

**O consórcio de milho com sorgo forrageiro influencia a produção de biomassa, a
qualidade bromatológica da silagem e a viabilidade econômica?**

**Does intercropping maize with forage sorghum effect biomass yield, silage
bromatological quality and economic viability?**

**El consorcio de maíz con sorgo forrajera influye en la producción de biomasa, la calidad
bromatológica del ensilado y la viabilidad económica?**

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Resumo

As culturas de milho e sorgo têm uma relevante importância econômica no Centro-Oeste do Brasil e há a necessidade de mais informações para seu cultivo em consórcio como uma estratégia para o produtor rural reduzir a necessidade de insumos. O objetivo deste trabalho foi avaliar se o consórcio de milho com sorgo forrageiro exerce influência em características agronômicas e bromatológicas da silagem, em função de diferentes momentos de aberturas do silo e na viabilidade econômica de todos tratamentos. O experimento foi realizado em condições de campo e foram utilizados sete tratamentos, consistindo de monoculturas de híbridos de milho e sorgo, assim como estas culturas consorciadas. O maior rendimento da massa fresca foi observado no monocultivo de sorgo Agri001 e milho Agri 320, bem como no consórcio dos híbridos de milho Agri 320, Agri 340 e Agri 104 com o sorgo forrageiro Agri 001. As plantas de milho consorciadas não apresentaram acamamento, redução de altura, nem diminuição na altura da inserção da primeira espiga. As silagens oriundas do consórcio dos híbridos de milho com o sorgo forrageiro apresentaram um melhor padrão de fermentação, reduzindo as concentrações de amônia. No entanto, devido ao maior teor de NDF e ao menor de TDN no sorgo, os valores nutricionais das silagens oriundas do consórcio eram geralmente menores do que quando eram compostos apenas pelo milho. Observou-se que o cultivo do sorgo Agri 001 para silagem proporcionou mais lucro que os demais tratamentos.

Palavras-chave: *Sorghum bicolor*; *Zea mays*; Sustentabilidade.

Abstract

Maize and forage sorghum crops have a relevant economic importance in Midwest Brazil and there is a need for more information for their intercropping as a strategy for the farmers to reduce inputs. The objective of this work is evaluate if forage sorghum and maize intercropping effects agronomic traits, the bromatological characteristics of silage from the consortium at different times of silo openings, and the economic viability of all crop systems. This experiment was carried on in the field with seven treatments, consisting of monoculture and intercropping of corn and sorghum hybrids. Monoculture of sorghum Agri 001 and maize Agri 320, as well as in maize Agri 320, Agri 340 and Agri 104 intercropped with sorghum Agri 001 had the highest biomass yield. Intercropped maize did not have lodging, reduction in height, nor decrease in the first ear height in relation to the intercropped plants. Maize hybrids intercropped with sorghum led to a better fermentation pattern of silages, reducing ammonia concentrations. However, due the higher contents of NDF and the lower TDN contents of sorghum, nutritional values of intercropped silages were generally smaller than when they were composed only with maize. It was observed that the monoculture of sorghum Agri 001 for silage showed a higher profit compared to the other treatments.

Keywords: *Sorghum bicolor*; *Zea mays*; Sustainability.

Resumen

Los cultivos de maíz y sorgo tienen una importancia económica significativa en el Medio Oeste de Brasil y es necesario obtener más información para su cultivo en consorcio como estrategia para que el productor rural reduzca los insumos. El objetivo de este trabajo era evaluar si el consorcio de maíz con sorgo forrajera ejerce influencia en las características agronómicas y bromatológicas del ensilado, debido a diferentes momentos de aperturas de silo y la viabilidad económica de todos los tratamientos. El experimento se llevó a cabo en condiciones de campo y se utilizaron siete tratamientos, consistentes en monocultivos de maíz y sorgo híbridos, así como estos cultivos intercroplados. El mayor rendimiento de masa fresca se observó en el monocultivo de sorgo Agri001 y maíz Agri 320, así como en el consorcio de los híbridos agri 320, agri 340 y 104 de maíz con el sorgo forraje Agri 001. Las plantas de maíz intercropping no presentaron escamas, reducción de altura, ni disminución en el momento de la inserción del primer oído. Los silages del consorcio de híbridos de maíz con sorgo forrajera presentaron un mejor patrón de fermentación, reduciendo las concentraciones de amoníaco. Sin embargo, debido al mayor contenido de NDF y al Menor TDN en sorción, los valores nutricionales de los silages originarios del consorcio eran generalmente más bajos

que cuando estaban compuestos sólo de maíz. Se observó que el cultivo del Sorgo Agri 001 para ensilado proporcionaba más beneficios que los otros tratamientos.

Palabras clave: *Sorghum bicolor*; *Zea mays*; Sostenibilidad.

1. Introduction

Maize is one of the most important agricultural commodities due to the high grain production that are destined for human food, livestock, biofuel and agro-industrial systems (Silva et al., 2012; Golin et al., 2020; Moreira et al., 2020). It is an excellent forage resource, as it produces a biomass of excellent quality forage, due to the high values of digestibility and energy, allowing meeting part of the needs of animals in systems of confinement (Holt et al., 2016).

On the other hand, maize crop demands high investments in fertilization and pesticides, challenging the practice of a sustainable cultivation (Silva et al., 2012, Qing et al., 2016; Artuzo et al., 2018). Despite this, several research has indicated the possibility of reducing inputs in agricultural crops in Brazil, such as: reduced soil tillage, integrated pest and disease management, integrated livestock production systems and the use of silicon (Silva et al., 2012; Theodoro et al., 2018; Guazina et al., 2019; Kichel et al., 2019; Fernandes et al., 2020; Guazina et al., 2020; Pezzopane et al., 2020; Souza et al., 2020).

According to Brooker et al. (2014), the cultivation of different species or genotypes in the same area and period of time is very important in crop systems with low resources. Intercropping allows yield and ecological benefits without increasing the need of increased inputs and it is considered a way to sustainable crops and, consequently, to decrease emissions of greenhouse gases.

There are benefits in growing maize intercropped with various species, such as climbing beans (Armstrong et al., 2007), common bean (Latati et al., 2013), forage grass (Cagna et al., 2019), peanut (Jua et al., 2019), vegetable cowpea (Parimaladevi et al., 2019), soybean (Ren et al., 2017) and wheat (Yin et al., 2018). Intercropping of two or more plant species increases primary production due to optimization in the use of the available abiotic resources (Cardinale, 2011; Cruz et al., 2002; Lange et al., 2015). In addition, in the intercropping usually plants present oscillations in the specific dry weight (g cm^{-1}) of each botanical component, and can influence the nutritional value (Cruvinel et al., 2017; Tambara et al., 2017; Epifanio et al., 2019), because there is a reduction in fiber and lignin deposition

in sclerenchyma cells, so cells have less thick walls (Deinum et al., 1996); increasing the bioavailability of compounds with higher nutritional value.

Forage sorghum has interesting characteristics that makes it interesting to be employed in a way intercropped with maize. It exhibits rapid establishment, resistance to water deficit, and, compared to other cultures, presents low requirements of soil fertility (Bogdan, 1977), being an excellent alternative for tropical climate regions, where there are low levels of natural fertility (Santos et al., 2018). Despite being a culture of broad aptitude, the potential of sorghum is little explored because it is considered a minor crop; although there are cultivars for forage, soil cover, grain yield and silage (Ribeiro et al., 2015, Ribeiro et al., 2017).

In three regions of North Kadota, USA, Samarappuli & Berti (2018) evaluated the cultivation of forage sorghum intercropped with corn, mixing the seeds and sowing them randomly. The treatments were four monocultures (grain and silage maize and two sorghum hybrids), four row intercropped maize-sorghum (combination of the same hybrids), and four within-row intercropped maize-sorghum. The authors concluded that intercropping of forage sorghum with maize is a promising alternative to maize silage for forage or as feedstock for biogas production. Despite this, there is a lack of information about the behavior of maize and sorghum cultivars used in Midwest Brazil as well as the characteristics of silage and whether its production can be economically favorable.

The objective of this work is evaluate if forage sorghum and maize intercropping effects agronomic traits, the bromatological characteristics of silage from the consortium at different times of silo openings, and the economic viability of all crop systems.

2. Material and methods

Experimental location

The work was carried out at the school farm of Faculdade de Medicina Veterinária e Zootecnia, Fundação Universidade Federal de Mato Grosso do Sul (20°26'50.6"S54°50'34.0"W), in the city of Terenos, MS at 407 meters altitude. The soil classification was obtained from physical analysis, and thus classified as Red Latosol, with very clayey texture (660 g kg⁻¹ clay, 210 g kg⁻¹ sand, 130 g kg⁻¹ silt) and the climate of the region identified as Aw - Tropical climate, with dry winter and the average annual rainfall is 1201 mm.

Pre-Experimental Management and Treatments

The soil was occupied by intense spontaneous vegetation and *Urochloa* grass that were desiccated by glyphosate (3 L ha^{-1}) application in the first half of April 2017. Using a 90 horsepower and 3,580 kg tractor a 14-inch, 36-inch, full-cut disc harrow operation was performed to create favorable conditions for primary tillage (Theodoro et al., 2018; Golin et al., 2020). The conventional preparation consisted of a plow operation with four 42-inch flat disks followed by four with the leveling harrow (Guimarães et al., 2019).

The experimental design used was randomized blocks with seven treatments and four replications. The experimental plot was 4 meters long and 2.5 meters wide, totaling 10 m^2 . The treatments were represented by monocultures of 3 maize single hybrids (early-cycle, semi-hard grain) and 1 forage sorghum hybrid (early-cycle) and the same maize cultivars intercropped with the forage sorghum hybrid, as follows: maize Agri 104 + sorghum Agri 001E; maize Agri 104; maize Agri 340 + sorghum Agri 001E; maize Agri 340; maize Agri 320 + sorghum Agri 001E; maize Agri 320; sorghum Agri 001. The sowing took place on November 14, 2017, manually, there was 0.50 m between rows, a population of 60.000 (maize) and 150.000 (sorghum) plants per hectare, and employed 145 kg ha^{-1} of fertilizer 8-20-20. In intercropping plots, two rows of maize were used for one of sorghum in intercropping plots, two rows of maize were used for one of sorghum (ratio 2:1), simulating what a farmer could do with a mechanized seeding. We used 180 kg ha^{-1} of N and 120 kg ha^{-1} of K_2O as cover fertilization in all treatments, divided into two phenological stages of maize (V4 and V6), according to Vergütz et al. (2017).

Evaluations

For maize and sorghum hybrids, plant height was determined measuring the distance between ground and the last fully expanded leaf height with a tape (Pricinotto et al., 2015); maize first ear height and plant lodging were determined according to Santos et al. (2010). The evaluation of agronomic traits was performed in 20 plants per plot and localized in central rows at VT phenological stage.

All maize and sorghum plants were cut at 20 cm high for silage when maize plants were in the R5.5 phenological stage, with the milk line positioned halfway between the tip and base of the kernel (Wiersma et al., 1993). The fresh mass of this material was weighed on an analytical balance to estimate the biomass yield. Subsequently, it was stored in experimental silos, formed by PVC pipes (10 cm diameter x 40 cm height) capped with a PVC cover and stored in shed and the silage was compacted with 600 kg m^{-3} (Ítavo et al.,

2010). During the silage process, two experimental silos of each replication were made with the same quantities, compaction, and size.

The opening happened 60 and 120 days after the silage process, one silo of each treatment for a period. After the opening, the silage pH was measured through the liquid obtained in a pressing process of a portion of the material. A sample of the silage was also taken from the silage to be dried in a 55 °C forced-air oven for 72 hours, allowing the definition of the dry matter. After drying, the material was submitted to the milling process in a 2 mm sieve knife mill in order to obtain the samples for bromatological analysis (Cysneiros et al., 2006).

The following variables were evaluated in a factorial design during the bromatological analysis: final dry matter (DM), mineral matter (MM), ethereal layer (EL), neutral detergent fiber (NDF), acid detergent fiber (ADF), crude protein (CP), ammonia nitrogen (N-NH₃) and total digestible nutrients (%TDN).

Statistical analysis

The data were analyzed by means of variance analysis and when statistical difference was observed, the means were compared by the Tukey test with significance of 5%.

Economic analysis

The costs of production, revenue, profit, profit margin, net present value (NPV), internal rate of return (IRR), financial return in years (simple pay-back and discounted pay-back), benefit /cost ratio (Ratio B/C) and profitability index (IL) were evaluated.

Although there is no information available on the economic and financial aspects for silage production at the site of this experiment, the basis for measuring each item was based on literature adapted for other crops (Guazina et al., 2020). To evaluate production costs, we used the operating cost model proposed by Matsunaga et al. (1976) and the evaluations took place through the following cost centers: inputs (herbicides, insecticides, seed treatment, seeds and fertilizers); mechanization (manpower by tractor operation, light and heavy harrow operation, fertilization, sprays and sowing); harvesting, transporting, silage and packaging (machine harvesting operation, compaction with tractor, crop transport truck for silo, canvas and packaging).

The costs of the input item were calculated by multiplying between the amount of each input used per hectare, versus the unit value of each. The costs of the mechanization item

were made according to data from the Fundação ABC (2019), which elaborates the costs per hectare (C) for each agricultural operation required. Although all operations were not carried out in a mechanized way in the experiment, we understood the need to seek information that approximates the reality of the producer, which usually carries out all cultural treatment operations with machinery and agricultural implements. In short, the values are calculated from the sum of the cost calculations per hour of tractor (T), implement (I), and labor (Mo), multiplied by the yield of each hourly activity per hectare (R), described in the formula: $C = (T + I + MO) * R$

The costs of the harvest item (H), transport (T), silage (SI) and packaging (PACK) were calculated from values provided in market research with service providers companies in the region. Thus, the calculations were due to the adequacy of the values reported for the respective services, multiplied by the yield of each activity or production volume as follow: H = US\$ per hectare; T = Value per hour truck / Yield on hectares per hour of harvest; SI = Compaction value + Canvas value; Compression = US\$ per hour tractor / Yield in tons per hour; Canvas = US\$ per tons produced; PACK = US\$ per tons produced.

Revenue was calculated, according to the methodology described for Martin et al. (1994), which is expected revenue for certain activity given to technology (yield) for a predefined sales price. From this perspective, in the present study, the sales price was set at US\$ 112.04 per ton, based on the region's market values. The profit variable was calculated by the difference between revenue and effective operating cost. The profit margin was prepared by the formula: $\text{Profit margin} = (\text{Profit} * 100) / \text{Revenue}$.

All the following calculations were based on the equations proposed by Gitman (2001) and Assaf Neto (2006). The NPV that was calculated by the difference between the expected profit accumulated in the 5-year period and the value of the land acquisition investment, which was estimated at US\$ 7,002.80 per hectare: $\text{NPV} = \text{Current value of accumulated profit} - \text{net investment}$

Internal rate of return, which is the discount rate that leads the current value of the accumulated profit to equal to zero, since this amount becomes equal to the value of the net investment. Simple pay-back and discounted pay-back, which consists of determining the time required (in years) for the net investment amount to be recovered by cash entries. The difference between simple and discounted is that the simple does not consider the opportunity cost in correcting cash entries. In this case, the discounted pay-back considered a cost of opportunity of 6% per year, considering that this would be the profitability proposed by savings in Brazil, for the year of the experiment. The same opportunity cost value was used in

the other financial analyzes: Pay-back = Net investment/Annual cash inbox; The benefit/cost ratio (B/C) consisting of the result of dividing the current value of revenue by the current value of projected costs, including investments.

If the B/C ratio has a result of one or more, the investment is accepted. $B/C = \frac{\sum \text{Projected recipe}}{(\sum \text{Costs} + \sum \text{Investment})}$; Profitability index (PI) which is the expression of the financial return value for each Real invested, being calculated by the formula: $PI = \frac{\sum \text{Current value of cash entries}}{\text{Net investment}}$.

All values were converted to dollar, considering the average value of the currency in the last three years to R\$3.57 for every US\$1, according to information from the Central Bank of Brazil.

3. Results and discussion

Forage production

For fresh forage mass, oscillations were observed between the cultivation systems ($P < 0.05$), in which the monoculture of sorghum Agri 001 presented the highest value (54.25 t ha⁻¹) in relation to other cultivation systems and the monoculture of maize Agri 104 had the lowest biomass value than intercropping (Table 1). These results corroborate with Martin et al. (2012), which found a wide variation in biomass yield among 36 maize genotypes for silage.

Table 1 - Agronomic traits of maize hybrids in monoculture and intercropped with forage sorghum. Terenos, MS, Brazil. Crop season 2017/18.

Treatment	Biomass (t ha ⁻¹)	Plant height (m)	First ear height (m)	Plant lodging (%)
T1	39.67 ^{abc}	1.60	0.76	0
T2	27.92 ^c	1.66	0.75	0
T3	45.96 ^{ab}	1.64	0.67	0
T4	35.92 ^{bc}	1.64	0.69	0
T5	41.00 ^{abc}	1.73	0.78	0
T6	40.33 ^{abc}	1.81	0.79	0
T7	54.25 ^a	1.61	-	0
CV (%)	15.74	11.31	10.42	-

T1: Maize Agri 104 + Sorghum Agri 001; T2: Maize Agri 104; T3: Maize Agri 340 + Sorghum Agri 001; T4: Maize Agri 340; T5: Maize Agri 320 + Sorghum Agri 001; T6: Maize Agri 320; T7: Sorghum Agri 001. Averages followed by lowercase equal letters in the columns do not differ from each other by the Tukey test 5% probability. CV: coefficient of variation.

Sorghum in the consortium can positively influence biomass yield (Table 1), in some cases, the consortium of plants belonging to different functional groups and/or distinct growth habits promotes biomass production values higher than the monoculture (Guzatti et al., 2015; Duchini et al., 2018a; Duchini et al., 2018b; Grace et al., 2018). This advantage in the association of conservative resource plants (e.g., sorghum) with demanding plants in fertility (e.g., maize) was presented by Cruz et al., (2002); the authors expose that the strategic association of these plant groups promotes a better use of the agricultural inputs used (e.g., N-P-K), besides impacting a greater conversion of atmospheric carbon into forage biomass.

For plant height, no disproportionality was observed between cultivation systems ($P > 0.05$) and it is possible to estimate an average height of 1.67 m plant⁻¹ (Table 1). As well as plants in the consortium present at the same height it is possible to deduce that a heterogeneity in the distribution of leaf laminas in the canopy, indicating that there was little competition for luminosity among the tillers, an event that makes it more flexible to coexistence of the forage resources intercropping (Barbosa et al., 2018). The first ear height in maize plants did not show oscillations (Table 1). It is possible to deduce that the production of plant⁻¹ grains of maize will be similar among cultivation systems, due to the absence of disproportionality at the time of ear (Table 1); because it is variable is closely correlated with grain production (Ribeiro et al., 2008). These findings gives confidence of the intercropping systems since, according to Szubori et al. (2002), besides relying on the genetic background of cultivars, plant and first ear height is directly related to dry mass yield and also influenced by environmental factors and plant cultivation methods.

It was expected that intercropped plants could modify the growth habit, due to possible intraspecific competition for luminosity; tillers increase to stem height, and reduce their diameter (Nakao et al., 2018) making plants more prone to lodging. However, this event was not observed in intercropping (Table 1), indicating that the population of plants used allowed the coexistence of grasses throughout the silage production cycle.

Nutritive value of silage in cultivation systems

For the bromatological composition of silage there was no interaction between silage opening and cultivation systems ($P < 0.05$). The pH showed no difference between the cultivation systems (Table 2), being close to the values considered (Gurgel et al., 2019), indicating that the consortium allows the production of a quality silage (Ribeiro et al., 2017).

Table 2 - Bromatological composition of sorghum silage and maize hybrids in monoculture and intercropped with forage sorghum. Terenos, MS, Brazil. Crop season 2017/18.

Treatment	pH	N-NH ₃ (mg dl ⁻¹)	DM (%)	EE (%)	CP (%)	NDF (%)	ADF (%)	MM (%)	TDN (%)
T1	3.66	16.54 ^b	27.01 ^{ab}	2.16	6.96 ^{abc}	53.77 ^{ab}	34.63 ^{ab}	5.59 ^{ab}	58.30 ^{ab}
T2	3.69	23.51 ^a	32.13 ^a	2.13	6.78 ^{abc}	51.74 ^{ab}	30.89 ^{bc}	4.88 ^{bc}	59.85 ^{ab}
T3	3.66	16.55 ^b	28.58 ^{ab}	2.12	6.62 ^{abc}	53.18 ^{ab}	34.46 ^{abc}	5.57 ^{ab}	58.74 ^{ab}
T4	3.68	23.05 ^a	31.96 ^a	2.32	7.28 ^a	49.06 ^b	28.66 ^c	4.70 ^c	61.90 ^a
T5	3.71	17.69 ^{ab}	27.38 ^{ab}	2.19	6.53 ^{bc}	52.67 ^{ab}	32.94 ^{bc}	5.29 ^{abc}	58.14 ^{ab}
T6	3.68	20.74 ^{ab}	32.25 ^a	2.18	7.04 ^a	47.73 ^b	30.15 ^{bc}	4.84 ^{bc}	62.92 ^a
T7	3.65	16.29 ^b	23.97 ^b	1.93	6.31 ^c	58.29 ^a	39.42 ^a	5.84 ^a	54.84 ^b
CV (%)	1.2	17.6	14.2	14.4	6.75	10.18	11.51	10.69	6.85

T1: Maize Agri 104 + Sorghum Agri 001; T2: Maize Agri 104; T3: Maize Agri 340 + Sorghum Agri 001; T4: Maize Agri 340; T5: Maize Agri 320 + Sorghum Agri 001; T6: Maize Agri 320; T7: Sorghum Agri 001.. Averages followed by lowercase equal letters in the columns do not differ from each other by the Tukey test 5% probability. CV: coefficient of variation. Dry matter (%DM), mineral matter (%MM), ether extract (%EE), neutral detergent fiber (%NDF), acid detergent fiber (%ADF), crude protein (%CP), ammoniacal nitrogen (N-NH₃), total digestible nutrients (%TDN).

The monocultures of maize (Agri 104 and Agri 340) have higher N-NH₃ values, suggesting that both forage materials have moderate aptitude to be ensilage, on the other hand, with the inclusion of the sorghum the N-NH₃ values reduced (Table 2), indicating that adequate fermentation occurred in the partner, corroborating Cruvinel et al. (2017).

Maize monocultures have the highest estimates of DM (Table 2), close to the values considered adequate (Rezende et al., 2008), the consortium was expected to reduce the DM

fraction due to the structural changes that plants present in biodiversity environments (Cruvinel et al., 2017).

Silage from the monoculture of sorghum Agri 001 had the lowest CP values (6.31%), on the other hand, high values of MM, NDF and ADF in relation to other cultivation systems (Table 2) is observed, so the consortium has a tendency to produce a less fibrous material and possibly with low fractions of lignin (Epifanio et al., 2019).

The consortium with sorghum did not positively influence the fraction of CP, because the highest values were recorded in maize monocultures (Agri 340 and Agri 320), also presenting the highest estimates of TDN (62.41%) in relation to other cultivation systems (Table 2). Regarding EE it is possible to observe an average value of 2.14% for cultivation systems (Table 2), these low estimates of EE often observed in C₄ grasses (Souza et al., 2019).

Nutritive silage value between silo opening days

The silage opening time influenced pH ($P < 0.05$), where after 120 days of storage generated an average value of 3.72. It was not observed difference between storage days for N-NH₃, DM, CP, NDF, ADF, EE, MM and TDN no differences are observed (Table 3).

Table 3 - Comparison between silage opening times with silage maize hybrids in monoculture and intercropped with forage sorghum. Terenos, MS, Brazil. Crop season 2017/18.

Variable	Silo opening		CV (%)
	60 days	120 days	
pH	3.63 ^b	3.72 ^a	1.21
N-NH ₃ (mg.dL ⁻¹)	4.35	4.28	10.48
DM (%)	29.89	28.32	12.86
EL (%)	2.07	2.22	17.02
CP (%)	6.60	6.97	6.75
NDF (%)	53.28	51.41	10.18
ADF (%)	33.27	32.77	11.51
MM (%)	5.29	5.20	10.69
TDN (%)	58.67	60.10	6.85

Averages followed by different letters in the line differ from each other by the Tukey test 5% probability. CV: coefficient of variation. dry matter (%DM), mineral matter (%MM), ethereal layer

(%EL), neutral detergent fiber (%NDF), acid detergent fiber (%ADF), crude protein (CP %), ammonia nitrogen (N-NH₃), total digestible nutrients (%TDN). CV: coefficient of variation.

According to Leibensperger and Pitt (1987), there is an interaction between pH and DM content to inhibit the development of bacteria of the genus *Clostridium*, therefore, for silages with lower MS content, lower pH values are needed to inhibit the bacterial growth. In this case, the silo open at 120 days would be subject to *Clostridium* development in silage.

Economic evaluations

Regarding the economic evaluations, as a consequence of productivity, the revenues presented by the treatments, in increasing order, were: maize Agri 104, maize Agri 340, maize Agri 104 + sorghum Agri 001, maize Agri 320, maize Agri 320 + sorghum Agri 001, maize Agri 340 + sorghum Agri 001 and sorghum Agri 001 (Table 4). These values alone do not provide sufficient information to producers, but are the basis of profit calculation and profit margin, which are most significant data at their decision-making in or not to perform the activity.

Table 4 - Economic results of the commercialization of maize hybrids silages in monoculture and intercropped with forage sorghum. Terenos, MS, Brazil. Crop season 2017/18.

Variable	T1	T2	T3	T4	T5	T6	T7
Fresh mass yield (t.ha ⁻¹)	39.67	27.92	45.96	35.92	41	40.33	54.25
Revenue (US\$.ha ⁻¹)	4,444.82	3,128.29	5,149.58	4,024.65	4,593.84	4,518.77	6,078.43
Effective operating cost (US\$.ha ⁻¹)	2,133.94	1,857.17	2,360.24	2,168.87	2,205.3	2,244.78	2,468.83
Inputs (US\$.ha ⁻¹)	867.16	900.11	927.67	1000.95	903.47	960.61	817.75
Mechanization (US\$.ha ⁻¹)	102.55	102.55	102.55	102.55	102.55	102.55	102.55
Harvest, transport, silage and packaging (US\$.ha ⁻¹)	1,164.22	854.51	1,330.02	1,065.38	1,199.28	1,181.62	1,548.53
Profit (US\$.ha ⁻¹)	2,310.88	1,271.13	2,789.34	1,855.78	2,388.54	2,273.99	3,609.6
Profit margin (%)	51.99	40.63	54.17	46.11	51.99	50.32	59.38

T1: Maize Agri 104 + Sorghum Agri 001; T2: Maize Agri 104; T3: Maize Agri 340 + Sorghum Agri 001; T4: Maize Agri 340; T5: Maize Agri 320 + Sorghum Agri 001; T6: Maize Agri 320; T7: Sorghum Agri 001

The results related to production costs demonstrated peculiar values for each treatment. The treatments of lower and highest effective operating cost, respectively, was the monoculture of the maize Agri 104, which counted production cost in the amount of US\$1,857.14; the cultivar of sorghum Agri 001 presented production cost of US\$2,468.83.

The values obtained were different from those presented in EMBRAPA technical communiqués (Richetti & Cecon, 2014, Richetti et al. 2017) for the production of second season maize grains and graniferous sorghum. In these announcements, the actual operating cost was US\$568.22 for maize and \$285.69 for sorghum. The great difference between these values and those obtained in the present study is explained mainly by the value disbursed in fertilizers, since the recommendation of fertilization for silage is greater than the recommendation for grain production (Vergütz et al., 2017).

Santos et al. (2017) presented average ECO (effective operating cost) for silage production in the states of Minas Gerais and São Paulo in the 2015/16 harvest of US\$1,320.19, a value lower than that obtained in the present work but closer in relation to the values mentioned in the paragraph above. The difference in the numbers of Santos et al. (2017) can be justified by the difference in market values between the regions, by the cultivars in question and mainly by the values attributed to the packaging process for marketing.

The cost center called "inputs" accounted for equal values in all treatments, with regard to expenses with: herbicides, insecticides, fertilizers and seed treatment. In this center, the only difference found was the cost of acquiring the seeds of the hybrids used in each treatment. Sorghum Agri 001 had the lowest seed cost (US\$58.82) and this is due to the high amount of seeds per kilo, which provides a higher yield, in addition to high plant population per hectare.

This fact corroborates with Pinho et al. (2007), who related the sorghum had a lower production cost, considering the lower consumption and price of seeds. Neumann et al. (2003) also present input costs and operations with sorghum hybrids that vary depending on the purchase price of the seed.

The mechanization, as well as the input center, accounted for equal costs for all treatments (US\$102.55), since they were considered the same crop operations, which were

considered: a heavy harrowing, four light harrowing, sowing, two fertilizations and three pesticide sprays.

However, these values were accounted for from information provided by the Fundação ABC, since the services performed in the experiment were done manually and this study seeks to bring the information closer to the reality of the farmers. The center harvest, silage and packaging presented different costs for each treatment, since this center has factors directly related to yield. The values that contribute the most to the increase of this cost center are the ones spent with: harvest, canvas and packaging for sale. The largest and lowest value of this center, are arranged for the treatments: sorghum Agri 001 (US\$1,548.53) and maize Agri 104 (US\$854.51), a fact that is again justified by the volume of fresh mass produced by the treatments. Neumann et al. (2003) also observed costs of harvesting and silage process varying according to fresh mass production.

In this study, the cost of \$20.06 per tonne was considered to pack silage in order to allow its commercialization in bags with 27kg. Santos et al. (2017) does not stipulate packaging costs for the commercialization of silage and, this difference entails a value almost twice as large to the cost center harvesting, transport, silage and packaging in relation to the harvesting and silage center presented by the author. In the face of this information, a ratio of operational cost and productivity was observed, since, as the operating cost increased, production also, the opposite in the same way. It was observed in the treatment composed only by the sorghum Agri 001 a higher profit, followed by treatments composed of: maize Agri 340 + sorghum Agri 001; maize Agri 320 + sorghum Agri 001; maize Agri 104 + sorghum Agri 001; maize Agri 320; maize Agri 340 and maize Agri 104, respectively (Table 5).

Table 5 – Financial analysis of maize hybrids silages in monoculture and intercropped with forage sorghum. Terenos, MS, Brazil. Crop season 2017/18.

Treatment	NPV (US\$)	IRR (%)	Pay-back simple	Pay-back discounted	Ratio B/C	Profitability Index
T1	2,731.47	19.0	4	4	1.17	1.39
T2	-1,648.36	-3.0	6	6	0.88	0.76
T3	4,746.93	28.0	3	3	1.28	1.67
T4	814.40	10.0	4	5	1.05	1.11
T5	3,058.60	21.0	3	4	1.18	1.43

T6	2,576.06	19.0	4	4	1.15	1.36
T7	8,202.14	43.0	2	3	1.47	2.17

T1: Maize Agri 104 + Sorghum Agri 001; T2: Maize Agri 104; T3: Maize Agri 340 + Sorghum Agri 001; T4: Maize Agri 340; T5: Maize Agri 320 + Sorghum Agri 001; T6: Maize Agri 320; T7: Sorghum Agri 001.

It is evident that treatments with maize intercropped with sorghum stand out in terms of profitability compared to treatments with maize in monoculture, this is due to the increase in the volume of silage production. No results were found in the literature regarding profit and profit margin from the sale of silages. However, Neumann et al. (2004) obtained higher profit per animal in confinement using sorghum silage, compared to maize silage, since this result had a direct influence on the production cost of the silages.

The indicators NPV (net present value), IRR (internal rate of return), simple and discounted payback, cost benefit ratio (B / C) and IL (profitability index) were presented in the financial analysis table (Table 5). This information will provide real input to the producer in Mato Grosso do Sul at the moment of making the decision to start or continue the production and commercialization of silage. A linear behavior was observed in the financial analyzes, with the treatments showing values of NPV, IRR, B / C ratio and PI, in 5 years in decreasing order, in the order: treatment 7 (sorghum Agri 001), followed by treatments 3 (maize Agri 340 + sorghum Agri 001), 5 (maize Agri 320 + sorghum Agri 001), 1 (maize 104 + sorghum Agri 001), 6 (maize Agri 320), 4 (maize Agri 340) and 2 (maize Agri 104) , respectively.

The monoculture of sorghum Agri 001 (T7) presented the lowest values for simple and discounted pay-back, in 2 and 3 years, respectively. Treatment 4 (maize Agri 340) presented the highest values within the evaluated period, 4 and 5 years, for simple and discounted pay-back, respectively, and treatment 2 (maize Agri 104) was the only one that failed to present pay- simple and discounted backs within the analyzed period. No materials were found that address financial analysis for the production and commercialization of silages. Therefore, this study serves as an information base for further research with other cultivars, crop systems, hybrids and even locations.

4. Final Considerations

The results obtained showed that maize intercropped with forage sorghum influences biomass production, silage quality and economic viability of the evaluated systems. Future studies should investigate the effect of different moments of cutting, less inputs, and ratio between maize and forage sorghum rows, as well the evaluation of sorghum cultivars with different aptitudes.

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