Tropical Animal Health and Production
https://doi.org/10.1007/s11250-017-1505-3

REGULAR ARTICLES

Dairy cows fed on tropical legume forages: effects on milk yield, nutrients use efficiency and profitability

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Received: 23 June 2017 / Accepted: 17 December 2017

Abstract
Two trials with multiparous dairy cows were conducted. Experiment 1 tested the effects of increasing forage proportion in the diet (500, 600, and 700 g/kg DM) when a mixed sorghum (*Sorghum bicolor*) and jackbean (*Cannavalia ensiformis*) silage was used as forage. Experiment 2 studied the substitution of sorghum silage and soybean meal by jackbean silage or fresh cowpea (*Vigna unguiculata*) forage in the diet. All diets were iso-energetic and iso-proteic. In each experiment, 30 cows were used and separated into three groups. In experiment 1, there were no differences in dry matter intake (DMI), milk yield (MY), or apparent total tract digestibility (aTTd) among the three diets, but milk fat content increased with increasing forage proportion, even though the similar neutral detergent fiber of all diets. Nitrogen use efficiency was highest in the diet containing 600 g forage/kg DM, and some evidence was observed for a better profitability with this forage proportion. In experiment 2, feeding legumes increased DMI despite no effects on aTTd. Milk yield increased in line with DMI, with a larger increase for the fresh cowpea. Nitrogen use efficiency and milk composition were not affected by the diets. The increased MY and lower feed costs increased the economic benefits when feeding legumes, particularly when feeding fresh cowpea. Feeding fresh cowpea or jackbean silage to dairy cows appears to be an alternative to soybean as protein source, ideally at a forage proportions of 600 g/kg DM, without altering milk yield and quality and increasing the farm profitability.

Keywords Tropical legumes · Cowpea · Jackbean · Forage proportion · Dairy cows

Introduction

In dairy farms, silages represent an essential part of the diet, especially during the dry season. Sorghum (*Sorghum bicolor*) is an alternative to maize for silage production in tropical areas with tendencies to draughts or limited precipitation (Marsalis et al. 2010). Even though whole crop silages are generally rich in starch, to meet the animals' requirements for energy and protein, particularly in dairy cows, diets have to be supplemented with grains and pulses, in many cases imported and expensive. Soybean is the most commonly used protein sources in El Salvador and many other regions; however, high prices and dependency from imports affect not only the profitability and sustainability of the farm, but it likely increases the carbon footprint of the animal products in such regions. Early studies suggested the use of forage legumes as alternative protein sources that can be locally produced (e.g., Obeid et al. 1992), whereas a recent review summarized the potential effects of legume silages fed to ruminants (Castro-Montoya and Dickhoefer 2017); however, their incorporation into the production systems is still not fully adopted, likely related to the large range of leguminous materials available in the tropics and the limited information existing on each of those forages compared with temperate legumes. Therefore, the objectives of the current work were to study (1) the effects of increasing proportions of forage in the diet, when legume silages (Jackbean (*Cannavalia ensiformis*)) are fed on milk yield, nutrients digestibility, nitrogen excretions, and profitability; and (2) the effects of feeding two sources of legumes, Jackbean fed as silage, and cowpea (*Vigna unguiculata*) fed fresh, on the same parameters.

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Published online: 02 January 2018

Materials and methods

Two experiments were performed by modifying typical sorghum silage-based diets supplemented with soybean-based concentrate that are generally used in the region. Crossbred cows (3/4 Holstein × ¼ Zebu) were used for the trials. The trials were performed at the Astoria Cooperative farm in La Paz, El Salvador, and the experimental procedures applied to animals were approved by the Research Council of the University of El Salvador.

Each study lasted 21 days divided in 14 days of adaptation and 7 days of sample collection and measurements.

Experiment 1

Starting in October 2015, 30 dairy cattle with an average (± standard deviation) body weight (BW) of 450 ± 27.4 kg, milk yield of 16.2 ± 3.63 kg/day, and 86.6 ± 75.3 days in milk were divided into three groups of 10 cows. In this experiment, three forage proportions in the diet were tested (500, 600, and 700 g/kg DM), where the forage part was compounded of sorghum-jackbean silage.

Experiment 2

Starting at the end of November 2015, 30 dairy cattle with an average (± standard deviation) BW of 506 ± 26.7 kg, milk yield of 21.3 ± 3.79 kg/day, and 83.7 ± 70.8 days in milk were divided into three groups of 10 cows. Three diets were tested: sorghum silage (control), sorghum + jackbean silage, and sorghum silage + fresh cowpea with a 60:40 forage to concentrate ratio (DM basis).

In both studies, the diets were fed as a total mixed ration (TMR) and were designed to be iso-energetic (9.4 and 9.2 MJ ME/kg DM, for experiments 1 and 2, respectively) and iso-proteic (167 g/kg DM, both experiments), distributed in four meals (0700, 0900, 1300, and 1600 h). Diet composition and nutrients concentrations are presented in Table 1. Moreover, cows were kept in the barn (ca. 8 m^2 per cow) with concrete floor and were milked twice daily (0000 and 1200 h). Before the noon, milking cows were ventilated during 30 min with 1.02 m fans to reduce heat stress.

Forage production and preparation

All crops were established in the rainy season. Seven hectares of sorghum (variety CENTA S2) were planted and harvested after 85 days. Similarly, 7 ha of sorghum and jackbean were intercropped in alternated rows, which equates to a 60:40 on DM basis yield for sorghum and jackbean, respectively (Corea et al. 2010). Rows were separated 80 cm with 5 (sorghum) and 10 (jackbean) plants per meter. The plants were harvested 90 days after seeding when sorghum was in milky stage and jackbean in post-flowering stage. Cowpea was planted in plots of 0.5 ha in rows at 80 cm and five plants per meter, at diverse moments throughout the experiment and was harvested 60 d

Table 1 Diet composition and nutrient concentration of total mixed rations fed to crossbred dairy cows in experiment 1 and experiment 2

	Experiment 1			Experiment 2		
	Forage proportion in the diet (g/kg DM)			Sorghum silage	Jackbean-sorghum silage	Cowpea hay
	500	600	700			
Feedstuff (g/100 g DM)						
Soybean	10.6	12.2	13.4	17.6	11.5	11.8
Dried distillers grains with solubles	11.2	9.76	8.0	8.64	8.97	8.94
Maize	6.52	7.27	5.8	3.72	7.14	5.8
Wheat bran	11.0	4.19	0.0	3.72	6.17	6.3
Molasses	9.01	6.03	0.0	6.16	5.5	6.38
Animal fat	0.0	0.0	1.09	0.0	0.0	0.0
Mineral premix	0.54	0.52	0.48	0.46	0.51	0.48
NaCl	0.54	0.52	0.48	0.46	0.51	0.48
Sorghum silage	0.0	0.0	0.0	59.7	0.0	42.8
Sorghum-jackbean silage	50.6	59.6	69.2	0.0	59.7	0.0
Cowpea forage	0.0	0.0	0.0	0.0	0.0	17.1
Nutrients composition (g/100 g DM)						
Crude protein	16.6	17.0	16.7	17.9	17.0	17.6
Neutral detergent fiber	50.6	52.3	52.8	47.4	50.8	47.2
Metabolizable energy MJ/kg DM	9.6	9.6	9.2	9.2	9.2	9.2

after seeding. In all cases 32 kg/ha of N as formula 16-20-0 were applied at seeding. Sorghum received additional 21 kg/ha of N as ammonium sulfate 20 days later.

Samples collection and analyses

During the sampling period dry matter intake (DMI) was estimated on a group basis by the difference of offered and refused feed; similarly, all feces were collected and weighed per group, and 1 kg of fresh feces was sampled and stored for further analyses. Milk yield was recorded daily for each cow. On days 17 and 20, samples of each TMR (1 kg fresh matter) and milk (120 ml per cow) were collected and stored for further analyses.

Feed and feces samples were dried at 55 °C during 24 h, followed by a further drying at 103 °C overnight; nitrogen was determined by Kjeldahl (AOAC 2005), and NDF following the procedure of Van Soest (1967). Milk was analyzed for fat content by Babcock and nitrogen by Kjeldhal (AOAC 2005) multiplying the N concentration by the factor 6.38 to obtain milk protein. Milk urea N was analyzed spectrophotometrically by the diacetyl monoxime method (Merck, Darmstadt, Germany).

Economic evaluation

Based on agricultural supplies and feed prices at the time of the study, ration cost (US$/kg TMR) was calculated. Similarly using the milk price paid to producers (US$ 0.45/kg milk) at the time of the study, the milk production value was calculated. Income over feed cost (IOFC, US$) was then calculated as the difference between the production value and feed cost per cow (Bailey et al. 2005).

Statistical analysis

An analysis of variance was done using the GLM procedure of SAS (Version 9.4, SAS Institute Inc., Cary, NC, USA). For experiments 1 and 2, the effects of diet type on milk yield and composition were determined with the underlying model:

$$Y_{ij} = \mu + \alpha_i + e_i,$$

where Y_{ij}: result of i^{th} diet; μ: overall mean; α_i: main effect of the i^{th} diet; and e_i: residual error of Y_i.

For all other variables, the analysis was done using the MIXED procedure of SAS considering diet as fixed effect

Table 2 Effects of increasing forage proportion in the diet of crossbred dairy cows using jackbean-sorghum as forage source on nutrients intake, digestibility, milk production, nitrogen utilization, and economic parameters in El Salvador

Parameters	Forage proportion in the diet (g/kg DM)[1]			SEM	P value[2]	
	500	600	700		L	Q
Dry matter intake (kg/day)	15.7	15.8	15.7	0.33	0.98	0.89
Apparent dry matter digestibility (g/100 g)	57.0	58.7	55.0	1.31	0.53	0.36
Apparent crude protein digestibility (g/100 g)	66.2	68.5	63.5	1.21	0.33	0.16
Production parameters						
Milk yield (kg/day)	17.3	20.7	18.8	0.78	0.44	0.11
Energy-corrected milk (kg/day)	17.5	21.7	20.0	0.84	0.22	0.10
Milk fat (g/100 g)	3.44[B]	3.66[AB]	3.80[A]	0.075	0.05	0.80
Milk protein (g/100 g)	3.17	3.23	3.23	0.044	0.6	0.78
Milk urea nitrogen (mg/dL)	10.2	10.6	10.7	0.39	0.62	0.81
Nitrogen parameters						
N Intake (g/day)	427	419	418	7.4	0.66	0.82
N in feces (g/day)	146.1[A]	107.7[B]	154.4[A]	12.11	0.77	0.09
N utilization efficiency (NUE) (g N in milk/100 g N intake)	20.6[b]	25.6[a]	23.3[ab]	0.69	0.02	< 0.01
Economic parameters						
Cost per cow (US$)	4.08	4.03	3.99	0.084	0.69	0.99
Cost per kg DM (US$)	0.21	0.19	0.20	0.009	0.63	0.57
Milk value (US$/day)	7.83	9.37	8.50	0.354	0.44	0.11
Income over feed cost (IOFC) (US$/cow/day)	5.79	6.95	6.51	0.393	0.47	0.35

[1] Different superscripts in a row indicate differences between means ($P < 0.05$); tendencies are denoted by uppercase letters ($P < 0.10$)

[2] Probability of linear (L) and quadratic (Q) effect

and day of sampling as a repeated measurement, with the underlying model:

$$Y_{ij} = \mu + \alpha_i + d_{ij} + e_{ij},$$

where Y_{ij}: result of i^{th} diet; μ: overall mean; α_i: main effect of the i^{th} diet; f_{ij}: random effect of day; and e_{ij}: residual error of Y_{ij}.

Differences were declared at $P < 0.05$, and tendencies were assumed if $0.05 < P < 0.10$. For experiment 1, the probability of a linear or a quadratic effect of the forage proportion in the diet was studied by orthogonal polynomial contrasts. For experiment 2, mean differences were estimated by performing a Tukey test.

Results

Experiment 1

Dry matter and N intake, as well as aDMd and aCPd were not affected by the forage proportions in the diet (Table 2). Similarly, milk yield, milk protein, and MUN concentration remained unchanged by the forage proportion (Table 2); however, a tendency for a higher fat concentration was observed with increasing forage proportion. Nitrogen use efficiency showed a quadratic increase with a higher efficiency with the 60:40 diet. Feeding costs, milk value, and IOFC were not affected by increasing forage proportion in the diet.

Experiment 2

Dry matter intake increased when jackbean silage and cowpea were fed compared with the control diet, as a consequence, N intake also increased, with cowpea showing higher N intake than with jackbean silage (Table 3). Apparent digestibility of DM and CP was not affected by feeding legumes. Milk yield also increased with cowpea feeding but not with jackbean silage compared with the control diet (Table 3) without affecting fat and protein content in milk. Energy-corrected milk and MUN showed tendencies for higher values with the cowpea diet, with the jackbean diet as intermediate. Nitrogen secretion in milk (g/day) was highest for the cowpea diet, but not for the jackbean diet, whereas no effects were observed for nitrogen utilization efficiency (NUE, g N in milk/100 g N intake).

The inclusion of forage legumes in diets decreased the costs of feeding, with a greater decrease for cowpea. Milk value and IOFC increased for the cowpea diet compared with the control, but not for the jackbean diet (Table 3).

Discussion

Even though the animals used in both trials belonged to the same farm and where in similar lactation stage, DMI and milk yield were clearly lower in the first experiment. This was due to the hotter and more humid conditions found in October in El Salvador compared with the cooler drier conditions found

Table 3 Effects of substituting sorghum silage and soybean meal by jackbean silage or fresh cowpea on nutrients intake, digestibility, milk production, nitrogen utilization, and economic parameters of crossbred dairy cows in El Salvador

Parameter	Sorghum silage	Jackbean-sorghum silage	Fresh cowpea	SEM	*P* value
Dry matter intake (kg/day)	17.5^{b}	18.0^{a}	18.3^{a}	0.13	0.01
Apparent dry matter digestibility (g/100 g)	58.7	59.8	59.8	1.28	0.93
Apparent crude protein digestibility (g/100 g)	66.6	67.6	67.2	1.03	0.94
Production parameters					
Milk yield (kg/day)	19.4^{b}	20.8^{ab}	22.0^{a}	0.42	0.03
Energy-corrected milk (kg/day)	20.1^{B}	21.4^{AB}	22.8^{A}	0.49	0.06
Milk fat (g/100 g)	3.60	3.55	3.59	0.061	0.93
Milk protein (g/100 g)	3.15	3.20	3.18	0.035	0.88
Milk urea nitrogen (mg/dL)	12.7^{B}	13.5^{AB}	14.9^{A}	0.398	0.07
Nitrogen parameters					
N Intake (g/day)	470^{c}	504^{b}	528^{a}	6.9	< 0.01
N in feces (g/day)	156.6	163.2	172.9	5.21	0.47
N utilization efficiency (NUE) (g N in milk/100 g N intake)	20.8	21.1	21.3	0.33	0.35
Economic parameters					
Cost per cow (US$)	4.52^{a}	4.24^{b}	4.03^{c}	0.059	< 0.01
Cost per kg DM (US$)	0.22^{a}	0.20^{b}	0.17^{c}	0.006	< 0.01
Milk value (US$/day)	8.77^{b}	9.39^{ab}	9.97^{a}	0.190	0.03
Income over feed cost (IOFC) (US$/cow/day)	4.25^{b}	5.15^{ab}	5.94^{a}	0.209	< 0.01

[1] Different superscripts in a row indicate differences between means ($P < 0.05$); tendencies are denoted by uppercase letters ($P < 0.10$)

at the end of November. The animals in experiment 1 likely suffered the impact of heat stress to a greater extent than those in experiment 2.

Experiment 1

Several studies have reported a decrease in digestibility (e.g., Lascano et al. 2016; Moorby et al. 2006) and a consequent milk yield decline with increasing forage proportion (e.g., Moorby et al. 2006; Yang et al. 2001). However, in the current study, increasing the forage proportion in the diet did not affect aDMd and aCPd when feeding sorghum-jackbean silage, similarly, milk yield did not differ between diets. Most of the studies associate a decreased milk yield with a decreased DMI due to higher forage proportion (Jiang et al. 2017). In contrast, in the current study, DMI was not affected by the forage proportion, likely due to the similar nutrients composition among the diets and the high NDF concentration of all diets regardless of the forage proportion (between 47.2 and 50.8 g/100 g DM). By comparison, the NDF concentration in the study of Jiang et al. (2017) increased with increasing forage proportion and ranged from 35.4 to 43.4 g/100 g DM. A reduced aDMd could have been expected knowing that tropical forages are generally richer in undegradable fiber than wheat bran (used to equalize the NDF concentration among the diets), which proportion in the diet increased with decreasing forage. Additionally, a higher proportion of forage is expected to increase the residence time of the diet in the rumen and with it, its digestibility, but we do not consider this as a plausible effect due to the similar intake level of the animals. However, it is important to keep in mind that with increasing forage proportion, the proportion of jackbean silage in the diet also increased. A recent meta-analysis of Castro-Montoya and Dickhoefer (2017) demonstrated that tropical legume silages have a higher organic matter, NDF and CP apparent total tract digestibility than sorghum silages, which could have minimized the overall effects of higher forage proportion in the diet. Moreover, increasing forage proportion in the diet tended to increase milk fat content, in agreement with previous studies (e.g., Yang et al. 2001) likely due to the production of acetate—a lypogenic fatty acid—from fiber fermentation as observed by e.g., Dong et al. (2015) and Moorby et al. (2006).

An interesting finding was that NUE was quadratically affected by the forage proportion in the diet and was higher when 600 g forage/kg DM were fed, in agreement with a previous study who found higher NUE in diets with 600 g forage/kg DM compared with diets with 500 g forage/kg DM (Martínez et al. 2009). However, in the current study when further increasing the forage proportion in the diet, NUE dropped again. A higher NUE indicates a more efficient incorporation of dietary N into milk protein, and this is mediated by the utilization of N by rumen microbes or by an absorption of dietary amino acids in the duodenum that escaped rumen degradation. Microbial growth, in turn, is determined not only by the availability of both nitrogen and energy but also by their synchronization. It could be therefore, hypothesize that among the current diets, the intermediate one was the most advantageous for the microbes to use energy and N for growth. The higher N output in milk and the tendency for the lower N excretion in feces indicate that N excreted in urine might have decreased, resulting in a beneficial environmental effect with the diet containing 600 g forage/kg DM. However, neither the increased microbial protein synthesis, nor the decreased N urine excretion could be proven within the current study and should be therefore tested in further studies.

Experiment 2

When feeding two different legume sources, DMI increased compared with the diet without legume, an effect commonly observed in temperate legumes and linked to an increased digestibility of such forages (Dewhurst 2013) but in contrast with Castro-Montoya and Dickhoefer (2017) who found no changes in DMI when legumes were included in the diet by up to 400 g/kg DM. Provided that aDMd was not affected by the legumes in the diets, the increase in DMI could have been caused by a higher passage rate, also associated with legume feeding (Dewhurst 2013). Additionally, the increased DMI with cowpea was previously observed under similar conditions (Corea et al. 2017), and it could be also attributed to the substitution of silage, as silage fermentation products are known to depress intake (Buchanan-Smith 1990).

In line with the effects of the diets on DMI, milk yield increased with fresh cowpea feeding, and was intermediate with jackbean silage, likely due to the increased metabolizable energy intake. Moreover, previous studies from temperate legumes have reported a decrease in milk fat when feeding legumes (Dewhurst 2013); however, this was not observed within this study, in agreement with Castro-Montoya and Dickhoefer (2017). All diets had similar NDF concentration, a known factor influencing fat synthesis; therefore, the similar fat concentrations are not entirely surprising.

Furthermore, legume forages have normally a higher rumen degradable protein (RDP) content than the soybean they substitute (Broderick 1995). An increase in RDP supply causes a higher N availability in the rumen for microbial growth, which under conditions of similar rate of energy supply, means a higher ammonia N that is absorbed by the rumen wall and excreted in urine. Milk urea nitrogen, a parameter highly correlated with N excretions in urine (Jonker et al. 1998), increased when legumes were fed, but this was in line with the higher N intake observed with both legume-containing diets. Similarly, no evidence of an enhanced microbial protein synthesis was observed, as both milk protein and NUE and N faceal excretions remained unchanged by legume feeding.

Economic evaluation

In experiment 1, no difference was identified by changing the forage proportion in the diet; however, a slight decrease in feed costs and a numerical increase in milk value caused an increase of 1.16 and 0.72 (US$/cow/day) in IOFC for the diets with 600 and 700 g/kg DM of forage, respectively, compared with the lowest proportion tested, which if achieved on farm, represent a significant improvement in the enterprise's profitability. In experiment 2, diets containing legumes were cheaper than the control diet, which coupled with the higher milk yields improved the IOFC, being highest for the cowpea diet.

Finally, using legume forages may help to increase food security in regions at risk by decreasing the utilization of potentially human edible food for cattle feeding. In experiment 2, the milk yield per kilogram of human edible protein (HEP, Wang et al. 2014) increased from 16.8 kg/kg HEP with the control diet to 24.1 and 25.1 kg/kg HEP when jackbean silage and fresh cowpea was added to the diet, respectively, mainly via substitution of soybean meal. The content of HEP per kilogram diet DM decreased (65.9, 47.8, 47.9 g/kg for control, jackbean-silage, and fresh-cowpea diets, respectively). On the contrary, as the proportion of forage in the diet increased, the HEP content in the diet increased as well, (45.7, 49.8, and 51.5 for 500, 600, and 700 g forage/kg DM, respectively), due to higher soybean inclusion levels needed to maintain the CP concentration in the diet. Therefore, milk output per unit of HEP remained largely unchanged at 24.0, 26.3, and 23.2 kg/kg HEP, with increasing forage proportion in the diet. Even though the nature of the experimental design did not allow to do a statistical analysis on this parameter, there is enough evidence to imply on the positive effect of legume forages on efficiency of non-edible resources. Nevertheless, caution should be taken when increasing the forage proportion in the diet while aiming at maintaining milk production.

Conclusions

When the forage portion of the diet was based on a sorghum-jackbean silage, a forage proportion of 600 g/kg DM showed evidence for an improved nitrogen use efficiency and profitability compared with forage proportions of 500 and 700 g/kg DM, even though there were no differences in intake, digestibility, or milk yield. By comparing a diet based on sorghum silage and soybean meal with diets including legume forages, milk yield increased when feeding legumes via an increase in dry matter intake without affecting digestibility and efficiency of nitrogen utilization. Despite the common notion that legume forages have a higher digestibility than whole crop grass forages, this was not observed in this study. However, and more important, feeding legumes increased the economic benefits from milk production compared with diets heavily relying on soybean as main protein source.

Acknowledgements To the Asociación Cooperativa Astoria for allowing us to work in their farm. To the department of agricultural chemistry for assisting in all nutrient determinations.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

AOAC, 2005. Official Methods of Analysis. 18th ed. Association of Official Analytical Chemists Int., Gaithersburg.

Bailey, K., Jones, C. and Heinrichs, A., 2005. Economic returns to Holstein and jersey herds under multiple component pricing. Journal of Dairy Science, 88, 2269–2280.

Broderick, G.A., 1995. Desirable characteristics of forage legumes for improving protein utilization in ruminants. Journal of Animal Science, 73, 2760–2773.

Buchanan-Smith, J.G., 1990. An investigation into palatability as a factor responsible for reduced intake of silage by sheep. Animal Production, 50, 253–260

Castro-Montoya, J.C. and Dickhoefer, U. 2017. Effects of tropical legume silages on intake, digestibility and performance in large and small ruminants: a review. Grass and Forage science. doi: https://doi.org/10.1111/gfs.12324

Corea, E.E., Aguilar, J.M., Alas, N.P., Alas, E.A., Flores, J.M. and Broderick, G.A., 2017. Effects of dietary cowpea (*Vigna sinensis*) hay and protein level on milk yield, milk composition, N efficiency and profitability of dairy cows. Animal Feed Science and Technology, 226, 48–55.

Corea E.E., Flores, J.M., Salinas, F.M., Crespin, E.A. and Elizondo-Salazar, J.A., 2010 Yield and quality of grasses and legumes for dairy cattle feeding. Journal of Dairy Science, 93, Suppl 1.

Dewhurst, R., 2013. Milk production from silage: comparison of grass, legume and maize silages and their mixtures. Agricultural and Food Science, 22, 57–69.

Dong, L., Ferris, C., McDowell, D., and Yan, T., 2015. Effects of diet forage proportion on maintenance energy requirement and the efficiency of metabolizable energy use for lactation by lactating dairy cows. Journal of Dairy Science, 98, 8846–8855.

Jiang, F., Lin, X., Yan, Z., Hu, Z., Liu, G., Sun, Y., Liu, X. and Wang, Z., 2017. Effect of dietary roughage level on chewing activity, ruminal pH, and saliva secretion in lactating Holstein cows. Journal of Dairy Science, 100, 2660–2671.

Jonker, J., Kohn R. and Erdman, R., 1998. Using milk urea nitrogen to predict nitrogen excretion and utilization efficiency in lactating dairy cattle. Journal of Dairy Science, 81, 2681–2692.

Lascano, G., Koch, L, and Heinrichs, A., 2016. Precision-feeding dairy heifers a high rumen-degradable protein diet with different proportions of dietary fiber and forage-to-concentrate ratios. Journal of Dairy Science, 99, 7175–7190.

Marsalis, M.A., Angadi, S.V. and Contreras-Govea, F.E., 2010. Dry matter yield and nutritive value of corn, forage sorghum, and BMR forage sorghum at different plant populations and nitrogen rates. Field Crops Research, 116, 52–57.

Martínez, C., Chung, Y., Ishler, V., Bailey, K. and Varga, G., 2009. Effects of dietary forage level and monensin on lactation performance, digestibility and fecal excretion of nutrients, and efficiency of feed nitrogen utilization of Holstein dairy cows. Journal of Dairy Science, 92, 3211–3221.

Moorby, J., Dewhurst, R., Evans, R. and Danelón, J., 2006. Effects of dairy cow diet forage proportion on duodenal nutrient supply and urinary purine derivative excretion. Journal of Dairy Science, 89, 3552–3562.

Obeid, J., Gomide, J. and Cruz, M., 1992. Silagem de milho (*Zea mays,* L.,) consorciado com leguminosas na alimentacao de novilhos de corte em confinamento. [Maize silage combined with leguminous in the feeding of stabled beef steers]. Revista da Sociedade Brasileira de Zootecnia, 21, 39–44.

Van Soest, P.J., 1967. Development of a comprehensive system of feed analyses and its application to forages Journal of Animal Science, 26, 119–128.

Wang, C., Liu, J.X., Makkar, H.P.S., Wei, N. and Xu, Q., 2014. Production level, feed conversion efficiency, and nitrogen use efficiency of dairy production systems in China. Tropical Animal Health and Production. 46, 669–673.

Yang, W.A., Beauchemin, K.A. and Rode, L.M., 2001. Effects of grain processing, forage to concentrate ratio, and forage particle size on rumen pH and digestion by dairy cows. Journal of Dairy Science, 84, 2203–2216.