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PRODUCTION AND QUALITY OF SORGHUM SILAGE INTERCROPPED WITH MARANDU GRASS AND PIGEONPEA

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Abstract

Lack of forage in the winter dry season is a concern for cattle production in tropical Brazil. Pasture renovation with silage production might solve an immediate concern for forage production and help develop an improved pasture condition after cropping. The present study was focused to compare the production and quality of monocropped sorghum and sorghum intercropped with Marandu grass and/or pigeonpea in two row spacings. The experiment was carried out on a sandy Oxisol in São Paulo state in Brazil with an experimental design of a 2 x 4 factorial arrangement with four replications. Treatments were: monocropped sorghum, sorghum intercropped with *Urochloa brizantha*, sorghum intercropped with *Cajanus cajan* (cv. BRS Mandarim), and sorghum intercropped with *Urochloa*+ pigeonpea with 0.45 and 0.90 m row spacings. Greatest forage production was with 0.45-m spacing for monocropped sorghum and dual-species intercropping. With 0.90-m spacing, greatest production was for *Sorghum*+*Urochloa*. *Sorghum*+*Urochloa*+*Cajanus* intercropping provided the highest concentrations of crude protein in silage, regardless of row spacing. An increase in ensiling time reduced quality of the silage due to a decline in crude protein and TDN and an increase in fibers. However, the reduced spacing between lines with the inclusion of legumes resulted in a greater amount of silage with a higher concentration of protein.

Keywords: *Sorghum bicolor*; *Urochloa brizantha; Cajanus cajan;* tropical grass.

PRODUÇÃO E QUALIDADE DE SILAGEM DE SORGO CONSORCIADO COM CAPIM MARANDU E FEIJÃO GUANDU

Resumo

A falta de forragem na estação seca é uma preocupação para os produtores de carne bovina no Brasil. A renovação de pastagens com produção de silagem pode se constituir em uma alternativa para a produção de alimento para o período seco do ano e, ao mesmo tempo, porporcionar a formação de pastagem de melhorar qualidade. O presente estudo teve como objetivo comparar a produção e a qualidade da silage de sorgo em monocultivo e consorciado com capim-marandu e/ou feijão-guandu em dois espaçamentos entre linhas. O experimento foi conduzido em Latossolo arenoso no estado de São Paulo com delineamento experimental em arranjo fatorial 2 x 4, com quatro repetições. Os tratamentos foram: sorgo em monocultivo, sorgo consorciado com *Urochloa brizantha*, sorgo consorciado com *Cajanus cajan* (cv. BRS Mandarim) e sorgo consorciado com U. *brizantha* + *C. cajan* com espaçamento de 0,45 e 0,90 m. A maior produção de forragem foi obtida com espaçamento de 0,45 m para sorgo monocultivo e no consórico de duas espécies. Com espaçamento de 0,90 m, a maior produção foi para sorgo+*U. brizantha*. O consórcio sorgo *U. brizantha*+*C. cajan* proporcionou as maiores concentrações de proteína bruta na silagem, independentemente do espaçamento entre linhas. O aumento do tempo de ensilagem reduziu a qualidade da silagem devido à queda de proteína bruta e NDT e aumento de fibras. O espaçamento reduzido entre linhas, com a inclusão de leguminosas resultou em maior quantidade de silage, e maior concentração de proteína.

Palavras-chave: *Sorgo bicolor*; *Urochloa brizantha; Cajanus cajan;* Grama tropical grass

1. Introduction

Cattle production is a large commercial activity in Brazil. Pasture land area is 165 Mha and corresponds to 18% of the total land area in Brazil (CARVALHO, 2017). This vast land use needs reclamation, as ~80 Mha have been degraded and more than half of this area (50 Mha) highly degraded (JANUSCKIEWICZ *et al.*, 2015). Cattle stocking rate is low, with no more than one animal per hectare (DIAS *et al.*, 2016).

Annual meat production in Brazil is 10.9 million tons, which corresponds to only 66 kg ha^{-} year^{-1} (ABIEC, 2019). Current productivity of Brazilian pastures may be only 1/3 of its potential (STRASSBURG *et al.*, 2014). Therefore, Brazil could double or even triple meat production per area with an increase in quality of pasture and cut production time to cattle maturity in half. With consideration of these factors (area and time), cattle meat production could be over 40 million tons per year.

One way to increase production is to intensify the correct grazing management pasture on land areas, and thereby limit the need to expand into tropical forest areas (MAZZETTO *et al.*, 2015). Pasture improvement culminates in greater productivity and efficiency, especially in the dry period of the year, resulting in economic and environmental gains from Brazilian livestock production (FLORINDO *et al.*, 2017). It has been projected that Brazil has enough land to meet the growing global demand for meat without deforestation (STRASSBURG *et al.*, 2014). In the past, degraded pastures were treated as a major problem, but nowadays they are considered a new agricultural frontier for greater food production. More efficient use of pasture land areas in Brazil is taking place thanks to the growing adoption of integrated crop-livestock systems.

The integrated crop-livestock systems have great potential in Brazil. However, the traditional systems of extensive livestock farming are still prevalent in the tropics, but are low in productivity and environmentally expensive (LATAWIEC *et al.*, 2014). Reclamation of degraded pastures is possible with integrated management practices (FLIEBBACH *et al.*, 2007; LANDERS; FAO, 2007). Traditional agricultural systems can be improved to minimize adverse environmental impacts (IQBAL *et al.*, 2019). One of the ways to rejuvenate pasture production and quality is with soil fertility inputs during initial transition with silage production in consortium with legumes. This focus on high-quality fodder production for livestock could help rejuventate soil and pasture. Production of silage puts emphasis on improving the fertility of the farm itself, rather than input of fodder externally.

Pasture renovation is also important to overcme low forage supply in the dry season in tropical regions (April to September). In the tropics, animal performance is limited by seasonality of forage production (MACIEL *et al.*, 2018). To circumvent the forage deficit, options are needed to intensify production and provide more year-round forage availability. One way to avoid the problem of forage production seasonality is by stocking silage, however, when it comes to sorghum silage there is little information regarding storage time and the effect on quality (FERNANDES *et al.*, 2020), especially when silage is made with a mix of species.

For sandy soils, species selection for silage production must prioritize tolerance to water deficit. Sorghum (*Sorghum bicolor*) may be a drough-tolerant species for silage production (NEUMANN *et al.*, 2002). It is an alternative to corn (*Zea mays*) and its production in Brazil has been expanding, mainly in water deficit regions (SOUZA *et al.*, 2003), where corn does not perform as well (NEUMANN *et al.*, 2005; RODRIGUES FILHO *et al.*, 2006). Sorghum has high photosynthetic rate (AMADUCCI *et al.*, 2004; ZHAO *et al.*, 2009) and high yield (FERNANDES *et al.*, 2009). It has great capacity to produce abundant biomass even in low fertility soils (RIBAS, 2010) and conditions of water deficit (SANI *et al.*, 2011).

Despite the increasing use of sorghum for silage production, its bromatological quality is somewhat lower than for corn silage, but with advantage of lower production cost (REZENDE *et al.*, 2015). In addition, it adapts well in different environments, especially under water deficient conditions (HARRIS *et al.*, 2007). Sorghum and legumes DM yields and quality can be improved sorghum plant density and potential annual legumes for intercropping (UMESH *et al.*, 2022). The issue of silage quality may be improved by intercropping with legumes and pasture grasses. These intercropped species with sorghum could provide immediate pasture with improved botanical composition after cutting the silage.

One type of integrated crop-livestock system is the Santa Ana system (Figure 1), which was developed by researchers from Unoeste and Embrapa, and tested on farms in the Western Paulista region (Fazenda Experimental da Unoeste and Fazenda Campina) (COSTA *et al.*, 2016; RIBEIRO *et al.*, 2017; IQBAL *et al.*, 2019). The Santa Ana system has four components for farmers to focus on: **(1)** chemical soil correction - no-tillage should be carried out one year before the implementation of forage for silage, or with tillage system when this time is not respected or when necessary; **(2)** forage planning for the dry season - the main crop for silage should always be intercropped with some forage species; **(3)** renovation of the pasture during production of silage; and **(4)** consideration of the area for other annual crops, such as soybeans - if it is of interest to the rancher for farm diversity.

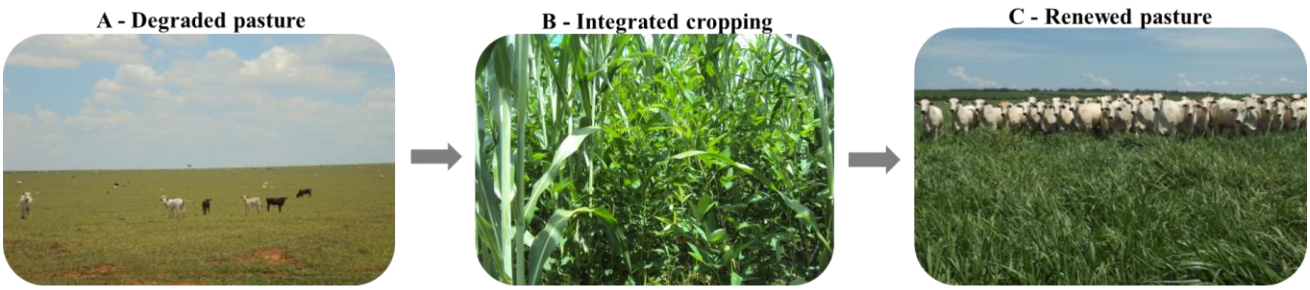

Figure 1. The Santa Ana integrated crop-livestock system approach to enhance soil fertility with production of silage during transition to renovated pasture.

Intercropping with forage grasses and legumes improves land use efficiency (HAUGGAARD-NIELSEN *et al.*, 2001), and it may provide better quality silage (ANDRIGUETTO; PERLY, 2002) and higher nutritional value of subsequent forage (DAWO *et al.*, 2007). When intercropping, increasing the density of plants and reducing row spacing may better optimize light interception by increasing leaf area index and improving the use of water and nutrients (MOLIN, 2000). Obtaining high nutritional quality of intercropped forage grasses will be extremely important for cropping systems (COSTA *et al.*, 2020).

Intercropping of leguminous and grass species is considered a promising and profitable alternative (MACHADO, 2009; OBALUM; OBI, 2010) resulting in benefits for production systems with increased biomass production, biological N fixation and forage quality for animal feed (TIRITAN *et al.*, 2013). In addition to the production of silage or grain, the intercropped system can improve the condition of pasture, especially in regions of tropical climate with water restriction, common in autumn and winter. *U. brizantha* cv. Marandu has proven to be one of the most aggressive grasses in Brazil. Intercropping *U. brizantha* with shrub legumes has been recommended (BARCELLOS *et al.*, 2008). Pigeonpea (*Cajanus cajan*) is a shrub legume and one of the main legumes grown in different regions of the world (TANGTAWEEWIPAT; ELLIOTT, 1989).

Pigeonpea can be used as a soil improvement plant, in crop rotation, to recover degraded areas, to renovate degraded pastures, use in animal feed as a protein bank, to cut for hay or silage, and for grazing (AZEVEDO *et al.*, 2007). When intercropped, it provides greater dry matter production (REZENDE *et al.*, 2001), and produces forage with higher levels of protein and minerals during the dry season (DAHIYA *et al.*, 2002). It is also an alternative to increase the sustainability of ruminant production systems (NERES *et al.*, 2012) by providing a naturally high protein level of 24% (MIZUBUTI *et al.*, 2007). Another advantage is the shrub and perennial growth (2 to 3 years) with deep roots, a characteristic that gives it tolerance to periods of water restriction (MAIOR JÚNIOR, 2009). Because it is a perennial species, it regrows after silage harvest and continues to be a source of protein for cattle.

The objective was to evaluate the quantity and quality of sorghum silage harvested in monocropped and intercropped cultivation with Marandu grass and/or pigeonpea in two different row spacing arrangements.

2. Material and Methods

The soil in the study region was a sandy, red Ultisol containing 12.6% clay, 15.4% silt, and 72.0% sand. Before initiating the experiment, soil chemical characteristics were evaluated according to methods of Raij (2001). Soil pH was 5.5, total soil organic matter was 7 kg m^{-3}, resin-extracted P was 10 mg kg^{-1}, and exchangeable K, Ca, Mg, and total acidity at pH 7.0 (H + Al) was 1.4, 14.5, 7.7 and 13.6 $mmol_c$ kg^{-1}, respectively. Soil pH was determined in a 0.01 mol L^{-1} $CaCl_2$ suspension (1:2.5 soil/solution). Soil organic matter was determined via the colorimetric method using a sodium dichromate solution. Phosphorus and exchangeable Ca, Mg, and K were extracted using an ion exchange resin and then quantified using atomic absorption spectrophotometry.

Integrated cropping systems were conducted as a completely randomized experimental design, with four replications, arranged in a 4x3x2 factorial scheme. Four cropping systems were: **(a)** monocropped sorghum (*Sorghum bicolor* cv. Gransilo), **(b)** sorghum intercropped with Marandu grass (*U. brizantha* cv. Marandu), **(c)** sorghum intercropped with pigeonpea (*C. cajan* cv. BRS Mandarim), and **(d)** sorghum intercropped with *U. brizantha* + *C. cajan*. Three silage storage periods were 0, 30 and 90 days after ensiling (DAE). Two row spacings of sorghum were 0.45 and 0.9 m.

The lime application of the amended experimental area was done in October 2013 in a dose of 2.0 Mg ha^{-1}. The dolomitic limestone consisted of 32% CaO and 12.0% MgO, with an 90%

effective calcium carbonate equivalence. The lime was applied with soil incorporation (disk tillage). The rate was calculated to increase the soil base saturation (0.00-0.20 m) to 60% (CANTARELLA *et al.*, 1997).

In January 2014, sorghum and pigeonpea were sown simultaneously. Sorghum sowing rate was 7 seeds m^{-1} row length for the 0.45 m spacing and 10 seeds m^{-1} row length for the 0.90 m spacing. At 0.15 m adjacent to each row of sorghum (just one side) was sown a row of *C. cajan* with 18 seeds m^{-1} row length. Marandu grass was broadcast at 10 kg ha^{-1} one day before sowing of sorghum and *C. cajan*.

Initial fertilization in the sowing furrow consisted of 28 kg N ha^{-1}, 98 kg P_2O_5 ha^{-1}, and 56 kg K_2O ha^{-1} in 08-28-16 formula. Sidedress fertilization consisted of 60 kg N ha^{-1} and 40 kg K_2O ha^{-1} in 30-00-20 formula.

One week before silage harvest, sorghum plant density was measured at four random 5-m row lengths. Final sorghum population was 13.3 plants m^{-2} for the 0.45 m spacing and 5.6 plants m^{-2} for the 0.90 m spacing.

At physiological maturity, sorghum was harvested using a mechanical harvester. All plant biomass, including intercropped forage was harvested at 0.20 m above the ground surface. Samples of approximately 10 kg for each replicate were randomly collected from the bulk carrier to determine dry matter and bromatological silage composition, before and after ensiling.

Samples of silage were ensiled in mini-silos, made of polyvinyl chloride (PVC) tubes of 9.5 cm diameter and 30 cm length. Mini-silos were prepared to be opened at 30 and 90 DAE by inoculating with Silobac 5 (1 g of Silobac 5 per ton of silage). Silage was manually compacted with the help of a wooden stick in 5-cm thick layers for maximum removal of oxygen to achieve ensiled mass density of 714 kg m^{-3}. Experimentally, this was 1.5 kg of forage ensiled in each mini-silo.

Forage dry matter production was determined at the time of silage harvest. Forage was weighed, and data extrapolated to Mg ha^{-1}. After cutting, part of the material was dried by forced air circulation at 65ºC for 72 h (0 DAE) and another part was ensiled. At 0, 30, and 90 DAE, forage nutritional quality was determined from dry matter content, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, cellulose, hemicellulose, total digestible nutrients (TDN) according to methods described by Van Soest *et al.* (1991).

Data were analyzed using ANOVA and the statistical software package SISVAR. When the F test indicated a significant result ($p \leq 0.05$), means were compared using a least significant difference (Tukey) test ($p \leq 0.05$). When the sorghum spacing effect was not sigificant, data from these two treatments were averaged to determine the intercropping treatment effects.

3. Results

3.1. Dry matter production

Silage dry matter production with 0.45-m row spacing was greater for monocropped sorghum and sorghum intercropped with *U. brizantha* and *C. cajan* together than with either of the other two intercropping systems (Figure 2). With 0.90-m row spacing, silage dry matter production was greatest in the sorghum with *U. brizantha* intercrop. Narrower row spacing had greater sorghum plant density, and this likely led to greater overall production.

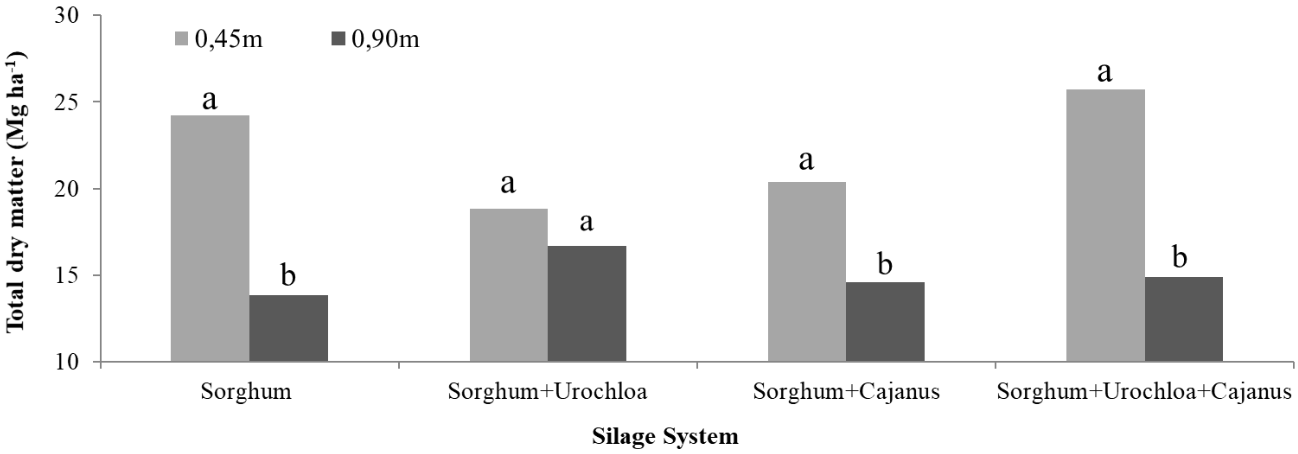

Figure 2. Dry matter production as a function of row spacing and intercropping system. Bars sharing the same letter are not significantly different according to Tukey's test at 5% of probability.

3.2. Dry matter concentration

Dry matter concentration was not influenced by sorghum spacing. Therefore, data were averaged across sorghum spacing treatments for each silage evaluation period in each intercropping system. There was an effect of intercropping system on dry matter concentration, but only when silage was evaluated at 30 DAE. Monoculture sorghum had the lowest concentration relative to other treatments. Increasing storage time reduced dry matter concentration, but not signficantly for the *Sorghum+Urochloa+Cajanus* system (Figure 3).

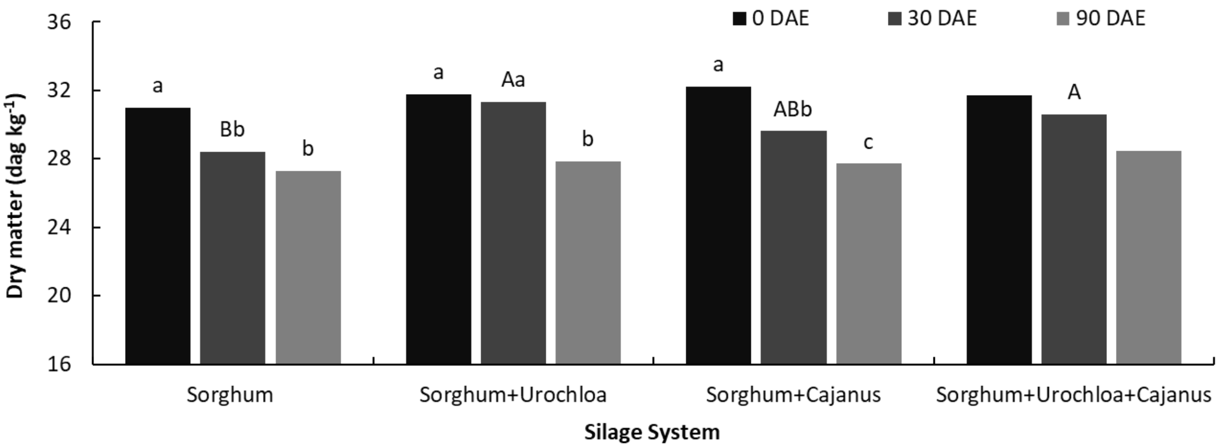

Figure 3. Dry matter concentration of silage as affected by intercropping system and time after ensilage. Bars with the same uppercase letter among intercropping systems and with the same lowercase letters for ensilage time were not significantly different according to Tukey's test at 5% of probability. DAE: Days after ensilage.

3.3. Crude Protein (CP)

Mean CP concentrations in the different cropping systems were 6.0, 6.1, 7.0 and 7.5 dag kg^{-1} for *S. bicolor*, *Sorghum+U. brizantha*, *Sorghum+C. cajan*, and *Sorghum+Urochloa+C. cajan*, respectively. This result demonstrated the importance of including the leguminous *C. cajan* as an intercrop to increase CP concentration of silage with *S. bicolor*. Crude protein concentration was 25% greater with the three-species mixture than monoculture *S. bicolor*. The longest ensiling time caused a reduction in CP in monoculture sorghum and the three-species mixture, but not in other cropping systems (Figure 4).

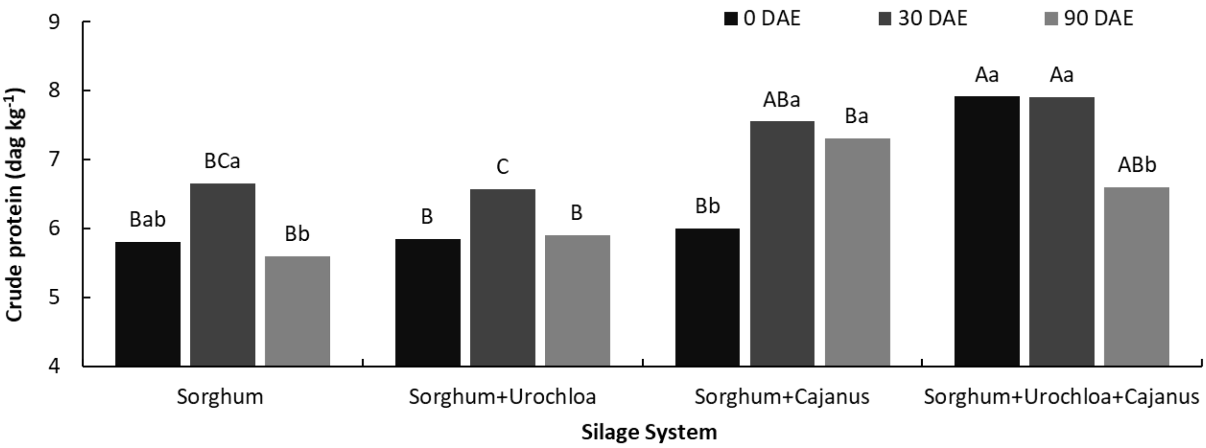

Figure 4. Crude protein concentration of silage as affected by intercropping system and time after ensilage. Bars with the same uppercase letter among intercropping systems and with the same lowercase letters for ensilage time were not significantly different according to Tukey's test at 5% of probability. DAE: Days after ensilage.

3.4. Neutral detergent fiber (NDF)

Initially greater NDF concentration with Cajanus in the cropping system prior to ensiling disappeared to no differences in NDF among cropping systems with greater lengths of ensiling (Figure 5). At 0 DAE, NDF was greatest for *Sorghum+Urochloa+Cajanus*. At 30 DAE, NDF was greatest for monoculture sorghum. At 90 DAE, NDF was not different among cropping systems. Concentration of NDF generally increased with increasing ensiling time (Figure 5). This result indicates there was a loss of soluble substances and accumulation of fibers (cellulose and lignin).

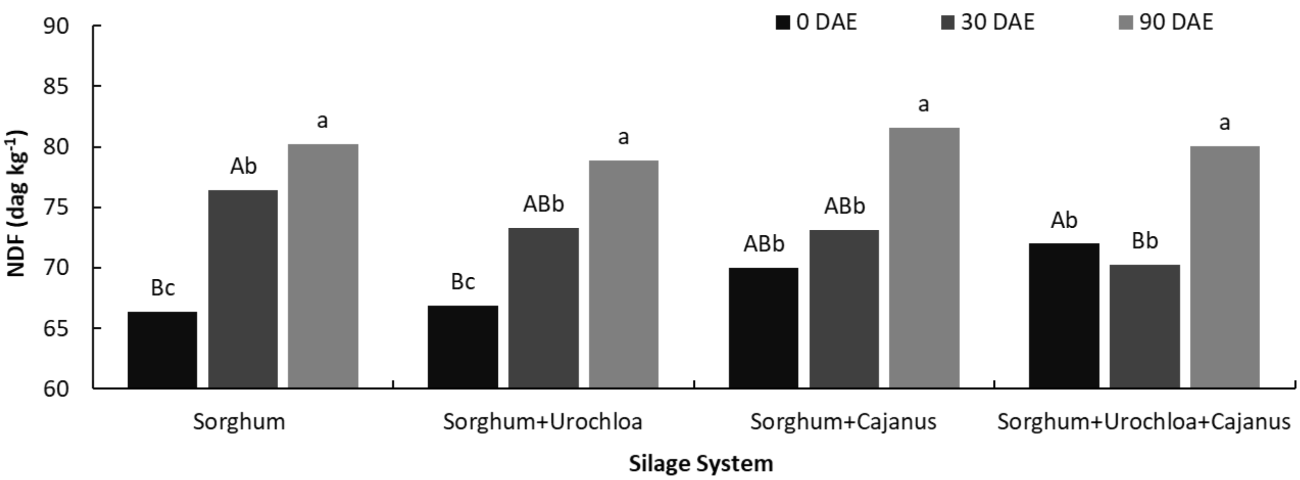

Figure 5. Neutral detergent fiber (NDF) concentration of silage as affected by intercropping system and time after ensilage. Bars with the same uppercase letter among intercropping systems and with the same lowercase letters for ensilage time were not significantly different according to Tukey's test at 5% of probability. DAE: Days after ensilage.

3.5. Acid detergent fiber (ADF)

Concentration of ADF varied among cropping systems at different stages of ensiling (Figure 6). Initially at 0 DAE, ADF was greatest in *Sorghum+Urochloa+Cajanus* and lowest in monoculture sorghum. At 30 DAE, ADF was greatest in *Sorghum+Cajanu*s and lowest in *Sorghum+Urocholoa*. At 90 DAE, ADF was greatest with monoculture sorghum and lowest in *Sorghum+Urochloa*. Concentration of ADF increased with ensiling time. This increase in ADF with time of ensiling followed that found for NDV, indicating there was a loss of soluble substances and accumulation of fibers (cellulose and lignin).

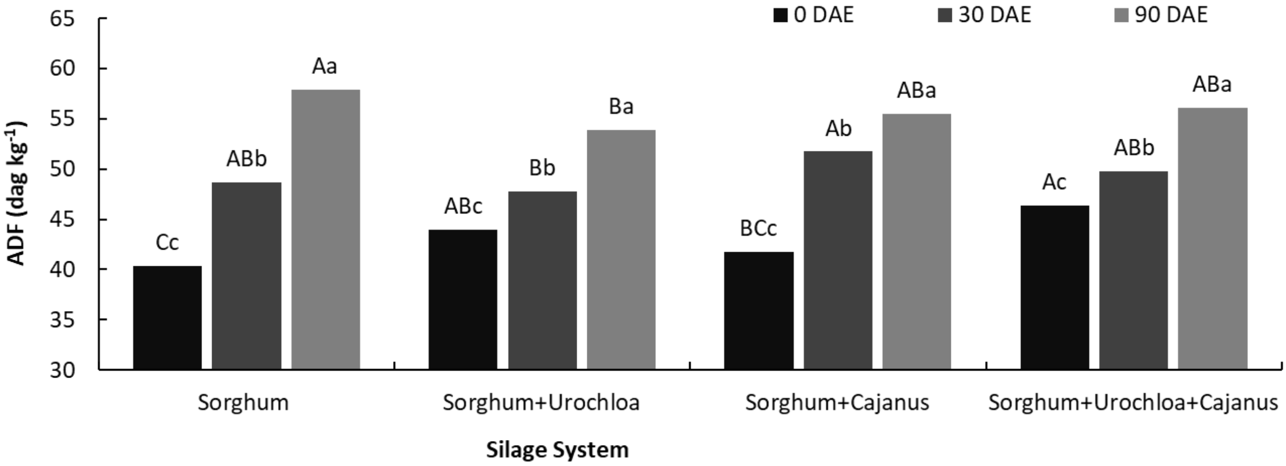

Figure 6. Acid detergent fiber (ADF) concentration of silage as affected by intercropping system and time after ensilage. Bars with the same uppercase letter among intercropping systems and with the same lowercase letters for ensilage time were not significantly different according to Tukey's test at 5% of probability. DAE: Days after ensilage.

3.6. Cellulose

Cellulose concentration was affected by cropping system only initially prior to ensiling (Figure 7). Cellulose was greater in *Sorghum+Urochloa+Cajanus* than in monoculture sorghum and *Sorghum+Urochloa*. With ensiling, no differences in cellulose concentration emerged. Cellulose concentration increased with time of ensiling in all cropping systems.

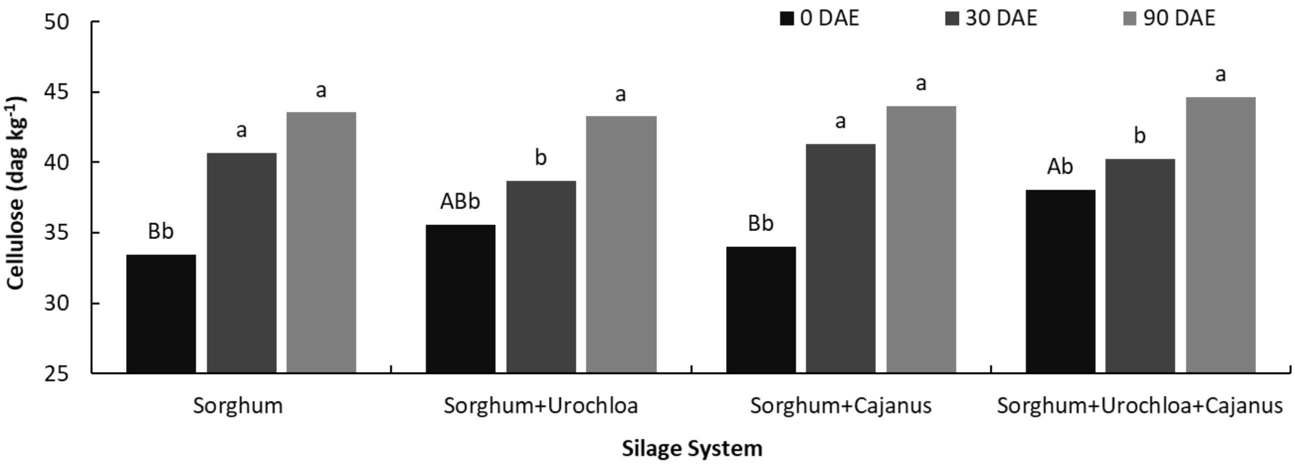

Figure 7. Cellulose concentration of silage as affected by intercropping system and time after ensilage. Bars with the same uppercase letter among intercropping systems and with the same lowercase letters for ensilage time were not significantly different according to Tukey's test at 5% of probability. DAE: Days after ensilage.

3.7. Hemicellulose

Hemicellulose concentration was affected by cropping system at 0 and 30 DAE, but not at 90 DAE (Figure 8). At 0 DAE, hemicellulose concentration was greatest for *Sorghum+Cajanus* and lowest for *Sorghum+Urocholoa*. At 30 DAE, hemicellulose concentration was greatest for monoculture sorghum and lowest for *Sorghum+Cajanus* and *Sorghum+Urochloa+Cajanus*. Ensiling time had variable effects on hemicellulose concentration, depending on cropping system. No differenc in hemicellulose concentration with ensiling time occurred for *Sorghum+Urochloa*, but some decline occurred with time in all other systems, although the effect was not consistent.

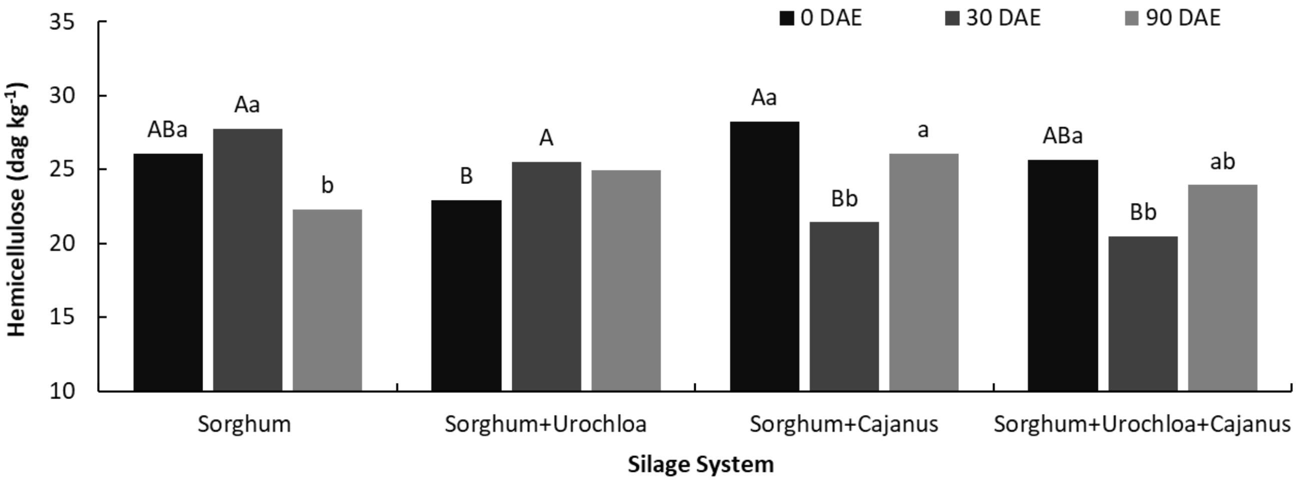

Figure 8. Hemicellulose concentration of silage as affected by intercropping system and time after ensilage. Bars with the same uppercase letter among intercropping systems and with the same lowercase letters for ensilage time were not significantly different according to Tukey's test at 5% of probability. DAE: Days after ensilage.

3.8. Lignin

Lignin concentration was not affected by cropping system prior to ensiling, but was variably affected by cropping system at different times of ensiling (Figure 9). At 30 DAE, greatest lignin concentration was with *Urochloa+Cajanus* and lowest was with monoculture sorghum. At 90 DAE, lignin concentration was greater with monoculture sorghum than with all other systems. Lignin concentration increased with time of ensiling, like the results for ADF, NDF, and cellulose.

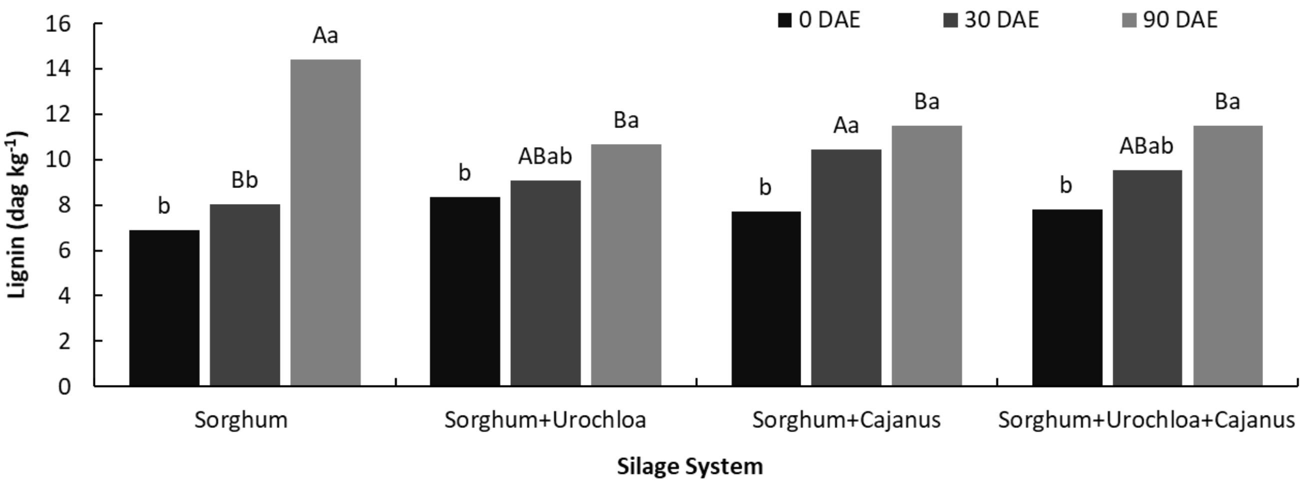

Figure 9. Lignin concentration of silage as affected by intercropping system and time after ensilage. Bars with the same uppercase letter among intercropping systems and with the same lowercase letters for ensilage time were not significantly different according to Tukey's test at 5% of probability. DAE: Days after ensilage.

3.9. Total digestible nutrients (TDN)

Concentration of TDN was variably affected by cropping system depending on the time of ensiling (Figure 10). At 0 DAE, TDN concentration was greatest for monoculture *Sorghum* and lowest for *Sorghum+Urochloa+Cajanus*. At 30 DAE, TDN concentration was greatest for *Sorghum+Urochloa* and lowest for *Sorghum+Cajanus*. At 90 DAE, TDN concentration was greatest for *Sorghum+Urochloa* and lowest for monoculture sorghum. Concentration of TDN declined with ensiling time in all cropping systems. This indicated there was a loss of TDN, supported by the increase in concentrations of cellulose and lignin (Figure 7 and 9).

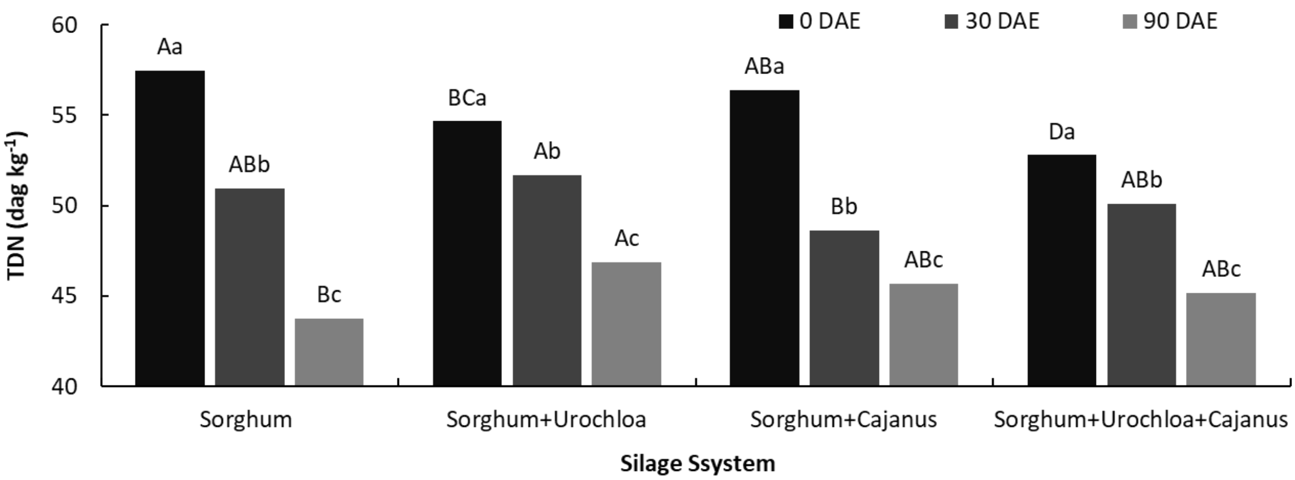

Figure 10. Total digestible nutrient (TDN) concentration of silage as affected by intercropping system and time after ensilage. Bars with the same uppercase letter among intercropping systems and with the same lowercase letters for ensilage time were not significantly different according to Tukey's test at 5% of probability. DAE: Days after ensilage.

4. Discussion

In the figure 11 illustrates the time course of development of sorghum and intercropping treatments. Successful establishment of intercropped forages occurred and subsequent renovation of pasture was an outcome. Both high quality silage and pasture renovation were possible in this system.

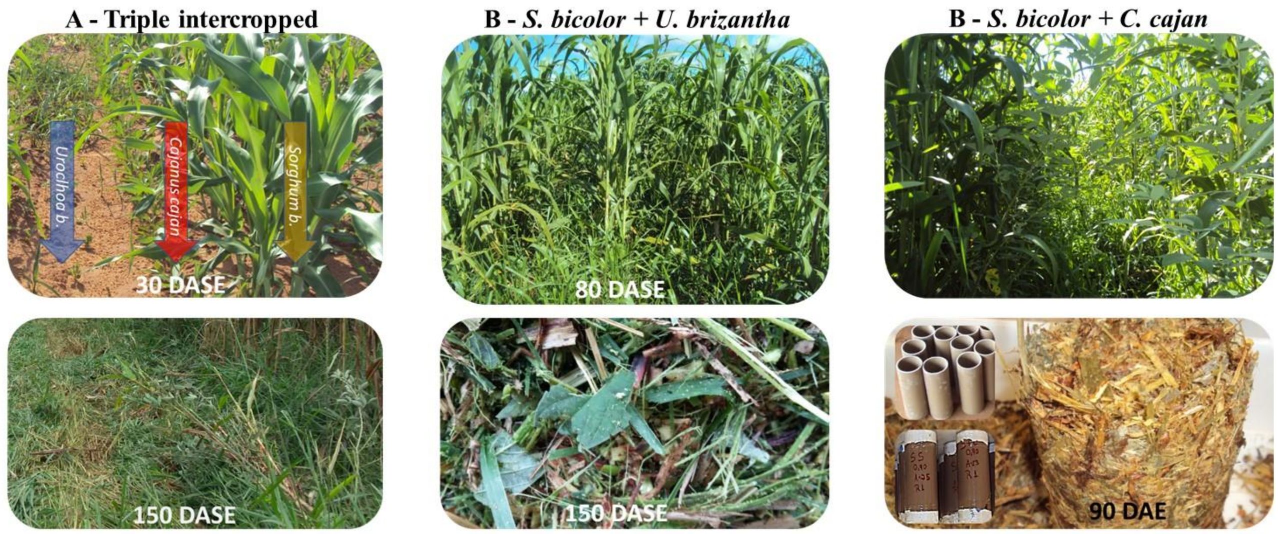

Figure 11. Stages of development of species during the experiment and aspect of silage on the day of cutting and 90 days after ensiling. DASE: Days after sorghum emergence; DAE: Days after ensilage.

4.1. Dry matter production of forage

Greatest forage production occurred with monocropped sorghum and the triple intercropping system. Monocropped sorghum had the least competition with other species, and so it was able to proliferate (COSTA *et al.*, 2016). In the triple intercropping system, high forage production was a function of the sum of dry matter from the three species (Figure 2A). Forage production was greater with 0.45-m row spacing than with 0.9-m row spacing in all cropping systems. This was generally a function of plant population. Mean production with 0.45-m row spacing was 22.3 Mg ha^{-1} and with 0.9-m row spacing was 15.1 Mg ha^{-1} (Figure 2B).

When intercropped, significant decline in biomass production can be due to competition for resources between species (IQBAL *et al.*, 2019). Competition may have been more severe when there was more space between sorghum rows (0.9 m). It is known that during early crop development, sorghum has slow growth. Competition with other species can seriously reduce development of sorghum (MAGALHÃES *et al.*, 2003). Greater development of intercropped pasture was at the expense of reduced vegetative development of sorghum (CABEZAS, 2011). Greater light penetration with 0.90-m row spacing favored growth of Marandu grass. Presence of a legume can reduce total biomass production compared with grass species (IQBAL *et al.*, 2019). This issue was evidenced in the two spacings used.

4.2. Dry matter concentration of silage

The association of *U. brizantha* and/or *C. cajan* with sorghum increased dry matter concentration at 90 DAE. Dry matter concentration of forage at the time of ensiling is one of the main determinants of the success of the fermentation process, and consequently, of the quality of the silage produced (COSTA *et al.*, 2016). Ideal dry matter concentration for sorghum is 25 to 35% (MOLINA *et al.*, 2002), and generally for adequate fermentation, plants should be ensiled at 30% dry matter (VAN SOEST, 1994). The study, all systems had adequate levels of dry matter for ensiling. With ensiling time, there was an average reduction in dry matter concentration of 12%. Silage with low DM concentration can have fermentation problems, causing losses by gases and effluents, which end up carrying several water-soluble nutrients and raising the fibrous fraction (MONTEIRO *et al.*, 2011).

4.3. Crude protein (CP)

Intercropping of pigeonpea promoted an increase in CP level. The average increase in CP in the Shorgum+Cajanus and *Sorghum+Urochloa+Cajanus* was 15% and 22%, respectively when compared to monocropped shorgum. Intercropping with forage legumes has been shown to enhance dry matter yield (REZENDE *et al.*, 2001), and forage production with higher CP (DAHIYA *et al.*, 2002). Intercropping of grasses with legumes has previously provided better quality silage and greater CP concentration (ANDRIGUETTO *et al.*, 2002; EVANGELISTA *et al.*, 2005; IBRAHIM *et al.*, 2005; JOBIM *et al.*, 2007). Intercropping of legumes is important because sorghum is rich in digestible fibers, but it has low CP concentration (CONTRERAS-GOVEA *et al.*, 2011). When combining Piatã grass with pigeonpea, CP increased and NDF was reduced, due to the participation of the legume in the forage produced (NERES *et al.*, 2012). Intercropping grass and legume is a good alternative for animal protein supplementation, as well as to fix N for soil organic matter accumulation and to favor subsequent grass growth. *Cajanus cajan* contains 13.6% CP in the entire plant and 23.8% CP in the leaves (OLIVEIRA *et al.*, 2017).

4.4. Neutral detergent fiber (NDF)

The NDF concentration of harvested forage was greater when sorghum was intercropped with *C. cajan* compared to monocropped shorgum. The increases were 5.5% and 8.5% for *Shorgum+Cajanus* and *Sorghum+Urochloa+Cajanus*, respectively, respectively. Greatest NDF was observed at 90 DAE in all forms of intercropping. The high NDF concentration was due to the lower dry matter percentage of sorghum (27%) and higher proportion of sorghum in silage. The height of sorghum plants was ~4 meters, and therefore, a lower proportion of panicles in the ensiled mass. Lower levels of NDF are found when there is a greater proportion of panicles in DM compared to the proportions of leaf and stem (VON PINHO *et al.*, 2007). Calaça (2014) working with forage and *Shorgum+Urochloa* in the ICLS system, found NDF levels from 66 to 74%, similar to the present study. The consumption of DM is linked to the concentration of NDF in the forage. The higher the NDF content, the lower the intake of DM. This is due to the greater space occupied in the rumen (DETMANN *et al.*, 2003).

4.5. Acid detergent fiber (ADF)

Mean ADF concentration across cropping systems and before ensiling was 43 dag kg^{-1}. This value increased in all cropping systems during the ensiling process. The average increase was 15 and 30% at 30 and 90 DAE, respectively. ADF determines the quality of the cell wall and expresses the indigestible fraction, therefore, it correlates negatively with digestibility (RESTLE *et al.*, 2002).

4.6. Cellulose, Hemicellulose, and Lignin

Cellulose concentration showed similar behavior to the results of ADF. The values increased as ensiling time was extended. Hemicellulose was the fibrous component that had the smallest variations due to ensiling time.

Lignin concentration increased with ensiling time. Greatest lignin concentration was observed in monocropped sorghum at 90 DAE with 14.4 dag kg^{-1}. The association of sorghum with other intercropped species resulted in a decrease in lignin values. Legumes tend to improve the quality and nutritional value of mixed fodder due to their higher protein content (IQBAL *et al.*, 2019).

4.7. Total digestible nutrients (TDN)

Concentration of TDN decreased with increasing ensiling time. This decline occurred alongside an increase in fibrous material of the silage. The presence of legumes in the silage, theoretically would increase TDN. However, in the present study, the presence of pigeonpea caused a reduction in the concentration of TDN in the triple intercropped. This likley occurred due to the shrubby nature and woody stem of pigeon pea during maturation (GODOY; SANTOS, 2011).

The reduction in NDT may be associated with the loss of DM from the silage (Figure 3). Silage fermentation produces volatile compounds (KRISTENSEN *et al.*, 2010) and effluent. Sorghum silage loses more effluents when compared to corn silage (OLIVEIRA *et al.*, 2010). Despite the loss of quality, silage storage is important to go through the period of lowest forage supply, especially in regions with a defined dry season.

5. Conclusions

Silage production was maximized with or without intercrop whenever sorghum row spacing was narrow (0.45-m row spacing versus traditional row spacing of 0.9 m). If traditional row spacing were used, then intercropping with Marandu grass and pigeonpea improved silage production and led to improved silage quality. Silage quality declined with increasing storage time, as a result of the increase of fibers (cellulose and lignin) and reduction of total digestible nutrient concentration.

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