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Nutritive value of Tanzania grass for dairy cows under rotational grazing

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ABSTRACT - A nutritional analysis of Tanzania grass (*Megathyrsus maximus* Jacquin cv. Tanzânia was conducted. Pasture was managed in a rotational grazing system with a 30-day resting period, three days of paddock occupation and two grazing cycles. Ten Holstein × Zebu crossbred cows were kept within a 2-ha area divided into 11 paddocks ha^{-1}. Cows were fed 2 kg of corn meal daily and performance was evaluated by weighing the animals every 14 days and by recording milk production twice a day. Nutritional composition of the Tanzania grass was determined from forage (extrusa) samples collected by esophageal fistulae from two animals. The nutritive value of Tanzania grass was estimated according to a modification of the CNCPS evaluation model. Tanzania grass supplemented with 2 kg of corn meal supplied 33.2% more net energy for lactation than required by the animals to produce 13.7 kg of milk day^{-1}. Nevertheless, the amount of metabolizable protein met the daily protein requirement of the animals. Although the model used in the study requires adjustments, Tanzania grass has the potential to produce milk in a rotational grazing system.

Key Words: animal performance, dairy cows, tropical pastures

Introduction

Tanzania grass (*Megathyrsus maximus* (Jacquin); Simon and Jacobs, 2003) is a good alternative for milk production grazing systems due to its high nutritive value compared with its tropical counterparts (Chambela Neto et al., 2008). Tropical forages produce large amounts of dry matter per area and, consequently, support high stocking rates (Mott, 1960; Hodgson et al., 1981). In addition to high grass production, the efficiency of forage conversion into animal products depends on two factors. First, the quantity of nutrients ingested must be sufficient to meet the animal requirements for a specific production level. Second, enough material must be left after grazing to allow for vigorous regrowth and maintenance of the pasture, without compromising animal performance (Hodgson, 1985; Wilson and Mertens, 1995; Fisher et al., 1996; Lemaire and Chapman, 1996; Buxton and Redfearn, 1997; Gomide and Gomide, 2001; Nelson, 2011).

The knowledge accumulated over the last 100 years regarding the interactions between feed nutritional quality and the efficiency of feed utilization by animals justified the development of animal-performance evaluation systems based on feed intake and nutrient composition (Fox et al., 2004). Recently, mathematical models for diet formulation using non-linear optimization techniques have been suggested by several authors (Souza, 2006; Tedeschi et al., 2008; Jardim et al., 2013). These models allow for simultaneous diet formulation and evaluation to meet animal protein, energy, and fiber requirements, subject to the constraint of maximum fiber intake capacity (Favoreto et al., 2008; Jardim et al., 2013). However, these models need to be repeatedly evaluated and updated to enhance predictive and optimization powers.

The objective of this study was to estimate the nutritive value of Tanzania grass for lactating Holstein × Zebu crossbred cows under rotational grazing, using a non-linear model that accounts for the interactions between dietary components and the digestion and metabolism of these components by the animal.

Material and Methods

The experiment was conducted from January to April 2009 in the Zona da Mata Region of Minas Gerais. The experimental area has an average altitude of 435 m, and a Cwa climate according to the Köppen classification.

The experimental area included eleven 910-m^2 paddocks divided by electric fences and planted with Tanzania grass

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(*Megathyrsus maximus* Jacquin cv. Tanzania (Simon and Jacobs, 2003)) in 2007. The pasture was fertilized with N and K_2O (220 kg ha^{-1} year^{-1} each), and with 55 kg ha^{-1} year^{-1} of P_2O_5. The fertilizer was applied when animals left the paddocks. Paddocks were managed on a schedule of three-day occupation with thirty-day rest intervals. Ten Holstein × Zebu crossbred cows (60 days of lactation) with an average body weight of 495 kg and an average body condition score of 2.8 were used, resulting in a stocking rate of 5.3 animal units (AU) per hectare. Whenever necessary, dry cows were used to maintain a grazing balance of 0.3-m post-grazing residual height in each grazing cycle. Animal performance was evaluated by recording milk production of the cows at 06.00 h and 13.00 h daily and by weighing cows every 14 days. The concentrate feed (2 kg of corn meal) was split into two meals and offered during milkings. Mineral salt and water were available to the animals *ad libitum*. Milk samples from each cow were collected for determination of crude protein, fat, lactose, total solids, and non-fat total solids.

During the three-day grazing period, extrusa was collected from two half-bred, non-lactating cows via esophageal fistulae equipped with collecting bags of synthetic canvas with netted bottoms, adjusted below the fistula for saliva drainage (Bishop and Froseth, 1970). Fistulated animals were subjected to 12 hours of fasting before each collection to avoid contamination by regurgitated material. The sampling period in each paddock was approximately 30 minutes. Samples were stored in plastic bags and frozen (−20 °C) until the end of the field experiment.

Extrusa samples were analyzed for dry matter (DM), ash (MM), ether extract (EE), and crude protein (CP) according to AOAC (1990) and for neutral detergent fiber (NDF), lignin, and neutral detergent fiber corrected for protein and ash (NDFap) according to Goering and Van Soest (1970). Non-fibrous carbohydrates (NFC), fibrous carbohydrates (FC), and indigestible carbohydrates (C' fraction) were analyzed according to Sniffen et al. (1992). Neutral detergent insoluble fibrous carbohydrates (B_2' fraction) was calculated as fraction C' subtracted from total FC. Fractions A' (simple sugars) and B_1' (non-fibrous complex carbohydrates) were estimated by *in vitro* gravimetric and gas production techniques. A gravimetric profile of degradation of neutral detergent fiber corrected for ash and protein (NDFap) was obtained after incubation of samples (Favoreto et al., 2008).

Protein fractions were determined as follows: fraction A (non-protein nitrogen) as the difference between total N and N insoluble in trichloroacetic acid; fraction C as the acid detergent insoluble protein (ADICP) that is indigestible in the gastrointestinal tract of the animal; fraction B_2 (protein with a slow degradation rate) as the difference between neutral detergent insoluble protein (NDICP) and ADICP according to Sniffen et al. (1992); and fraction B_1 (protein with a faster degradation rate than fraction B_2) by the difference, according to the equation $100 - (A + B_2 + C)$ (Favoreto et al., 2008).

Feces samples were collected directly from the rectum of lactating cows and frozen (−20 °C) in plastic bags. After sampling, feces were pre-dried in a forced air oven (55 °C for 72 hours), processed and ground in a Wiley-type mill to pass through a 1-mm sieve, and stored in glass flasks at room temperature until chemical composition determination.

Dry matter intake (DMI) was estimated using animal fecal production data; and indigestibility of forage was based on the estimated NDF indigested residual from forage as the asymptotic indigestible residue (U_p; Eq. 1). Fecal production was determined with chromium oxide (10 g cow^{-1} d^{-1}), with 5 g administered orally twice per day, over 16 days. The first ten days established the marker excretion; over the last six days, feces were collected directly from the rectal ampoule. Feces samples were stored in plastic bags at −20 °C. After the sampling period, feces were dried in a laboratory oven at 55 °C for 72 hours until the determination of chromium concentration.

The food matter dynamics were estimated based on *in vitro* gravimetric techniques, cumulative gas production from microbial fermentation, and determination of transit kinetics (particles and liquid phase) through the gastrointestinal tract. *In vitro* degradation of fiber was measured by heat incubation (39 °C) of samples in duplicate. At each incubation time (0, 1, 3, 6, 9, 12, 24, 36, 72 and 96 hours), samples were ground to 1 mm and added to tubes with buffer solution and ruminal inocula; and the residual content of NDF corrected for ash and protein (NDFap) was determined at each incubation time (Goering and Van Soest, 1970). The fiber degradation kinetics was interpreted by the decreasing sigmoid model proposed by Vieira et al. (2008a):

$$R(t) = A_p\left\{\delta_a^{N_a}\exp(-k_{d3}t) + v\exp(-\lambda_a t)\sum_{i=0}^{N_a-1}\left[\frac{(1-\delta_a^{N_a-i})(\lambda_a t)^i}{i!}\right]\right\} + U_p + \varepsilon \quad (1)$$

In the model, $R(t)$ (g g^{-1}) is the incubation residue after *in vitro* incubation for a given period of time t (h); A_p (g g^{-1}) represents the potentially degradable fiber not available for digestion at time zero; N_a (dimensionless) is the order of time dependency (positive integer) related to the preparation of the fraction A_p for digestion; k_{d3}' (h^{-1}) corresponds to the fiber degradation rate; λ_a (h^{-1}) is the fiber availability rate of A_p as a function of time (dynamic lag); parameter U_p

(g g^{-1}) is the asymptote of the function when t tends to infinite, equivalent by definition to the indigestible fraction of the nutrient being studied; and ε refers to random error, with an assumed normal and independent distribution.

The following equation (Vieira et al., 2008b) was used to estimate the effective ruminal degradability (DE) of fiber:

$$DE = B'_2 k_{d3'}\left\{\sum_{i=1}^{N}[\lambda_r^{\,i-1}/(\lambda_r + k_{d3'})^i] + \lambda_r^{\,N}/[(\lambda_r + k_{d3'})^N (k_e + k_{d3'})]\right\} \quad (2)$$

In which B'_2 (g g^{-1}) is equal to the potentially degradable fiber; λ_r (h^{-1}) represents the transfer rate of particles to the potential escape zone; N is the dependence order (positive integer) of the particle transfer to the potential escape zone; and k_e (h^{-1}) is the passage rate of particles in the potential escape zone. The other terms were previously described.

Kinetic parameters of NFC and B'_2 fractions were estimated by the gas production technique. Cumulative gas production by fermentation was obtained after *in vitro* anaerobic incubations in a water bath at 39 °C, based on methodologies described by Malafaia et al. (1999). Incubations were conducted in glass flasks (100 mL) with butyl rubber stoppers and aluminum seals containing 75 mL of culture medium, 5 mL of ruminal inocula and approximately 250 mg of DM. Gas volume was measured at 0, 1, 3, 6, 9, 12, 24, 48, 72 and 96 hours.

After acquiring the gas production profile from the extrusa dry matter, the final gas volume was estimated by adjusting the model:

$$V_{(t)} = V_f(1 - \exp(-ct)) + \varepsilon \quad (3)$$

In this model, $V(t)$ corresponds to the accumulated volume of gas at time t, expressed in mL; V_f is equal to the maximum volume produced; and c represents the availability of substrate for digestion and its degradation rate, expressed in h^{-1}.

The contributions of the FC and NFC (CT – FC) to the final gas production (V_f) were predicted based on the assumption that the volume of gas produced per monomeric unit of carbohydrate assimilated and fermented by microbial mass is the same for fibrous and non-fibrous carbohydrates (Beuvink et al., 1992; Schofield et al., 1995). The following equations were used:

$$V_{NFC}(t) = V_{fNFC}[1 - \exp(-k_{d1'}t)] + \varepsilon \quad (4)$$

$$V_{FC}(t) = V_{FC}\,[1 - \{\delta_a^{Na}\exp(-k_{d3'}t) + \exp(-\lambda_a t)\Sigma_{i=0}^{Na-1} [(1-\delta_a^{Na-i})(\lambda_a t)^i/i!]\}] \quad (5)$$

In which $V_{FC}(t)$ (mL) represents the volume of gas produced from fibrous carbohydrates; $V_{NFC}(t)$ (mL) represents the volume of gas from non-fibrous carbohydrate fermentation; and $V_{fNFC}(t)$ (mL) represents the final volume of gas estimated from non-fibrous carbohydrates.

Mordant fiber for determination of solid phase rate of passage was obtained from the extrusa samples (Udén et al., 1980) treated with 20 mg chromium g^{-1} NDF. Three hundred grams of fiber treated with dichromate were offered to the animals in one dose during the morning milking. The rate of passage of fluids was determined using Co-EDTA (Udén et al., 1980). Five grams of Co-EDTA (with a concentration of 12.0%, determined in laboratory) packed paper cylinders were supplied orally to the animals. A total of 28 feces samples were collected at times 0, 1, 2, 4, 6, 8, 10, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 56, 64, 72, 80, 88, 96, 108, 120, 132, 144 and 192 h after mordant fiber administration. After collection and processing of feces (drying and milling), the levels of chromium and cobalt were determined by atomic absorption spectrometry.

The kinetic parameters of passage were estimated by adjusting the model to the indicator excretion profiles of the two-compartment generalized exponential model proposed by Pond et al. (1988), using the statistical program SAS (Statistical Analysis System, version 9). The parameters of passage rate were estimated by the GnG1 models, considering the Gamma probability density function over time $\Gamma(N, \lambda_r, t)$, according to Matis (1972), Pond et al. (1988), and Matis et al. (1989), N varying from 1 to 4.

$$C(t) = \varepsilon, \quad 0 \le t \le \tau \quad (6)$$

$$C(t) = C(0)k_e \cdot \{\delta^N \exp[-k_e(t-\tau)] - \exp[-\lambda_r(t-\tau)] \cdot \sum_{i=1}^{N} \frac{\delta^i \cdot [\lambda_r(t-\tau)^{N-i}}{(N-1)!}\} + \varepsilon t \ge \tau \quad (7)$$

In which the $\delta = \lambda_r/(\lambda_r - k_e)$ ratio was used to simplify the equation, and the model parameters were dependent on the restriction, $k_e < \lambda_r$. C is the fecal concentration of the indicator; $C(0)$ is the concentration of the indicator in the retention compartment at time zero; and τ is the transit time of particles through the gastrointestinal tract (discrete latency). The fluid passage rate was determined by fitting Eq. (6) and (7) to the excretion profiles of Cobalt and by assuming N = 1 and $k_e = k_1$.

Average ruminal retention time (RRT) was determined by the following expression:

$$RRT = \frac{N}{k_e} + \frac{1}{\lambda_r} \quad (8)$$

The nutritive value of Tanzania grass was estimated according to the CNCPS (Fox et al., 2004) with the following modifications: the requirements of total net energy (NE_t) and total metabolizable protein (MP_t) were determined using the equations described in NRC (2001), and the mathematical structures of the CNCPS and NRC

models were modified to accommodate four fractions of nitrogen compounds, according to Souza (2006). Relevant modifications were made based on the models of Vieira et al. (2008a,b), such as the calculation of effective ruminal degradability of protein and carbohydrate fractions and the prediction of fiber mass from the rumen-reticulum. The system of equations was programmed on Microsoft Excel® 2007 and the observed DMI, milk production, nutritional composition of feed data as well as feed degradation and passage rates through the gastrointestinal tract were included as inputs for the calculation of NE_t and MP_t requirements and intake. The intakes of NEt and MPt were compared with their required counterparts to verify the consistency of the model outputs. The predictive power of the system was evaluated by the comparison between the predicted and observed values of DMI and milk production as well as the requirements of net energy (NE_L) and metabolizable protein (MP_L) for lactation. Dry matter intake was predicted using the observed production data, whereas milk production was predicted using the observed DMI as an input to the model. Observed NE_L and MP_L were determined from the milk composition and production of each cow; the predicted NE_L and MP_L values were calculated by the system. The predictive capacity of the model was evaluated with Model Evaluation System (MES) according to methodology described by Tedeschi (2006).

Results and Discussion

The levels of fiber (Table 1) observed in extrusa were similar to the results reported by Barbosa and Euclides (1997) in a study on the nutritive value of three ecotypes of *Megathyrsus*, including Tanzania grass. Those authors obtained average fiber levels of 72.9% of DM.

The concentration of crude protein (Table 1) in Tanzania grass in the two periods was higher than the 121 g kg^{-1} of DM reported by Lima et al. (2001) when extrusa of this same forage was fertilized with 150 kg ha^{-1} $year^{-1}$ of nitrogen and managed in rotational grazing. That difference can be explained by the management of the present experiment, which allowed the animals to graze plants with a lower regrowth age, confirming that a higher physiological age of plants corresponds to higher levels of structural cell-wall components and lower nutritional quality (Van Soest, 1994). The values of DM observed in the present work do not differ from those reported in the literature (Gerdes et al., 2000; Lima et al., 2001).

Russell et al. (1992) described the importance of accurate determination of nitrogen fractions and their respective digestion rates to formulating diets that maximize the utilization efficiency of N by rumen microbes and by the host. The non-protein nitrogen proportion (fraction A) observed in the present study (Table 2) was lower than the levels of 18 to 28 g/100 g described by Balsalobre et al. (2003) from a study on Tanzania grass nitrogen fractions under a simulated-grazing treatment.

Nitrogen fraction B_2 (Table 2) corresponds to fraction B_3 of the fractionation proposed by Sniffen et al. (1992) and is below the values observed by Balsalobre et al. (2003) and by Silva et al. (2009), who found that fraction B_3 varied from 41.7 to 32.2 g/100 g at 0.20 m height and from 44.5 to 30.8 g/100 g at 0.40 m height. Similar values (26.9 g/100 g) were observed by Malafaia et al. (1999) for Tifton 85 cut at approximately 60 days of age. This fraction is slowly degraded in the rumen and is therefore an important source of amino acids to the small intestine (Sniffen et al., 1992).

Clipes et al. (2006), working with extrusa samples of Mombaça grass (*Panicum maximum* cv. Mombaça) pastures managed with three-day occupation periods and 36-day resting periods, reported values of 4.4 and 32.8 g/100 g for nitrogen fractions B_1 and B_2, respectively, on the first day of occupation, and values of 8.2 and 33.3 g/100 g, respectively, on the third day of occupation. In the present study, the value of fraction B_1, which is equivalent to the sum of fractions B_1 and B_2 of the Sniffen et al. (1992) fractionation, was 56.31 g/100 g of CP. Low concentrations of fractions B_1 and B_2 can decrease the availability of amino acids and peptides for the non-structural carbohydrate fermenters in the rumen and impede the supply of potentially digestible protein to the small intestine (Waters et al., 1992).

Fraction C, which represents the proportion of unavailable protein not digested in the rumen and intestines (Van Soest, 1994), may vary from 5 to 15 g/100 g of total N. These values were lower than the values for Tanzania grass

Table 1 - Chemical composition of the consumed forage (extrusa) and of the ground corn

Chemicalcomposition	Feed (g kg^{-1} of dry matter)		
	Tanzania grass (Extrusa samples)		Corn
	Period 1	Period 2	
Dry matter[1]	155	156	901
Ash	79	81	16
Crude protein	139	171	99
Crude fat	25	28	42
Neutral detergent fiber	735	711	95
Lignin	52	35	-
NDICP	117	147	90
ADICP	100	90	10
Total carbohydrates	758	720	843
Non-fibrous carbohydrates	163	197	-
Fibrous carbohydrates	595	523	-

[1] Percentage of fresh matter.
NDICP - neutral detergent insoluble crude protein; ADICP - acid detergent insoluble crude protein.

shown in Table 2, which may result in a lower microbial efficiency.

The concentration of rapidly degradable carbohydrates (soluble carbohydrates, starch and non-starch polysaccharides that constitute fractions A' and B_1') were similar (Table 3) to the 15.38 g/100 g for fractions A' + B_1' published by Balsalobre et al. (2003). According to Vieira et al. (2000), tropical grasses rarely have levels of soluble carbohydrates and starch higher than 20% of total carbohydrates. The same authors observed A' and B_1' concentrations of 13.6 and 1.57 g/100 g, respectively, in extrusa from natural pastures in the Zona da Mata Region (MG, Brazil) during the rainy season. The beneficial effects of sugars (fraction A') on the animals are related to the following factors: fast microbial growth caused by readily available energy and higher microbial utilization efficiency of soluble and non-protein nitrogen. Fraction B_1' is an intermediately available energy source for the microbiota (slower than soluble carbohydrates and faster than fibrous carbohydrates); improved B_1' utilization will depend on synchronization of nitrogen availability in the rumen to maximize the production of microbial protein (Sniffen et al., 1992).

The results obtained for the levels of fraction C' (Table 3) did not differ from the values normally observed in tropical grasses. Favoreto et al. (2008) observed levels of 20.37 g/100 g in star grass (*Cynodon nlemfuensis*). Vieira et al. (2000) highlighted the importance of determining this fraction, as it is considered to be unavailable in the rumen and the intestines. The same authors concluded that the increase in fraction C' occurs to the detriment of fraction B_2', increasing the rumen fill effect and decreasing the energy available to the rumen microorganisms.

Potentially degradable structural carbohydrates (fraction B_2') are the main source of energy for grazing animals. Levels of this fraction in Tanzania grass were 58.04 to 63.66 g/100 g of TC.

An asymptotic first-order model adjusted to gas production data from DM and FC allowed for the determination of the NFC gas production curve (Figure 1). The V_f of FC was 12.3 mL/100 mg DM, and the V_f of NFC was 2.2 mL/100 mg DM.

Fractions A' and B_1' could not be differentiated in this study, despite the possibility of determining those fractions with *in vitro* assays of gravimetric fiber degradation and cumulative gas production. Chemical determination of fractions A' and B_1' is very laborious due to the physicochemical properties of the large diversity of substances of which they are comprised (Van Soest et al., 1991). Therefore, the gasogenic contribution was estimated from NFC (considered to represent the sum of fractions A' and B_1'), and the two fractions were estimated by the mathematical procedures of Favoreto et al. (2008). CNCPS defines four fractions of carbohydrates according to their degradation rate in the rumen. These fractions are determined by chemical analysis (Sniffen et al., 1992);

Table 2 - Protein fractions[1] and their degradation rates[2]

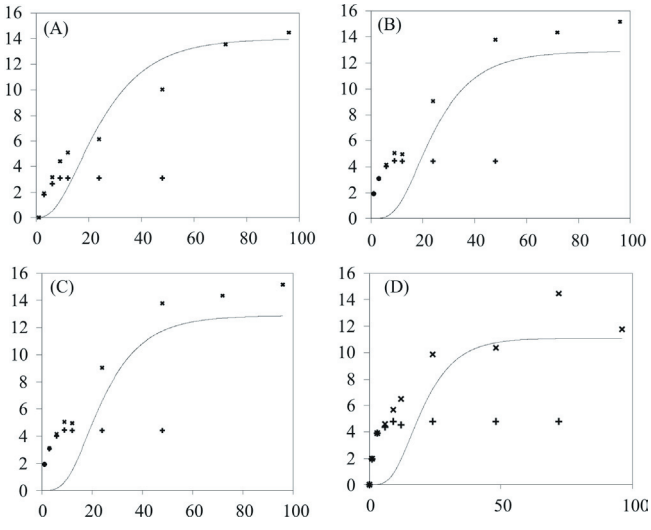
Item		Tanzania grass		Corn meal
		Period 1	Period 2	
Fractions (g kg^{-1} of crude protein)	A	25.5	25.5	120.7
	B1	563.1	563.1	784.3
	B2	245.9	245.9	75.4
	C	165.6	165.6	15.1
Degradation rates (h^{-1})	kd_1	1.67[3]	1.67[3]	0.26[3]
	kd_2	0.07[3]	0.07[3]	0.02[3]

[1] A - non-protein nitrogen; B1 - neutral detergent soluble true protein; B2 - potentially degradable true neutral detergent insoluble protein; C - unavailable neutral detergent insoluble true protein.
[2] kd_1 for B1 and kd_2 for B2.
[3] Values obtained from tables of CNCPS.

Table 3 - Carbohydrate fractions[1] of Tanzania grass (extrusa) and ground corn and their degradation rates[2]

Item		Tanzania grass		Corn
		Period 1	Period 2	
Fractions (% of total carbohydrate)	A'	19.78	16.28	8.94
	B1'	0.82	0.68	79.86
	B2'	58.04	63.66	10.66
	C'	21.36	19.38	0.57
Degradation rates (h^{-1})	kd_1'	0.46	0.46	0.35[3]
	kd_3'	0.08	0.08	0.06[3]

[1] A' - soluble sugars; B1' - neutral detergent soluble complex carbohydrates; B2' - degradable fibrous carbohydrates; C' - unavailable fibrous carbohydrates and lignin.
[2] kd_1' = kd_2' for the pooled A' + B1'; and kd_2' for B2'.
[3] Values obtained from tables of CNCPS.



The continuous line represents the gas production simulated for fibrous carbohydrates and the observed gas volumes presented are from DM (×) and non-fibrous carbohydrates (+).

Figure 1 - Gas production curves for period 1 (panels A and B) and period 2 (panels C and D).

however, each fermented substrate cannot be chemically determined with the gas production analysis; only large groups of compounds with similar degradation rates can be identified. Gas production analysis detects only the combined fraction of NFC (A' + B1'), which has a higher degradation rate than that of FC (B2'). The separation of these fractions into distinct pools is only possible when fermentation pattern and microbial growth are the only factors considered. These results corroborate the theory of Lucas and Smart (1959), which states that if a fraction of the food has uniform nutritional behavior, then sub-fractions that compose it will behave similarly.

The solid-phase passage rates observed in the literature are generally between 0.02 and 0.08 h^{-1} (AFRC, 1993); similar values were published by Lopes (2002) for lactating Gir or crossbred Holstein × Zebu cows grazing on tropical forages (Table 4).

Microbial degradation of cell-wall constituents in the rumen is a relatively slow process. Ruminants have evolved the ability to retain solid particles of food in the rumen for a longer time than fluids, allowing for more efficient microbial utilization of cell wall constituents (Van Soest, 1994). However, longer retention times may constrain voluntary intake due to the rumen-fill effect (Lechner-Doll et al., 1991). The mean retention times of solids and liquids were 25.2 and 10.7 h, respectively, in the present study. The greater the voluntary feed intake, the lower is the mean residence time of fibrous particles and the lower the metabolizability of the diet (Van Soest, 1994; AFRC, 1993). Nevertheless, despite a greater feed intake, it is possible to maintain the metabolizability of the diet constant irrespective of the plane of nutrition by means of nonlinear optimization techniques (Jardim et al., 2013).

Table 4 - Estimates of passage parameters of the particulate and fluid phases in the rumen

Parameters	Statistics		
	Mean	SE	CV%
λ_r (h^{-1})	0.3533	0.2354	66.63
k_e (h^{-1})	0.0626	0.0212	33.94
k_l (h^{-1})	0.0959	0.0161	16.77
SMRT (h)	25.2	5.5	21.8
LMRT(h)	10.7	1.6	14.96

SE - standard error; CV - coefficient of variation.
λ_r - passage rate of the particles from the raft; k_e - passage rate of particles from the escapable pool of the rumen; k_l - fluid passage rate; SMRT - mean retention time of solids in the rumen; LMRT - mean retention time of liquids in the rumen.

The average milk production was 13.7±2.5 kg d^{-1}, with fat and protein concentrations of 38 and 30 g kg^{-1}, respectively; the predicted production was 15.6±3.6 kg d^{-1}. The results of Mean Bias (MB) indicated that the predicted values were close to those observed; however, the predicted values were systematically overestimated (Table 5). After a Cochran and Cox (1954) test was conducted with the MB values, the DM intake (Table 5) and milk production estimates were not significantly different from zero, demonstrating the accuracy of the model in predicting those variables.

The agreement correlation coefficients that describe how close data are to the 1:1 line, and the intraclass correlation coefficient did not support rejection of the respective null hypotheses (Table 5), indicating the low precision of the model predicting milk production, DM intake, MP_L and NE_L requirements. The model should present accuracy and precision for a perfect adjustment (Tedeschi et al., 2004). Both characteristics are measured independently; therefore, a precise method does not guarantee accuracy and vice-versa.

Mean bias indicated an overestimation of the metabolizable protein requirement for lactation (MP_L) by the model. However, the accuracy for this variable was reasonable, indicating that the performance of the model was satisfactory, justifying its use (Tedeschi, 2006).

The predicted milk production was calculated using the first limiting nutrient as a restriction. When the ratio between NE_t intake and NE_t requirement was lower than the MP_t ratio (according to the same calculation), NE_t was considered the first limiting nutrient, and vice versa. This procedure enhanced the accuracy of the model predictions of milk production (Table 5). However, when MP_L and NE_L predictions were analyzed independently, the systematic error of the model increased, and the accuracy decreased, more significantly for NE_L than for MP_L. This effect is demonstrated by the P-values of the MB for milk production, NE_L and PM_L (Table 5). The MB value of DMI prediction was near zero, indicating that this variable

Table 5 - Summary of comparisons between observed and predicted values and respective P-values within parentheses

Variables	Tests			
	MB	CD	CCC	ICC
Milk production, kg d^{-1}	–1.846 (0.066)	0.364	0.182 (0.319)	0.193 (0.339)
MPL, g d^{-1}	–100.015 (0.036)	0.372	0.224 (0.202)	0.242 (0.235)
NEL, MJ d^{-1}	–27.176 (0.001)	0.059	0.043 (0.549)	0.055 (0.531)
DM intake, kg d^{-1}	–0.201 (0.800)	6.171	0.153 (0.329)	0.144 (0.335)

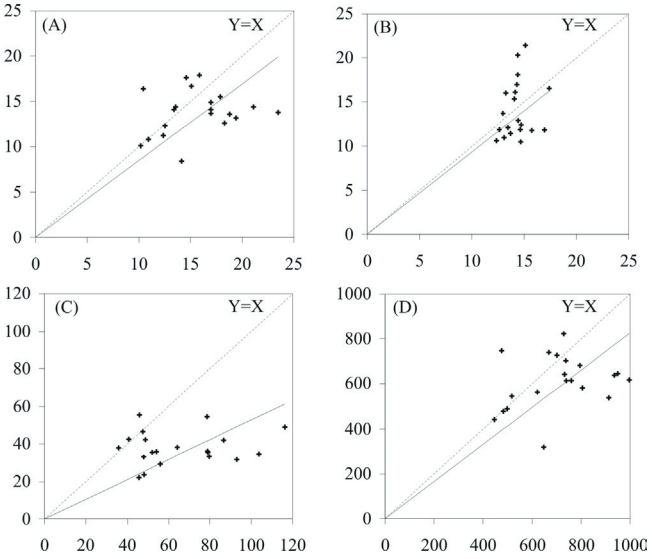
MB - Mean bias; CD - coefficient of determination of the model; CCC - concordance correlation coefficient; ICC - intraclass correlation coefficient.
MPL - metabolizable protein for lactation; NEL - net energy for lactation; DM - dry matter.

was independent of the adopted model. Nevertheless, the estimates of coefficient of determination, concordance correlation coefficient and intraclass correlation coefficient indicated low precision of the model predictions (Table 5).

The observed and predicted values were compared by robust regression, which showed an overestimation of the model predictions (Figure 2). The predictions of milk production were, on average, 18% higher than the observations (Figure 2A). The observed and predicted values of dry matter intake (Figure 2B) were highly correlated; thus, the model can be considered accurate, but not precise. In Figure 2C, the bias of the model in predicting NE_L is evident, as the regression shows a different slope from the unit line. A higher proportion of points below the 1:1 line illustrates the overestimation of the predicted values (Figure 2C). The same overestimation was observed for MP_L estimates (Figure 2D).

Assuming exact estimates by the model, the NE_t intake was 33.2% higher than the NE_t requirement for producing 13.7 kg d^{-1} of milk (Figure 3A). The energy obtained from forage and concentrate intake was enough to supply the production potential of the animals. This result indicates that the efficiency of utilization of the dietary energy was low, most likely because of an energy:protein imbalance.

On average, the consumed metabolizable protein matched the protein requirement of the lactating cows during the experiment (Figure 3B). According to the model predictions, metabolizable protein was the first limiting nutrient. In this case, the NE_t surplus (Figure 3A) should have resulted in an increase in both body weight and body condition score. However, these effects were not evaluated because body weight and body condition score measurements are not sufficiently sensitive for short experimental periods.



Robust estimations of the inclinations are 0.8472±0.0487 (P<0.001) for panel (A), 0.9323±0.0516 (P<0.001) for panel (B), 0.5275±0.0466 (P<0.001) for panel (C), and 0.8261±0.0424 (P<0.001) for panel (D).

Figure 2 - Comparisons between observed (Y axis) and predicted (X axis) values, related to the following variables: daily milk production (kg d^{-1}, panel A), dry matter intake (kg d^{-1}, panel B), net energy for lactation (kg d^{-1}, panel C) and metabolizable protein for lactation (kg d^{-1}, panel D).

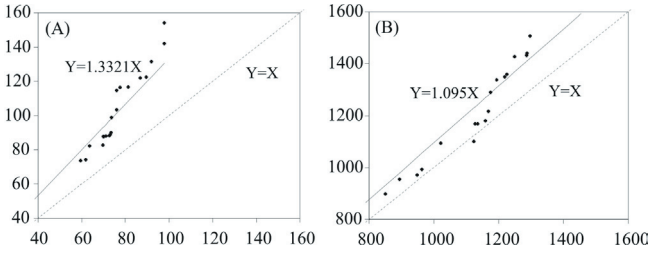


Figure 3 - Values supplied by the diet (Y) and required by the animal (X) in total net energy for maintenance and production (NE_t, MJ d^{-1}; panel A) and in metabolizable protein for maintenance and production (MP_t, g d^{-1}; panel B).

Conclusions

Tanzania grass has potential as forage for milk production in a rotational grazing system managed with three days of grazing and a thirty-day resting period. Because of a tendency toward overestimation of metabolizable protein and energy values, the model used in this study needs adjustments to enhance the accuracy and precision of predictions.

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