

Substitution of silage by soybean hulls in tropical forage-based dairy cow production system during the dry season

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ABSTRACT

Supplementary roughage during the dry season in forage-based systems mitigates the adverse effects of lower pasture availability and nutritional quality in forage-based milk production. This study evaluated the effects of soybean hulls as supplementary roughage on milk production, composition, and nitrogen utilization in lactating dairy cows in tropical forage-based systems during the dry season and verify the possibility of fully replacing silage with soybean hulls. Twelve multiparous Holstein-Zebu crossbred cows (453 ± 4.97 kg) in mid-lactation were used in a 4×4 Latin Square design. The cows grazed *Urochloa brizantha* cv. Marandu pasture with a continuous stocking rate and were subjected to four supplementation strategies: supplementation only with concentrate (Control); concentrate plus soybean hulls replacing 35% of forage intake (Soybean Hulls); concentrate plus corn silage replacing 50% of forage intake (Corn Silage); and concentrate plus sorghum silage replacing 50% of forage intake (Sorghum Silage). Soybean hulls and corn silage were the most consumed supplementary roughages ($P = 0.012$). Soybean hulls enhanced daily intakes of ether extract (EE) and neutral detergent fiber (NDF) ($P < 0.05$). Milk production increased with soybean hull supplementation ($P < 0.001$), however, did not differ to corn silage when corrected for 3.5% fat content. Milk fat and protein did not differ among treatments ($P > 0.05$), but lactose and total solids were higher in the soybean hull and control groups ($P < 0.05$). Soybean hull supplementation reduced milk urea nitrogen (MUN) compared to corn silage ($P = 0.022$). Overall, soybean hulls improved feed intake, milk production, and nitrogen utilization in dairy cows, supporting their use as a viable alternative to silage in forage-based tropical systems.

Keywords: corn silage, grazing, milk production, nitrogen, sorghum silage

Introduction

Forage-based milk production systems face limitations throughout the year due to the seasonality of forage production in tropical areas. Because there are periods of higher and lower forage production, which are usually related to factors that limit growth, such as precipitation, temperature, photoperiod and solar radiation (Sbrissia et al., 2018). In addition, throughout the growth cycle of forage plants, quality usually decreases due to a reduction in the participation of leaves and an increase in the proportion of stalks (Guzatti et al., 2017).

Thus, during the dry season, dairy cows raised in tropical pastures cannot meet their requirements for milk production only with the forage available in pastures. Therefore, the use of supplementary roughage can prevent fluctuations in milk production by correction on nutrient intake. Among the various options of roughage source, preserved forages such as corn and sorghum silage (Veriato et al., 2018), and non-forage fiber sources such as soybean hulls (Adin et al., 2009, Guo et al., 2021), are the most commonly used sources.

According to the NRC (2001), soybean hulls are defined as roughage source due to its fibrous characteristics act on physiological function, such as stimulation of chewing and saliva production. Soybean hulls have a high content of cellulose (app. 43% of DM), hemicellulose (app. 18% of DM), pectin (app. 30% of DM), and a low amount of lignin (app. 2% of DM) (Ipharraguerre and Clark, 2003; Snyder and Kwon, 1987) which can result in a high digestible feed and can replace high-quality roughage sources such as corn and sorghum silages.

Soybean hulls can replace corn grain to supply about 30% of the dry matter in high-grain diets without negatively affecting either the fermentation or digestion of nutrients in the gastrointestinal tract or the performance of dairy cows (Ipharraguerre and Clark, 2003). However, research is still needed to determine whether soybean hulls can be used as a roughage source to supplement dairy cows in tropical forage-based systems during the dry season when grass availability is reduced.

Therefore, the objective of this study was to determine whether the addition of soybean hulls as a supplementary roughage to the diet affect the milk production and composition, intake and apparent digestibility of nutrients, and nitrogen balance in tropical forage-based lactating dairy cows system during the dry season and to verify the possibility of fully replacing silage by soybean hulls.

Material and methods

The study was conducted in a rural property located in Rondonopolis, Brazil (16°23'05.1" S, 54° 35'32.7" W, 314 m altitude) from July to September, which is characterized as the dry season of the year. The temperatures and precipitation data are described in Figure 1.

2.1. Experimental design and treatments

Twelve multiparous 1/2 Holstein-Zebu crossbred cows weighing 453 ± 4.97 kg in the middle third of lactation were randomly allotted to a 4×4 Latin Square design. The experimental periods were conducted in 20 d, in which the first 14 d was used for diet adaptation and the last 6 d for data collection. The cows were managed in a grazing system with continuous stocking rate on a single *Urochloa brizantha* (Hochst. ex A. Rich.) R.D. Webster cv. Marandu paddock. The paddock contained 7.5 hectares resulting in a stocking rate of 0.37 animal unit (AU)/ha. All cows had access to water fountains and available shade. The treatments consisted of four feed supplementation strategies with a high protein concentrate and different types of roughage for dairy cows in grazing systems: supplementation only with concentrate (Control); concentrate plus soybean hulls to replace 35% of forage intake (Soybean Hulls); concentrate plus corn silage to replace 50% of forage intake (Corn Silage); and concentrate plus sorghum silage to replace 50% of forage intake (Sorghum Silage). The above substitutions were chosen to ensure that the diets had similar concentration of protein and carbohydrates.

The quantity of roughage to be offered in replace to the estimated forage intake was calculated from the intake prediction equation from the 7th edition of the Nutrient Requirements of Dairy Cattle (NRC, 2001), using an estimated average milk production of 15 kg milk/day. The predicted dry matter intake was 12 kg DM/cow/day. The diets were formulated to be iso-protein (136 g/kg CP) where the CP concentration was adjusted using two different high protein concentrates containing 220 and 240 g/kg of CP (Table 1). The concentrate supplement containing 220 g/kg of CP was used to adjust the protein content for the Soybean Hulls treatment, while the 240 g/kg of CP concentrate was used to adjust the treatments Control, Corn Silage, and Sorghum Silage. The ingredient composition of each concentrate supplement is presented in Table 2. The quantity of high protein concentrate supplement fed (5 kg/d) was the same for all treatments. The supplementary concentrates and roughages were fed twice a day at 06:00 and 16:00 h, immediately after milking, in individual feed bunk. The orts were weighed and recorded daily.

2.2. Forage, feed sampling and analysis

On the 15th day of each experimental period, the sward height was measured with a 1.0 m ruler graduated in centimeters in 100 random spots in the paddock. After the height measurement, four spots that most represented the average grass height in the paddock were selected to collect the grass. Using an iron square (0.5 × 0.5 m) the grass was harvested inside the iron square, and samples were placed in plastic bags and weighed in the laboratory. Two sub-aliquots were prepared from these samples: one was placed in a paper bag, placed in a forced-air oven at 55°C for 72 hours and then weighed to determine the forage mass; the other sub-aliquot was manually separated into leaf lamina, stem + sheath and dead material and dried following the same procedure. Subsequently, the samples were weighed, and the values were converted into kg/ha of dry mass (Figure 2; Table 3).

Sampling for qualitative evaluation of the pasture was obtained by the hand-plucked technique (Johnson, 1978) on the 15th day of each experimental period. The samples were dried in a forced-air oven at 55°C for 72 hours, ground in a knife mill using sieves with 1 mm and 2 mm sieves and placed in previously identified containers for further analysis.

The amounts of roughage, concentrate, and orts were weighed daily to evaluate the dry matter intake. Samples of forage, concentrate and orts were collected on days 16, 17 and 18, individually identified and dried in an oven with forced air circulation at 55°C for 72 hours. Roughage, concentrate, feces, and orts were processed in a knife mill to pass through 1-mm sieve for nutrient composition analysis and 2-mm sieve for indigestible neutral detergent fiber (iNDF) analysis, and the samples from the three collection days were composited per period.

Samples of forage, roughage, concentrate, orts and feces grounded in a 1-mm sieve were analyzed for dry matter (DM), organic matter (OM), crude protein (CP) and ether extract (EE) contents according to AOAC (2000). The neutral detergent fiber (NDFap) levels were measured according to Mertens (2002), with the use of thermostable α -amylase and omitted the use of sodium sulfite; corrections for protein and ash in the NDFap followed the procedures described by Licitra et al. (1996) and Mertens (2002), respectively (Table 1). Samples of forage, roughage, concentrate, orts and feces grounded in a 2-mm sieve were used for determination of iNDF according to Detmann et al. (2001). Briefly, samples were weighed in triplicated filter bags and incubated in the rumen for 288 hours in two cannulated steers grazing tropical forage and supplement with 2 kg/day of a commercial supplement, and the residual content of NDF was analyzed.

The nonfibrous carbohydrate (NFC) contents were obtained according to the equation proposed by Detmann and Valadares Filho (2010):

$$NFC = 100 - [Ash + EE + NDFap + (CP - CPu + U)]$$

where NFC = nonfibrous carbohydrate content; EE = ether extract content; NDFap = neutral detergent fiber content corrected for ash and protein; CP = crude protein content; CPu = content of crude protein derived from urea; and U = urea content. All terms are expressed as % of DM.

The potentially digestible DM (DMpd) in forage samples was estimated according to Porto et al. (2009):

$$\text{DMpd} = 0.98 (100 - \text{NDF}) + (\text{NDF} - \text{iNDF})$$

where NDF = neutral detergent fiber and iNDF = indigestible neutral detergent fiber.

2.3. Fecal sampling, forage intake and digestibility

Starting on d 10 of each experimental period, the animals were subjected to a nine-day digestibility evaluation, in which the first six days were used for adaptation to the external marker and the last three days for feces collection at different sampling times. The marker used was a powder form of titanium dioxide (TiO₂, Sigma Aldrich). A total of 20 grams of TiO₂ was supplied per animal per day, which was infused into the rumen with the aid of an applicator via the esophagus at 1300 h. Feces were collected at 1530, 1330 and 0430 h directly from the rectum or immediately after the defecation in approximate amounts of 200 g and individually identified.

Fecal samples were evaluated for TiO₂ content according to the colorimetric technique described by Titgemeyer et al. (2001). Fecal excretion (FE) was estimated as the relationship between the dose and the fecal concentration of TiO₂, in which: FE = (daily dose of TiO₂ / feces TiO₂ concentration). To estimate forage intake, the fecal contribution from concentrate (FEc) and silage (FEs) was determined as the amount offered multiplied by its iNDF concentration, and the value obtained was discounted from the fecal excretion to estimate forage intake:

$$\text{Forage intake (kg DM/d)} = \frac{\text{FE} \times \text{iNDF} - \text{FEc (kg)} - \text{FEs (kg)}}{\text{Forage iNDF}}$$

In which, FE = fecal excretion, FE_c = fecal contribution from concentrate, FE_s = fecal contribution from silage.

Apparent digestibility of nutrients was calculated as follow:

$$\text{Apparent digestibility (\%)} = 100 - 100 \times \left(\frac{\% \text{ iNDF in feed}}{\% \text{ iNDF in feces}} \times \frac{\% \text{ nutrient in feces}}{\% \text{ nutrient in feed}} \right)$$

2.4. Milking sampling and analysis

Milk yield was recorded individually on d 18 and 19 of each experimental period. Cows were milked at 05:30 and 15:30, the milk was weighed to quantify milk yield, and a sample was collected from each milking time, preserved using 4% 2-bromonitropropan-1,3 diol and composed by cow using the morning and afternoon samples. The samples were stored in freezer for 24 h and sent to laboratory for analysis of fat, protein, lactose, and total solids (Bentley 2000 analyzer; Bentley Instruments®) and milk urea nitrogen (ChemSpec 150; Bentley Instruments®) at the Laboratory of the Milk Clinic, Department of Animal Science, ESALQ/USP. Milk yield was corrected for 3.5% fat according to Sklan et al. (1992) using the equation:

$$\text{Milk yield 3.5\% fat} = (0.432 + 0.1625 \times \% \text{ milk fat}) \times \text{milk production (kg/d)}.$$

2.5. Blood and urine sampling and analysis

Blood and urine samples were collected on d 20 of each experimental period 4 hours after the morning supplementation. Blood collection was performed by puncturing the coccygeal vein using the direct needle method (with a large-volume syringe), and the blood was immediately collected in tubes with a clot accelerator and separator gel. The samples were centrifuged at 3,000 × g for 20 minutes to obtain the plasma, placed in 2 mL micro tubes and frozen at -20°C for later determination of plasma urea nitrogen (PUN) concentration. The PUN concentration was determined by the enzymatic colorimetric method using a commercial kit (Ref. 427; Análise®).

Urine was collected during spontaneous urination via the preparation of a spot urine sample (10 mL), which was subsequently acidified in 40 mL of 0.036 N H₂SO₄ (Valadares et al., 1999). After collection, the samples were stored at -20°C for subsequent quantification of creatinine and urea concentration. Urine creatinine was analyzed using the enzymatic colorimetric method by end-point reaction (Modified Jaffé), and urea was analyzed by the urease/GLDH enzymatic colorimetric method using commercial kit (Ref 335 and 427, Análise®). The urea was converted to urea nitrogen by multiplying the urea concentration by a factor of 0.4667. Total urine volume was estimated as the ratio between daily creatinine excretion as a function of body weight and urine creatinine concentration. The creatinine excretion per unit of body weight was obtained according to the following equation (Chizzotti et al., 2006):

$$EC = 32.27 - 0.01093 \times BW$$

where EC = daily creatinine excretion (mg/kg BW) and BW = body weight (kg).

The daily urinary excretion of urea was estimated by the product of its concentration in the urine samples and the estimated value of urine volume.

2.6. Statistical analysis

Data were analyzed as a replicated 4 × 4 Latin square design, using the MIXED procedure of SAS program (version 9.4, Instituto SAS, Cary, NC). The following model was fitted to all animal-related variables:

$$Y_{ijk} = \mu + A_i + P_j + T_k + e_{ijk}$$

where Y_{ij} is the dependent variable; μ is the overall mean; A_i is the random effect of the ith animal, P_j is the fixed effect of the jth period, T_k is the fixed effect of the kth experimental diets; e_{ijk} is the error associated with the ith animal, jth period and kth experimental diets. The treatments were compared using Tukey's test, with a 5% probability of error.

Results

The highest DM intake (DMI) ($P < 0.05$) was obtained for animals supplemented with soybean hulls (Table 4), with an increase of 48.2% compared to the control treatment. However, there was no difference in DMI among cows supplemented with corn silage, sorghum silage and control. Soybean hulls and corn silage were the most consumed supplementary roughage. No differences ($P > 0.05$) were observed for pasture DM intake among treatments.

Soybean hulls had the highest intake ($P < 0.05$) of CP, EE and NDF, with increases of 28.5%, 50.0%, and 61.9%, respectively, compared to those cows in the control treatment (Table 4). Corn silage improved the intake of CP and EE by 21.4% and 25%, respectively, compared to control, however, no difference was observed on NDF intake. Supplementation with sorghum silage did not differ from the control treatment on intake of nutrients. There were no differences ($P > 0.05$) in the apparent total tract digestibility of CP, EE or NDF among the treatments (Table 4), in which the mean digestibility coefficients of 74.75%, 49.3% and 46.62%, respectively.

A greater milk yield was observed ($P < 0.05$) for animals supplemented with soybean hulls. However, there was no difference ($P > 0.05$) for fat-corrected milk between soybean hulls and corn silage (Table 5). There was no difference between sorghum silage and control on milk yield and fat-corrected milk. No differences were found for the milk fat and protein contents among the treatments ($P > 0.05$). There was a difference on milk fat production ($P < 0.05$) in which soybean hulls, corn silage and control did not differ, however, sorghum silage produced less fat compared to soybean hulls. The milk production of protein, lactose and solids were higher ($P < 0.05$) for cows supplemented with soybean hulls. There was no difference ($P > 0.05$) in lactose and milk solids contents for the cows fed soybean hulls, corn silage and control cows, however, the supplementation of sorghum silage decreased the lactose and milk solids content compared to control. Soybean hulls provided the lowest milk urea nitrogen (NUL)

content among the treatments, however, did not differ from sorghum silage and control (Table 5).

There were no effects of supplementary roughages ($P > 0.05$) in urinary nitrogen or blood urea nitrogen (Table 6). The mean values of 2333 mg/dL for urea in urine, 181 g/day of nitrogen excreted in the urine and 18.17 mg/dL for urea nitrogen in the blood were observed.

No difference was observed ($P > 0.05$) on digested and retained nitrogen (Table 7). A greater N excretion in feces was observed ($P < 0.05$) for cows supplemented with soybean hulls, however, no differences were observed among corn silage, sorghum silage, and control. No difference in urinary N excretion was observed. Milk N excretion was similar between soybean hulls and corn silage; however, excretion was higher for cows supplemented with soybean hulls than control. No effects ($P > 0.05$) of supplemental roughage were observed on NUE.

Discussion

The average forage mass of the pasture observed during the study was 3.3 t DM/ha. The observed forage availability is higher than 2 t DM/ha, the minimum recommended to avoid limitation of DM intake by animals (Minson, 1990). The forage CP content from samples obtained by the hand-plucked technique remained above 7%, which is the minimum value necessary to ensure adequate digestion of fiber (Lazzarini et al., 2009). As demonstrated by Zanette et al. (2020) in intensive grazing system, which is observed increasing in forage production and protein content compared to the traditional system (without irrigation and fertilization), cows increase intake, milk production and nutrient digestibility.

The leaf blades reached a critical level of 4% during period 2 and remained unchanged until the end of the study. The leaf blades are a fraction with the highest CP content and digestibility of the grass structure and are preferably consumed by the animals (Batistoti et al.,

2012), which has a negative impact on cows performance if in lower availability (Curran et al., 2010).

In addition, there was a high proportion of dead material, which is a characteristic of non-irrigated pastures in the dry season. Under lower water availability and lower temperature conditions, many tillers begin to senesce which increases the amount of dead material. Therefore, the highest availability of pdDM was observed at the beginning of the grazing period due to the greater percentage of green leaf blades and stem + sheath considering that the pasture was not utilized in the period before the start of the study.

The total DM and NDF intake for the silage treatments and the control treatment were similar. This is contrary to reports in the literature, which indicate that the use of different roughages in the diet of lactating cows may affect nutrient intake (Teixeira Junior et al., 2016; Alessio et al., 2020). However, the 91.7% greater intake of supplemental roughage for corn silage compared to sorghum silage can be explained by a lower acceptability of sorghum silage by the animals observed during the study. This lower acceptability can be attributed to inadequate fermentation, and the presence of non-palatable and indigestible compounds.

The content of structural carbohydrates in soybean hulls results in a higher extent, time and rate of digestion compared to the forage sources used in the silages (Ipharraguerre and Clark, 2003). This faster digestion kinetics results in a higher outflow of ruminal content from rumen to the further gastrointestinal compartments, which increases the ruminal turnover time stimulating the appetite (Colucci et al., 1982). Although the pasture intake did not differ among treatments, the higher DMI observed in the soybean hulls supplemented cows was led mainly by the numerically greater pasture intake possibly stimulated by a higher passage rate. In a review performed by Ipharraguerre and Clark (2003), an increase of 0.3 kg/d of DMI was observed for cows fed diets replacing forage by soybean hulls. Furthermore, when compared to control the supplementation of soybean hulls had an additive effect on pasture intake which

increased the total DMI which is not observed for the treatments. Unlikely, the supplementation of corn silage showed a substitutive effect on pasture intake

Due to the intake of soybean hulls being greater compared to other treatments, higher digestibility would be expected, however, this effect was not observed. The higher DM intake is known to be associated with the higher passage rate of feed throughout the gastrointestinal tract (Colucci et al., 1982). The relatively faster passage rate observed for soybean hulls can be explained by their small particle size and high specific gravity when hydrated (Titgemeyer, 2000). However, the supplementation of soybean hulls, corn silage and sorghum silage did not affect the apparent total tract digestibility. Unlike the results found in the present study, Adin et al. (2009) observed an increase in NDF digestibility using soybean hulls as a partial replacement for grass in dairy cows in mid-lactation. However, when Graft et al. (2005) partially replaced grazing of a mix of temperate grass species by supplementation of corn silage also did not observe differences in digestibility of nutrients.

The milk yield of cows supplemented with soybean hulls increased by 20.3% when compared to cows with no supplemental roughage. This higher production is attributed to the positive associative effect on intake by cows supplemented with soybean hulls. The higher ingestion of feed provides more nutrients to be metabolized and used for milk production. Ipharraguerre and Clark (2003) reported that replacing forage by soybean hulls in lactating cows increased the milk yield in 0.7 kg/d, and fat corrected milk production in 0.4 kg/d. Similar behavior was described by Halachmi et al. (2004) and Weidner (1994), which observed increases of 6 and 9% in milk production, respectively, when alfalfa hay and corn silage were substituted by soybean hulls.

The molar proportion of propionate in ruminal fluid typically increased when dairy diets supplemented with soybean hulls instead of forage to supply 5 to 25% of dietary DM; however, changes in the molar percentages of acetate and butyrate are not frequently observed

(Ipharraguerre and Clark, 2003). Propionate is the primary VFA used for gluconeogenesis in the liver, where it is converted into glucose. The circulating glucose in the bloodstream is used in the cow's mammary epithelial cells to cell growth and lactose synthesis (Lin et al., 2016). With that, a higher availability of propionate for cows supplemented with soybean hulls led to the increase in milk production (Miettinen and Huhtanen, 1996). This theory also explains the higher production of lactose for cows supplemented with soybean hulls. However, the concentration of lactose in the milk among the treatments soybean hulls, corn silage and control were not different.

The higher milk yield and lactose production for cows supplemented with corn silage is also explained by the higher amount of NFC on corn silage (303 g/kg) compared to Marandu grass (213 g/kg) which is mainly used by propionate-producing bacteria. The absence of fat production and fat concentration on milk between corn silage and control cows, highlight that supposedly the main contribution of VFA production from the corn silage was in the synthesis of propionate, since acetate has key role on milk fat production (Urrutia and Harvatine, 2017) meaning that the availability of fibrous carbohydrates to cellulolytic bacteria metabolism was similar between these treatments avoiding milk fat depression.

One method by which the animal's body excretes excess nitrogen is through the MUN. Because it is a small molecule, excess nitrogen is quickly drained into the bloodstream and transferred to the mammary gland in the liver. The liver converts excess nitrogen into urea, which is then carried through the bloodstream to the kidneys where it is excreted in the urine or recycled via the ruminal wall and saliva (Gustafsson and Palmquist, 1993). Although no difference was detected on the urea and urea-N levels in the blood and urine, the cows supplemented with soybean hulls had the lowest excretion of urea on milk, and the cows supplemented with corn silage had the higher MUN excretion.

The supplementation of soybean hulls allowed greater nitrogen use, which reduced nitrogen excretion in milk. The carbohydrate source of high ruminal degradability present in soybean hulls may have favored the lower MUN content due to the lower loss of $\text{NH}_3\text{-N}$ from the rumen and the better profile of essential amino acids which improve the synthesis of protein by ruminal microorganisms (Theurer et al., 1999). The 12 to 17 mg/dL variation in MUN concentration, according to Hutjens and Barmore (1995), suggests that the proper ratio of rumen fermented energy and degraded protein has been achieved. In the present study, the average MUN observed was 16.13 mg/dL.

Nutrition is a very important factor for dairy cows performance, and the supplementation of good-quality, low-cost roughage is necessary during the dry season in tropical areas to increase dairy farming profitability. It is important to highlight the positive effect of soybean hulls and corn silage supplementation on the performance of dairy cows during the dry season, which in a low-quality pasture were able to increase the milk yield by 13.6%. Although the higher performance observed for these roughage sources, it is crucial for dairy farms in tropical areas to evaluate how economically the supplementation of roughage impacts the cost of production and profitability.

Therefore, the nutritional characteristics of soybean hulls to increase performance of dairy cows observed in this study, associated with the availability of the product on the market, competitive prices, commercialization as a dry feed in pelletized form, and easier transport, storage, handling and mixing of the diet, are advantages of the use of this product compared to silages.

Soybean hulls can be used as supplementary roughage source and substitute the use of corn and sorghum silage during the dry season in tropical forage-based dairy cows system and improve milk production and use of nitrogen by cows. The supplementation of soybean hulls

for tropical forage-based dairy cows showed a positive associative effect on intake increasing the overall dry matter intake which contributed for the better performance.

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Data availability: The datasets generated and/or analyzed during the current study are not publicly available but are available from the corresponding author on reasonable request.

Ethics approval: All animals were managed with accepted husbandry procedures and in accordance with the protocol approved by Federal University of Rondonopolis, Ethics Committee on Animal Use (Protocol # 42/2022).

References

- Adin G, Solomon R, Nikbachat M, Zenou A, Yosef E, Brosh A, Shabtay A, Mabjeesh SJ, Halachmi I, Miron J (2009) Effect of feeding cows in early lactation with diets differing in roughage-neutral detergent fiber content on intake behavior, rumination, and milk production. *J Dairy Sci* 92:3364–3373. <https://doi.org/10.3168/jds.2009-2078>.
- Alessio DRM, Velho JP, Tambara AAC, Gomes IPO, Knob DA, Haygert-Velho IMP, Busanello M, Thaler A (2020) Dietary roughage sources affect lactating Holstein × Zebu cows under experimental conditions in Brazil: a meta-analysis. *Trop Anim Health Prod* 52:185–193. <https://doi.org/10.1007/s11250-019-02005-x>.
- Association of Official Analytical Chemists (AOAC) (2002) *Official Methods of Analysis*, 17th ed. AOAC International, Washington, DC.
- Batistoti C, Lempp B, Jank L, Morais MG, Cubas AC, Gomes RA, Ferreira MVB (2012) Correlations among anatomical, morphological, chemical and agronomic characteristics of leaf blades in *Panicum maximum* genotypes. *Anim Feed Sci Technol* 171:173–180. <https://doi.org/10.1016/j.anifeedsci.2011.11.008>.

427 Chizzotti ML, Valadares Filho SC, Valadares RF (2006) Intake, digestibility and urinary
 428 excretion of urea and purine derivatives in heifers with different body weights. *Braz J Anim Sci*
 429 35:1813–1821. <https://doi.org/10.1590/S1516-35982006000600032>

430 Colucci PE, Chase LE, Van Soest PJ (1982) Feed intake, apparent diet digestibility, and rate of
 431 particulate passage in dairy cattle. *J Dairy Sci* 65:1445–1456.
 432 [https://doi.org/10.3168/jds.S0022-0302\(82\)82367-9](https://doi.org/10.3168/jds.S0022-0302(82)82367-9).

433 Curran J, Delaby L, Kennedy E, Murphy JP, Boland TM, O'Donovan M (2010) Sward
 434 characteristics, grass dry matter intake and milk production performance are affected by pre-
 435 grazing herbage mass and pasture allowance. *Livest Sci* 127:144–154.
 436 <https://doi.org/10.1016/j.livsci.2009.09.004>.

437 Detmann E, Paulino MF, Zervoudakis JT, Valadares Filho SC, Euclides RF, Lana RP, Queiroz
 438 DS (2001) Chromium and internal markers in intake determination by crossbred steers,
 439 supplemented at pasture. *Braz J Anim Sci* 30:1600–1609. [https://doi.org/10.1590/S1516-](https://doi.org/10.1590/S1516-35982001000600030)
 440 35982001000600030

441 Detmann E, Valadares Filho SC (2010) On the estimation of nonfibrous carbohydrates in feeds
 442 and diets. *Braz Arch Vet Med Anim Sci* 62:980–984. [https://doi.org/10.1590/S0102-](https://doi.org/10.1590/S0102-09352010000400030)
 443 09352010000400030

444 Graf CM, Kreuzer M, Dohme F (2005) Effects of supplemental hay and corn silage versus full-
 445 time grazing on ruminal pH and chewing activity of dairy cows. *J Dairy Sci* 88:711–725.
 446 [https://doi.org/10.3168/jds.S0022-0302\(05\)72735-1](https://doi.org/10.3168/jds.S0022-0302(05)72735-1)

447 Guo T, Wang ZL, Guo L, Li F, Li F (2021) Effects of supplementation of nonforage fiber source
 448 in diets with different starch levels on growth performance, rumen fermentation, nutrient

449 digestion, and microbial flora of Hu lambs. *Transl Anim Sci* 5:txab065.
 450 <https://doi.org/10.1093/tas/txab065>.

451 Gustafsson AH, Palmquist DL (1993) Diurnal variation of rumen ammonia, serum urea, and
 452 milk urea in dairy cows at high and low yields. *J Dairy Sci* 76:475–484.
 453 <https://doi.org/10.3168/jds.S0022-0302>.

454 Guzatti GC, Duchini PG, Sbrissia AF, Mezzalira JC, Almeida JGR, Carvalho PCF Ribeiro-
 455 Filho, HMN 2017 Changes in the short-term intake rate of herbage by heifers grazing annual
 456 grasses throughout the growing season. *Grassl Sci* 63:255–264.
 457 <https://doi.org/10.1111/grs.12170>.

458 Halachmi I, Maltz E, Livshin N, Chifre A, Ben-Ghedalia D, Miron J (2004) Effects of replacing
 459 roughage with soy hulls on feeding behavior and milk production of dairy cows under hot
 460 weather conditions. *J Dairy Sci* 87:2230–2238. [https://doi.org/10.3168/jds.S0022-](https://doi.org/10.3168/jds.S0022-0302(04)70043-0)
 461 [0302\(04\)70043-0](https://doi.org/10.3168/jds.S0022-0302(04)70043-0)

462 Hutjens MF, Barmore JA (1995) Milk urea test gives us another tool. *Hoards Dairy*. 140, 401.

463 Ipharraguerre IR, Clark JH (2003) Soyhulls as an alternative feed for lactating dairy cows: a
 464 review. *J Dairy Sci* 86:1052–1073. [https://doi.org/10.3168/jds.S0022-0302\(03\)73689-3](https://doi.org/10.3168/jds.S0022-0302(03)73689-3).

465 Johnson AD (1978) Sample preparation and chemical analysis of vegetation. In: t'Mannetje, L.
 466 (Ed.), *Measurement of Grassland Vegetation and Animal Production*. Commonwealth
 467 Agricultural Bureaux, Aberystwyth, pp. 96–102.

468 Lazzarini I, Detmann E, Sampaio CB, Paulino MF, Valadares Filho SC, Souza MA, Oliveira
 469 FA (2009) Intake and digestibility in cattle fed low-quality tropical forage and supplemented
 470 with nitrogenous compounds. *Braz J Anim Sci* 38:2021–2030. [https://doi.org/10.1590/S1516-](https://doi.org/10.1590/S1516-35982009001000024)
 471 [35982009001000024](https://doi.org/10.1590/S1516-35982009001000024)

472 Licitra G, Hernandez TM, Van Soest PJ (1996) Standardization of procedures for nitrogen
 473 fractionation of ruminant feeds. *Anim Feed Sci Technol* 57:347–358.
 474 [https://doi.org/10.1016/0377-8401\(95\)00837-3](https://doi.org/10.1016/0377-8401(95)00837-3)

475 Lin Y, Sun X, Hou X, Qu B, Gao X, Li Q (2016) Effects of glucose on lactose synthesis in
 476 mammary epithelial cells from dairy cow. *BMC Vet Res* 12:81. [https://doi.org/10.1186/s12917-](https://doi.org/10.1186/s12917-016-0704-x)
 477 016-0704-x.

478 Mertens DR (1992) Fiber analysis and its utilization in evaluation of feed and ration
 479 formulation. In: *Proceedings of the International Symposium on Ruminants, Lavras. SBZ-*
 480 *ESAL, Lavras, pp. 188.*

481 Miettinen H, Huhtanen P. (1996). Effects of the ratio of ruminal propionate to butyrate on milk
 482 yield and blood metabolites in dairy cows. *J Dairy Sci.* 79:851-61.
 483 [https://doi.org/10.3168/jds.S0022-0302\(96\)76434-2](https://doi.org/10.3168/jds.S0022-0302(96)76434-2).

484 Minson DJ (1990) *Forage in Ruminant Nutrition*. Academic Press, San Diego, CA.

485 National Research Council (NRC) (2001) *Nutrient Requirements of Dairy Cattle*, 7th rev. ed.
 486 National Academy Press, Washington, DC.

487 Porto MO, Paulino MF, Valadares Filho SC, Sales MFL, Leão MI, Couto VRM (2009) Protein
 488 sources in multiple supplements for finishing crossbred steers on *Brachiaria* pasture, in the wet
 489 season: productive and economical performance. *Braz J Anim Sci* 38:1553–1560.
 490 <https://doi.org/10.1590/S1516-35982009000800020>.

491 Sbrissia AF, Duchini PG, Zanini GD, Santos GT, Padilha DA, Schmitt D (2018) Defoliation
 492 strategies in pastures submitted to intermittent stocking method: underlying mechanisms
 493 buffering forage accumulation over a range of grazing heights. *Crop Sci* 58:945–954.
 494 <https://doi.org/10.2135/cropsci2017.07.0447>.

495 Sklan D, Ashkenazi R, Braun A, Devorin A, Tabori K (1992) Fatty acids, calcium soaps of fatty
496 acids, and cottonseeds fed to high yielding cows. *J Dairy Sci* 75:2463–2472.
497 [https://doi.org/10.3168/jds.S0022-0302\(92\)78008-4](https://doi.org/10.3168/jds.S0022-0302(92)78008-4).

498 Snyder HE, Kwon TW (1987) Soybean Utilization. Van Nostrand Reinhold, New York

499 Teixeira Júnior FEP, Rua JRM, Lopes MA, Costa MD, Pires DAA, Rocha Júnior VR (2016)
500 Effect of different alternative roughages on the profitability of milk production systems with
501 F1 Holstein × Zebu cows. *Ceres* 63:807–815. [https://doi.org/10.1590/0034-](https://doi.org/10.1590/0034-737X201663060009)
502 [737X201663060009](https://doi.org/10.1590/0034-737X201663060009).

503 Theurer CB, Lozano O, Alio A, Delgado-Elorduy A, Sadik M, Huber JT, Zinn RA, (1999)
504 Steam-processed corn and sorghum grain flaked at different densities alter ruminal, small
505 intestinal, and total tract digestibility of starch by steers. *J Anim Sci* 77:2824–2831.
506 <https://doi.org/10.2527/1999.77102824x>.

507 Titgemeyer EC (2000) Soy by-products as energy sources for beef and dairy cattle. In:
508 Drackley, J.K. (Ed.), *Soy in Animal Nutrition*. Fed. Anim. Sci. Soc., Savoy, IL, pp. 238–256.

509 Titgemeyer EC, Armendariz CK, Bindel DJ (2001) Evaluation of titanium dioxide as a
510 digestibility marker for cattle. *J Anim Sci* 79:1059–1063.
511 <https://doi.org/10.2527/2001.7941059x>

512 Urrutia NL, Harvatine KJ (2017) Acetate dose-dependently stimulates milk fat synthesis in
513 lactating dairy cows. *J Nutr* 147:763–769. <https://doi.org/10.3945/jn.116.245001>.

514 Valadares RFD, Broderick GA, Valadares Filho SC, Clayton MK (1999) Effect of replacing
515 alfalfa silage with high moisture corn on ruminal protein synthesis estimated from excretion of
516 total purine derivatives. *J Dairy Sci* 82:2686–2696. [https://doi.org/10.3168/jds.S0022-](https://doi.org/10.3168/jds.S0022-0302(99)75525-6)
517 [0302\(99\)75525-6](https://doi.org/10.3168/jds.S0022-0302(99)75525-6)

Valente TNP, Detmann E, Queiroz AC, Valadares Filho SC, Gomes DI, Figueiras JF (2011) Evaluation of ruminal degradation profiles of forages using bags made from different textiles. *Braz J Anim Sci* 40:2565–2573. <https://doi.org/10.1590/S1516-35982011001100039>

Veriato FT, Pires DADA, Tolentino DC, Alves DD, Jayme DG, Moura MMA (2018) Fermentation characteristics and nutritive values of sorghum silages. *Acta Sci Anim Sci* 40:e34458. <https://doi.org/10.4025/actascianimsci.v40i1.34458>.

Weidner SJ, Grant RJ (1994) Soyhulls as a replacement for forage fiber in diets for lactating dairy cows. *J Dairy Sci* 77:513–521. [https://doi.org/10.3168/jds.S0022-0302\(94\)76979-4](https://doi.org/10.3168/jds.S0022-0302(94)76979-4)

Zanette IEB, Sousa DP, Paula NF, Santos ARM, Macedo BG, Costa RV, Camargo KDV, Carvalho P, Cabral CHA, Cabral CEA (2020) Grazing systems and supplementation effects on tropical forage-based dairy systems in the dry season. *Livest Sci* 241. <https://doi.org/10.1016/j.livsci.2020.104250>

Tables

Table 1. Chemical composition of experimental feeds (g/kg DM).

Parameter ¹	Pasture	Roughage			Concentrate	
		Soybean	Corn	Sorghum	22%	24%
	Marandu	Hull	silage	silage	PB	PB
DM (g/kg feed)	755	907	254	292	933	932
OM	690	869	204	230	802	809
CP	72	127	94	85	228	254
EE	45	55	55	38	50	55

Ash	66	39	50	62	131	123
NDF	688	656	554	726	306	309
NDFap	605	555	498	657	154	161
iNDF	361	42	170	226	30	30
NFC	213	225	303	158	477	461

¹ Dry matter (DM); organic matter (OM); crude protein (CP); ether extract (EE); neutral detergent insoluble fiber (NDF); neutral detergent insoluble fiber corrected for ash and protein (NDFap); indigestible NDF (iNDF) and nonfibrous carbohydrates (NFC).

Table 2. Ingredient composition of the experimental concentrates (g/kg of natural matter).

Ingredients	Concentrate	
	22% CP	24% CP
Corn ground	440	432
Dried distillers grain	180	180
Soybean hulls	178	178
Cottonseed meal	118	118
Urea/ammonium sulfate	22	30
Dicalcium phosphate	25	25

Calcium carbonate	35	35
Mineral premix	2	2

Table 3. Mean structural characteristics of the grass *Urochloa brizantha* cv. Marandu under continuous grazing during the four experimental periods.

Item	Jul-23	Aug-17	Sep-02	Sep-24
DM ¹ (g/kg of grass)	760	800	750	710
Leaf blades, kg/ha	752	120	95	120
Stem + sheath, kg/ha	3066	330	79	291
Dead material, kg/ha	1589	2346	1986	2415
Leaf blades, g/kg	140	40	40	40
Stem + sheath, g/kg	570	120	40	100

Dead material, g/kg	290	840	920	850
Leaf: stem ratio	0.24	0.33	1.0	0.40

¹Dry matter

Table 4. Intake and apparent digestibility of dairy cows in a forage-based system during the dry season supplemented with different roughage sources.

Parameter	Treatments ¹				SEM	P-value
	Control	Soybean hulls	Corn silage	Sorghum silage		
Intake, kg/d						
Dry matter	8.7 ^b	12.9 ^a	10.5 ^b	9.8 ^b	0.42	0.002
Roughage ²	-	2.4 ^a	2.3 ^a	1.2 ^b	0.38	0.012
Pasture ²	4.1	5.3	3.0	4.1	0.64	0.203
Concentrate ²	4.6	5.1	5.1	4.4	0.22	0.190
Crude protein	1.4 ^c	1.8 ^a	1.7 ^{ab}	1.5 ^{bc}	0.05	0.006

Ether extract	0.4 ^c	0.6 ^a	0.5 ^b	0.4 ^{bc}	0.01	0.001
NDF	4.2 ^b	6.8 ^a	5.0 ^b	5.1 ^b	0.29	0.005
Apparent digestibility, %						
Crude protein	75.5	70.7	78.6	74.2	1.79	0.099
Ether extract	44.4	37.0	56.1	59.7	8.64	0.315
NDF	41.6	52.8	48.9	43.2	5.09	0.444

¹Treatments: supplementation only with concentrate (Control); concentrate plus soybean hulls to replace 35% of forage intake (Soybean Hulls); concentrate plus corn silage to replace 50% of forage intake (Corn Silage); and concentrate plus sorghum silage to replace 50% of forage intake (Sorghum Silage).

²Dry matter basis

Means in a row carrying different superscripts are significantly different at $P < 0.05$

Table 5. Milk production and composition of dairy cows in a forage-based system during the dry season supplemented with different roughage sources.

Parameter	Treatments ¹				SEM	P-value
	Control	Soybean	Corn	Sorghum		
		hulls	silage	silage		
Milk production, kg/d						
Milk yield	10.3 ^c	12.4 ^a	11.0 ^b	9.9 ^c	0.16	<0.001
Fat-corrected milk ²	9.5 ^b	11.6 ^a	10.5 ^{ab}	9.4 ^b	0.28	<0.001
Fat	0.332 ^{ab}	0.403 ^a	0.354 ^{ab}	0.309 ^b	0.018	0.012
Protein	0.291 ^{bc}	0.350 ^a	0.319 ^b	0.280 ^c	0.007	<0.001

Lactose	0.448 ^c	0.546 ^a	0.498 ^b	0.437 ^c	0.008	<0.001
Milk solids	1.16 ^{bc}	1.41 ^a	1.27 ^b	1.11 ^c	0.33	<0.001
Milk composition, %						
Fat	3.39	3.35	3.20	3.16	0.09	0.308
Protein	2.98	2.95	2.91	2.89	0.02	0.080
Lactose	4.57 ^a	4.59 ^a	4.54 ^{ab}	4.48 ^b	0.01	0.003
Milk solids	11.93 ^a	11.86 ^a	11.60 ^{ab}	11.47 ^b	0.09	0.010
Urea nitrogen (mg/dL)	16.28 ^{ab}	15.35 ^b	17.06 ^a	15.85 ^{ab}	0.35	0.022

¹Treatments: supplementation only with concentrate (Control); concentrate plus soybean hulls to replace 35% of forage intake (Soybean Hulls); concentrate plus corn silage to replace 50% of forage intake (Corn Silage); and concentrate plus sorghum silage to replace 50% of forage intake (Sorghum Silage).

²Milk corrected to 3.5% fat.

Means in a row carrying different superscripts are significantly different at $P < 0.05$

Table 6. Concentrations and excretion of urea and urea nitrogen in urine and blood of dairy cows in a forage-based system during the dry season supplemented with different roughage sources.

Item	Treatments				SEM	P-value
		Soybean	Corn	Sorghum		
	Control	hulls	silage	silage		
Urine						
Urea, mg/dL	2368	2433	2259	2274	91.92	0.508
Urea, g/day ²	420	320	462	352	45.23	0.134

Urea, mg/kg BW ²	920	688	1001	773	95.94	0.113
N-urea, mg/dL	1105	1135	1054	1061	42.90	0.508
N-urea, g/day ²	196	149	215	164	21.11	0.134
N-urea, mg/kg BW ²	429	321	467	360	44.78	0.113
Blood						
Urea, mg/dL	36.8	39.1	40.5	39.6	3.13	0.851
N-urea, mg/dL	17.1	18.2	18.9	18.5	1.46	0.851

¹Treatments: supplementation only with concentrate (Control); concentrate plus soybean hulls to replace 35% of forage intake (Soybean Hulls); concentrate plus corn silage to replace 50% of forage intake (Corn Silage); and concentrate plus sorghum silage to replace 50% of forage intake (Sorghum Silage).

²Excretion

Means in a row carrying different superscripts are significantly different at $P < 0.05$

Table 7. Nitrogen balance of dairy cows in a forage-based system during the dry season supplemented with different roughage sources.

Item	Treatments ¹				SEM	P-value
		Soybean	Corn	Sorghum		
	Control	hulls	silage	silage		
Ingested N, g/d	235.09 ^c	298.29 ^a	279.81 ^{ab}	248.92 ^{bc}	8.49	0.006
Digested N, g/d	178.12	211.67	220.07	185.14	10.62	0.083
Retained N, g/d	146.91	185.42	182.09	158.36	12.43	0.183
N excreted, g/d						

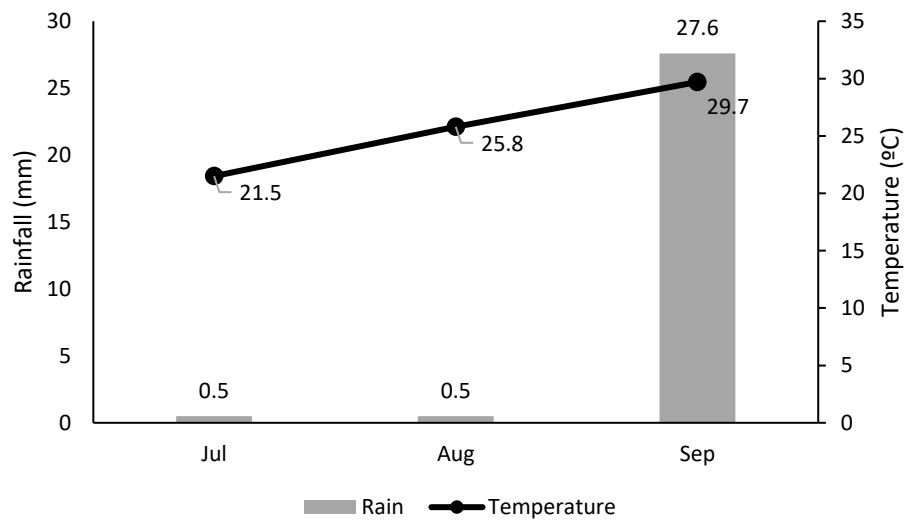
Feces	56.97 ^b	86.61 ^a	59.73 ^b	63.78 ^b	4.18	0.008
Urine	26.32	19.95	32.05	21.97	7.07	0.652
Milk	4.87 ^b	6.29 ^a	5.92 ^{ab}	4.79 ^b	0.26	0.017
NUE ² , %	62.54	61.88	65.15	63.56	2.81	0.855

¹Treatments: supplementation only with concentrate (Control); concentrate plus soybean hulls to replace 35% of forage intake (Soybean Hulls); concentrate plus corn silage to replace 50% of forage intake (Corn Silage); and concentrate plus sorghum silage to replace 50% of forage intake (Sorghum Silage).

²Nitrogen use efficiency: retained N / ingested N.

Means in a row carrying different superscripts are significantly different at $P < 0.05$

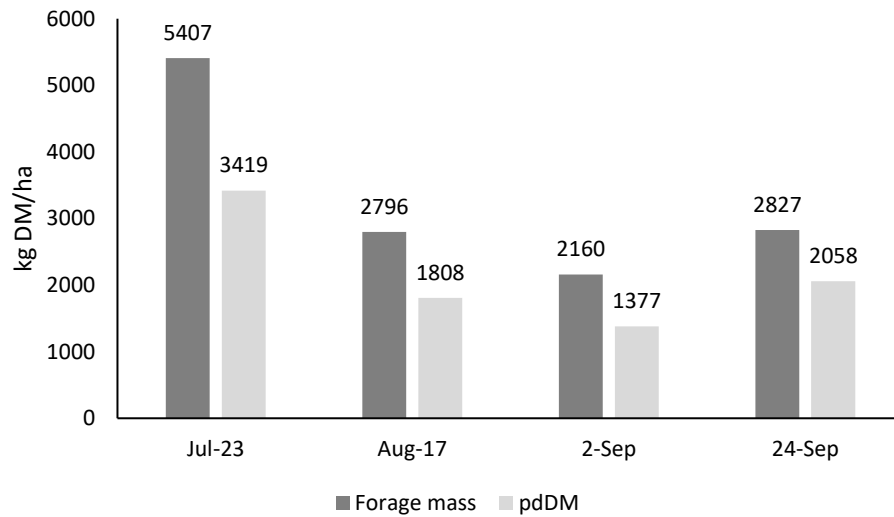
Figures



615

616 Figure 1. Monthly average rainfall (mm) and air temperature (°C) for the months of July to
 617 September 2021. Source: Padre Ricardo Remetter Agrometeorological Station (9
 618 DISME/INMET).

619



620

621 Figure 2. Total forage mass (kg DM/ha) and potentially digestible dry matter (pdDM) (kg
 622 DM/ha) during the four experimental periods.