performed on the means of the following variables: plant height, stem diameter, sorghum plant density, tiller density, soil coverage, and dry matter of sorghum and brachiaria.

Regression analysis was also performed to observe the response of total dry matter in regrowth over time during the second evaluation cycle. The regression models were chosen based on the significance of the regression coefficients using the t-test at 5% probability, the coefficient of determination (R2), and the biological phenomenon. The Sisvar and Sigmaplot 11 packages were used to perform the analyses indicated.

Results and Discussion

The results for the means test for the following parameters: plant density, stem diameter, plant height of sorghum, and the number of tillers of brachiaria (first cycle) are shown in Table 1. The mean values for sorghum plant density did

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not differ from each other; a mean value of around 81,934 plants ha^{-1} was observed, regardless of the sowing arrangement. In the first cycle, the rapid establishment and development of the sorghum plants compared to brachiaria prevented the brachiaria interference in the sorghum population (Freitas et al., 2005; Neto et al., 2014). Also, the evaluation of the stem diameter characteristics showed differences among the sowing arrangements. Simultaneously growing sorghum and brachiaria led to a significant reduction in this variable (Table 1) concerning MS, where the stems had a mean diameter of 21.22 mm. The simultaneous growth in SBB and SBBR caused a reduction of approximately 9% in the stem diameter of the sorghum plants. However, the most significant reduction was found in the SBBc arrangement, where stem diameter declined by approximately 15%.

The results suggest a compensation between the total plant densities (sorghum + brachiaria plants) and stem diameter in sorghum plants. The high densities in the SBB, SBBR, and especially in SBBc arrangements may have increased the interspecific competition for light, water, and nutrients, resulting in a reduction of the stem diameter in the sorghum plants (May et al., 2012). There were no changes in the plant height parameter between the MS and SBB arrangements, with a mean of 2.05 m in both cases. In the simultaneous growth in the SBBR and SBBc arrangements, the sorghum plant height increased 13 and 16 cm, respectively. In general, the plants exhibited a lower-than-expected mean height, which may be attributable to the late sowing in March (Santos al., 2013).

In the case of the SBBR arrangement, growing sorghum together with brachiaria in the same row led to great competition between the two forage crops, and the rapid initial development of the sorghum allowed rapid gain in height to compete better for light. In the SBBc treatment, the more significant gain in height suggests a tendency toward etiolation of plants. The high density in SBBc resulted in less space between plants per linear meter, leading to a combined effect of greater intraspecific and interspecific competition for water, nutrients, and light, with consequent stimulation of apical dominance and increase in plant height (Albuquerque

Table 1. Mean values obtained for plant density, stem diameter, plant height, and number of tillers

Sowing arrangement	1st cutting			
	Sorghum			Brachiaria
	Density (plants ha^{-1})	Stem diameter (mm)	Plant height (m)	Tillers m^{-2}
MS	86 798 ns*	21.22 A	2.05 B	-
MB	-	-	-	154 a
SBB	77 266 ns*	19.38 B	2.05 B	115.5 b
SBBR	75 157 ns*	19.20 B	2.18 A	87 b
SBBc	88 516 ns*	17.95 C	2.21 A	195 a
Mean	81 934	19.43	2.12	137.88

MS – monoculture sorghum; MB – monoculture brachiaria; SBB - sorghum + two rows of brachiaria between the sorghum plant rows; SBBR – sorghum with one row of brachiaria between the sorghum rows and another row of brachiaria in the sorghum plant row; SBBc – sorghum with broadcast brachiaria.

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et al., 2013; Brachtvogel et al., 2012; May et al., 2012). Concerning brachiaria, tillering was affected by the sowing arrangement. The most tillers m^{-1} was obtained in the SBBc arrangement, at around 195, exceeding the MB, at 154. In the SBB and SBBR arrangements, there was a reduction of around 25% and 44% in brachiaria tillering, respectively. The high number of tillers obtained in the SBBc is explained by the more considerable amount of seed used in this arrangement, along with the excellent quality seed, which resulted in greater germination and emergence.

Nevertheless, the tillers obtained were of a shorter height and had a smaller stem diameter. There was substantial compensation between the density and the size of the tillers (Santos et al., 2011). In the SBBR arrangement, the more remarkable initial growth and development of the sorghum led to shading the brachiaria in the plant rows, resulting in less growth of the brachiaria due to light deficiency. Under shading and the low light levels that characterize the fall-winter period, there are reductions in brachiaria growth and development (Crestani et al., 2019).

The results for the dry matter yield of sorghum and brachiaria in the first cycle are shown in Figure 2A. The dry matter yield of sorghum varied among the sowing arrangements. The highest value was in MS, with around 12.01 t ha^{-1} of dry matter. Under simultaneous growing of sorghum with brachiaria in the SBBc, SBB, and SBBR arrangements, there were sorghum yield reductions in the order of 7.3%, 15.7%, and 31%, respectively. The lower reduction observed in the SBBc arrangement may have been due to the late germination and emergence of the brachiaria. According to Freitas et al. (2005), this occurs due to broadcasting brachiaria without incorporating the seeds in the soil, augmenting the chance for sorghum to germinate, emerge, and be established. In the case of the SBB arrangement, the presence of brachiaria only between the sorghum rows and the rapid establishment of the sorghum allowed greater initial use of resources and accumulation of reserve substances, resulting in lower reductions in dry matter yield (Silva et al., 2014). In the SBBR, however, the presence of brachiaria in the sorghum plant rows and between the plant rows resulted in greater interspecific competition for light, nutrients, and water. In addition, the experiment conducted in the fall-winter period (low light levels) worsened competition for light, which may have brought about a low photosynthetic rate.

Therefore, it was expected that the experiment performed in the fall-winter period would lead to a drastic reduction in dry matter yield since sorghum is a species with a C4 photosynthetic mechanism, which requires high light levels and high temperatures. However, the drastic reduction did not occur. That is because the mean maximum temperature of 27°C and mean minimum temperature of 16°C observed (Figure 1) were within the mean maximum and minimum limits of 36ºC and 16ºC, respectively, required for the growth and development of the crop (Magalhães et al., 2003). Moreover, although the accumulated rainfall of 315 mm observed during the experiment (Figure 1) did not reach the 380 to 600 mm required by the crop (Sans et al., 2003), this water deficit was overcome by irrigation.

Plant height and stem diameter compensation were other factors that favored acceptable yield levels, even in simultaneous growing. Concerning brachiaria, the mean values obtained for dry matter yield were 4.63, 1.92, 2.39, and 3.4 t ha-1 in the MB, SBB, SBBR, and SBBc arrangements, respectively (Figure 2A). The low temperatures and rainfall may explain the low yield levels observed from March to

June. Even so, the main objective was achieved in the first cycle. The establishment of the brachiaria in this period was essential in all the sowing arrangements. The results for the partitioning of dry shoot matter are shown in Figure 2B. The proportions obtained in partitioning of dry matter for panicles, stems, and leaves were 39%, 56%, and 5% in MS; 37%, 57%, and 6% in SBB; 29%, 64%, and 7% in SBBR; and 41%, 52%, and 7% in SBBc. Partitioning of the dry matter is an indicator of forage quality. It can be presumed that forage quality increases with many panicles concerning stems and leaves. In addition, sorghum growing together with brachiaria in the SBB and SBBR arrangements showed a reduction of 2% and 10% in the partitioning of dry matter of panicles compared to the MS arrangement.

The opposite situation was observed in the SBBc arrangement, which showed a 2% increase compared to the MS arrangement. In the SBB arrangement, there was a reduction in the partitioned percentage of panicle dry matter, which can be explained by the competition between sorghum and the two rows of brachiaria grown between the sorghum rows. In SBBR, the smaller percentage of partitioned panicles can be explained by the intense competition in the row between sorghum and brachiaria, which may have resulted in an allocation of resources for competition in detriment to the accumulation of reserve substances. Contrary, in the SBBc arrangement, the increase of the panicles partitioned percentage can be explained first by brachiaria broadcast without incorporation, which favored the development and establishment of sorghum. Secondly, after emergence, the brachiaria developed rapidly and shaded the basal leaves of the sorghum plants, which could have resulted in etiolation and possible translocation of the photoassimilates to the uppermost part of the plants.

The results for the tiller parameter for the two forage crops and soil cover in the second evaluation cycle are shown in Table 2. The tillering of sorghum in regrowth was more significant in the MS and differed from the simultaneous growing in SBB, SBBR,

Table 2. Mean values obtained for number of sorghum and brachiaria tillers and percentage of soil cover in the 2nd cutting (155 days after the 1st harvest).

Sowing arrangement	2nd cutting		
	Sorghum	Brachiaria	Soil cover (%)
	Tillers m^{-2}		
MS	52 A	-	28 c
MB	-	536 b	95 a
SBB	35 B	386 c	53 b
SBBR	32 B	337 c	60 b
SBBc	33 B	767 a	86 a
Mean	38	507	64.4

MS – monoculture sorghum – Control 1; MB – monoculture brachiaria; SBB - sorghum + two rows of brachiaria between the sorghum plant rows; SBBR – sorghum with one row of brachiaria between the sorghum rows and another row of brachiaria in the sorghum plant row; SBBc – sorghum with broadcast brachiaria.

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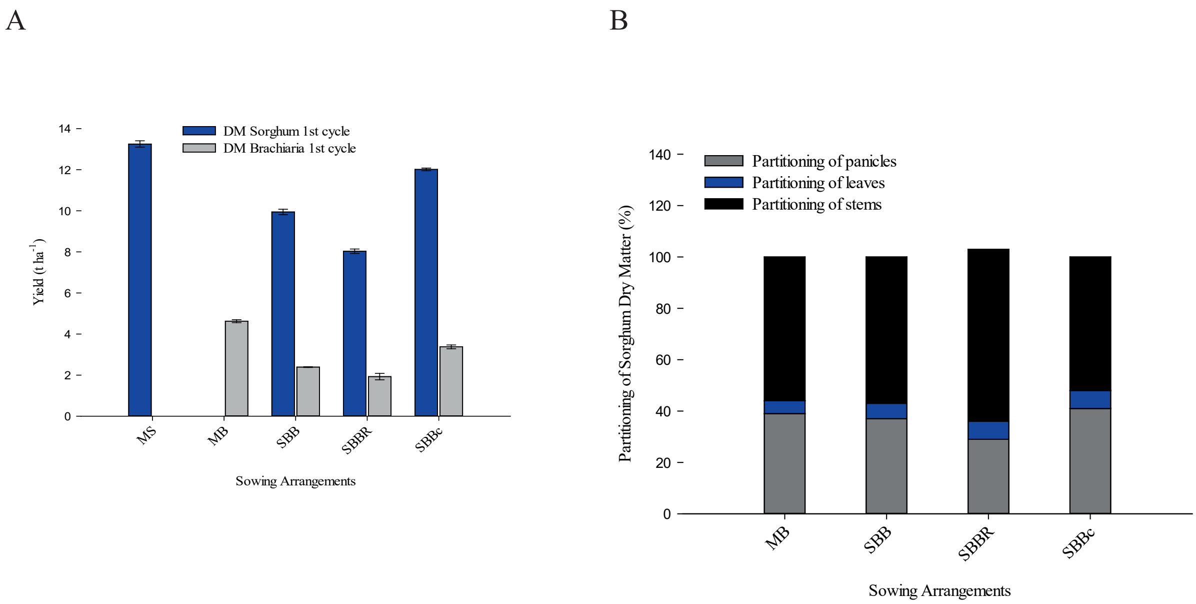

Figure 2. A: Dry matter yield of sorghum and brachiaria and B: Partitioning of plant dry matter of sorghum in the different sowing arrangements. Legend: DM Sorghum – sorghum dry matter and DM Brachiaria – brachiaria dry matter in the 1st cycle; MS – sorghum monoculture; MB – brachiaria monoculture; SBB - sorghum + two rows of brachiaria between the sorghum plant rows; SBBR – sorghum with one row of brachiaria between the sorghum rows and one row of brachiaria in the sorghum plant row; SBBc – sorghum with broadcast brachiaria.

and SBBc (Table 2). However, the latest treatments did not differ from each other. This result suggests a tendency toward reducing in tillering of the regrowth of the sorghum planted together with brachiaria. In simultaneous growing of sorghum with brachiaria, there was probably allocation of resources for the growth and development of the already existing tillers in detriment to the formation of new ones. Another noteworthy aspect is the lower value for tillering of the sorghum in the SBBR arrangement, which may suggest a significant competition when brachiaria was planted in the sorghum row.

The SBBc arrangement had a more significant number of brachiaria tillers in regrowth (767 tillers m^{-2}) and differed statistically from the other sowing arrangements, as shown in Table 2. As the first cycle, tillering in SBBc was more significant than in MB, probably as a consequence of the greater sowing density in this arrangement, along with the excellent quality of both the brachiaria seeds and soil moisture conditions in the post-sowing period (Figure 1), favoring the establishment of the seedlings. Nevertheless, the tillers obtained in the SBBc arrangement had smaller diameter stems than those obtained in MB. Notably, there was compensation between the number of tillers and their stem diameter (Santos et al., 2011). At high population densities, the plants allocate their resources to more rapid growth to avoid shading, thus increasing the possibility of growth above the canopy, though this reduces the stem diameter (Rodrigues et al., 2018; Santos et al., 2011).

The other arrangements, SBBR and SBBc, had lower values for tillering, at 386 and 337,

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respectively. Once more, the SBBR arrangement had the lowest mean value, suggesting that there was a greater competition between sorghum and brachiaria when the brachiaria was planted in the sorghum row, resulting in the allocation of resources for the growth and development of the already existing tillers in detriment to the formation of new ones. There were significant differences for the soil cover parameter evaluated at 155 days after sorghum harvest (Table 2). A more significant percentage for soil cover was obtained in the MB and SBBc arrangements, with 95% and 86% of the soil covered, respectively (Table 2). The percentages of soil cover in the SBB and SBBR arrangements also did not differ from each other, at 53% and 60%, respectively (Table 2).

Notably, these indices were lower than those obtained in the MB and SBBc treatments. The MS arrangement had the lowest soil cover percentage at around 28%. The total soil cover achieved in the MB and SBBc arrangements is a consequence of the quality of the brachiaria seed, along with suitable temperature and rainfall conditions (Figure 1) observed near the end of the evaluation period, from September to November, which resulted in greater availability of resources for tiller growth and development (Timossi et al., 2007). In the SBB and SBBR arrangements, the partial cover obtained resulted from the greater competition between the sorghum and brachiaria in the first cycle, which resulted in less growth and development for both crops. Then, in the second cycle, even with improvement in climate conditions, the plant response of sorghum and brachiaria was slow.

Nevertheless, probably a more remarkable growth and development of brachiaria would occur if the evaluation had been prolonged until December. In the MS arrangement, the lower soil cover was due to the absence of brachiaria and the lower growth and development of the sorghum regrowth. The sorghum regrowth achieves more or less 60% of the dry matter obtained in the first cutting (Botelho et al., 2010), which presumes drastic reductions in plant biomass production and soil cover capacity. The results for sorghum and brachiaria dry matter in the second cycle are shown in Figure 3. The sowing arrangements differed regarding the dry matter yield of the sorghum. The MS arrangement exceeded the others, obtaining around 11.01 t ha^{-1}, which corresponds to 91% of the yield obtained in the first cutting, more significant than the 60% considered satisfactory by Botelho et al. (2010). In simultaneous growing of sorghum with brachiaria in the SBBc, SBB, and SBBR arrangements, there were reductions in dry matter yield in the order of 61%, 35.1%, and 17.5%, respectively, concerning the MS.

In the MS, the yield obtained is a consequence of the absence of interspecific competition in the row and between the rows, which increases the absorption efficiency of nutrients, light, and water (Albuquerque et al., 2011). Although there were reductions in the dry matter yield of sorghum in the second cycle, the levels obtained were satisfactory in the SBB and SBBR arrangements, which may be attributed to the topdressed fertilization performed at the beginning of this growing period. Together with that, improvement in climate conditions, with higher temperature and soil moisture from September to November (Figure 1), favored the growth and development of the sorghum crop.

The forage sorghum with a C4 photosynthetic metabolism is considered a crop sensitive to photoperiod, requiring high temperatures and high light levels to develop fully (Magalhães et al., 2003). However, the sorghum dry matter yield in the SBBc

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arrangement was unsatisfactory and corresponded to approximately 45% of the first cycle. This result suggests that the greater sowing density of brachiaria in this arrangement, together with fertilization, use of seed with a good germination rate, and improvement in climatic conditions from September on (Figure 1), favored the rapid growth and development of brachiaria, suppressing the sorghum plants (Timossi et al., 2007) and reducing their yield.

Furthermore, although satisfactory levels for dry matter yield of brachiaria were not obtained in the first cycle, the establishment of the forage crop was achievable in all the arrangements tested. In the second cycle, satisfactory levels of dry matter of brachiaria were obtained (Figure 3), which confirmed the phenotypic plasticity of brachiaria and its tolerance in response to shading. These features probably allowed to brachiaria establish in simultaneous growing during the first cycle and achieve satisfactory yield levels in the second cycle (Freitas et al., 2005). In the MB and SBBc arrangements, higher brachiaria dry matter yields, 9.1 t ha^{-1} and 8.81 t ha^{-1}, respectively, were obtained. In the SBB and SBBR arrangements, there were reductions in the order of 51% and 44%, respectively, concerning MB.

Although in the SBBR arrangement, there was a suppression of the brachiaria sown in the sorghum rows, there was no interference on the brachiaria plants between the rows. These brachiaria plants were established in the first cycle and, already in the second cycle, with improvement in climatic conditions (Figure 1) from September on, there was rapid growth and development of the brachiaria. Brachiaria species are tropical grasses with a C4 mechanism (Pariz et al., 2010); thus, they require radiant light and high temperatures. Brachiaria grasses thus have better yield performance in the rainy season (Timossi et al., 2007). Contrasting with the first cycle, in the SBB experiment, the yield levels were low, which suggest that the sowing of two rows of brachiaria between sorghum, spaced by 0.5 m, resulted in greater intra- and interspecific competition, consequently

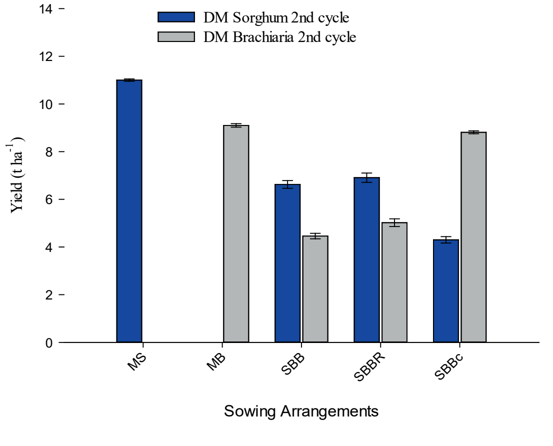

Figure 3. Dry matter yield of sorghum and brachiaria; Legend: DM Sorghum – sorghum dry matter yield and DM Brachiaria – brachiaria dry matter yield in the 2nd cycle; MS – sorghum monoculture; MB – brachiaria monoculture; SBB - sorghum + two rows of brachiaria between the sorghum plant rows; SBBR – sorghum with one row of brachiaria between the sorghum rows and one row of brachiaria in the sorghum plant row; SBBc – sorghum with broadcast brachiaria.

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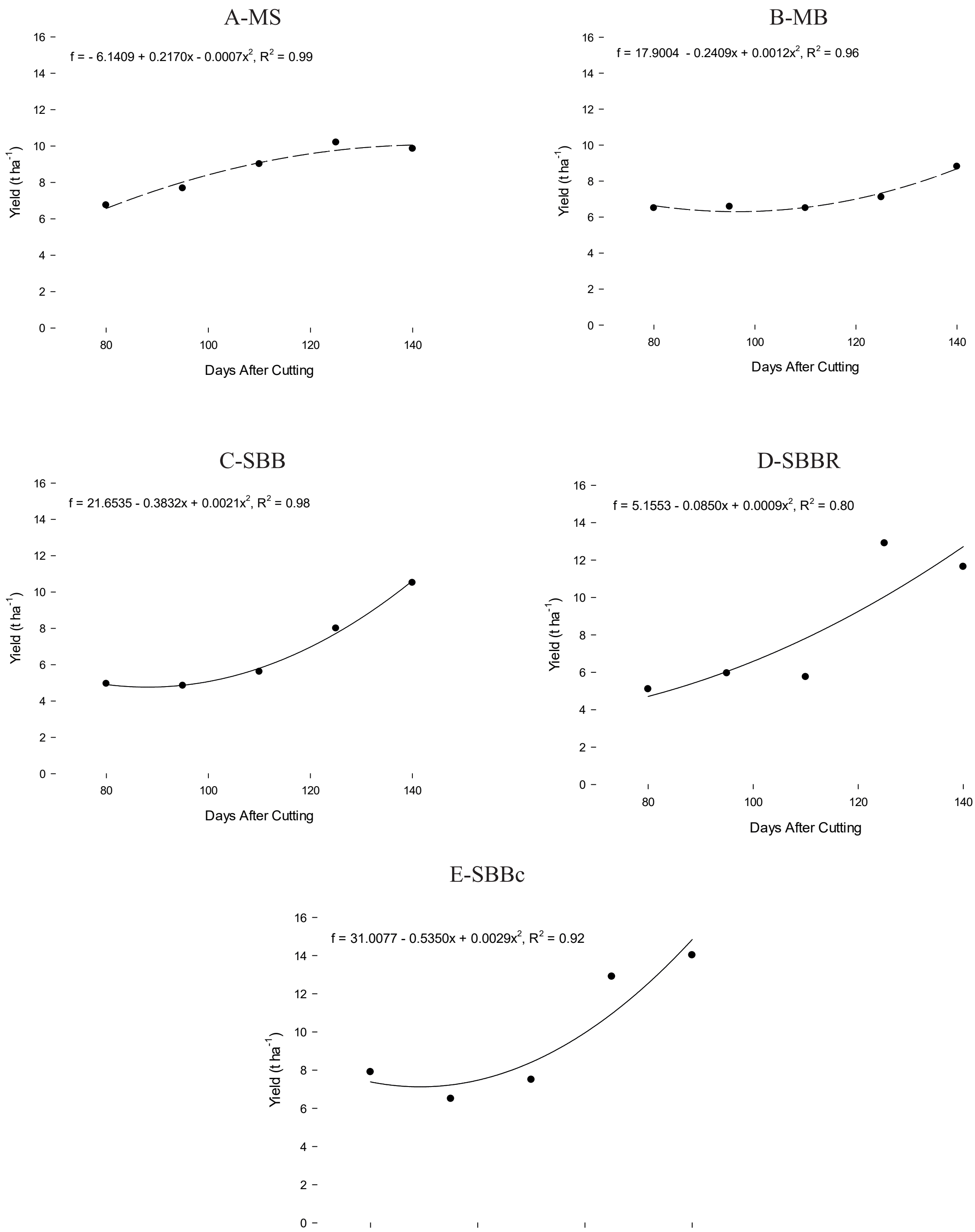

Figure 4. Response of total dry matter over the period of evaluation in the 2nd cycle: A-MS: monoculture sorghum; B-MB: monoculture brachiaria; C-SBB: sorghum + two rows of brachiaria between the sorghum rows; D-SBBR: sorghum with one row of brachiaria between the sorghum rows and one row of brachiaria in the sorghum plant row; and E-SBBc: sorghum with broadcast brachiaria.

leading to a yield reduction of both crops, especially brachiaria. The results for the response of total dry matter accumulation in the second cycle are shown in Figure 4. This total dry matter accumulation had a quadratic response (Figure 4). First, there was an increase in plant matter production. Then, from 140 DAC, the dry matter began to decline, probably due to the beginning of sorghum plant senescence. More gains in sorghum dry matter are not expected from that point on. As senescence begins, there is a gradual reduction in leaf area, which is reflected in the reduction in the dry leaf matter, impacting the total dry matter in sorghum plants (Barbosa et al., 2019). The total dry matter had an increasing quadratic response in all the arrangements involving intercropping of sorghum with brachiaria (4C, D, and E). However, the highest increase rates in the dry matter were found at 140 DAC in the SBBc arrangement, with the accumulation of 14.02 t ha^{-1}, which is due to the combination of good yield indices for sorghum and brachiaria. This result was followed by SBBR (11.64 t ha^{-1}), and the lowest value was for SBB (10.51 t ha^{-1}). It should be highlighted that the total yield of plant biomass in simultaneous growing was more significant than the yields in the respective monocultures. The greater density of brachiaria leading to rapid colonization by the plants can explain the high indices of total dry matter accumulation in the SBBc arrangement. This results in greater use of light and nutrients, consequently, a more significant gain in plant biomass. (Costa et al., 2012; Timossi et al., 2007).

From the total dry matter accumulation, it can be inferred that the simultaneous growing of sorghum and brachiaria proved to be viable for forming pasture or forming soil cover for no-till planting. Regardless of the sowing arrangement, adequate plant biomass was formed both for pasture and desiccation and the formation of straw cover. All the treatments had dry matter yield greater than 6 t ha^{-1}, the amount recommended for forming adequate soil cover (Silva et al., 2014; Timossi., 2007).

Conclusions

Efficiency in production of sorghum forage in the 1st cycle and formation of pasture and/or soil cover in the 2nd cycle varies among the sowing arrangements under dryland conditions. With the aim of producing sorghum in the 1st cycle along with formation of pasture and/or greater soil cover in the 2nd cycle under dryland conditions, the arrangement of sorghum with broadcast brachiaria was most promising because it had sorghum yield near that of monoculture growing in the 1st cycle and, at the same time, provided for soil cover by brachiaria in the 2nd cycle similar to that of brachiaria monoculture.

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