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Supplementation of growing bulls grazing *Panicum maximum* cv. Coloniao increases average daily gain and does not impact subsequent performance in feedlot phase

Suplementação de tourinhos em crescimento pastejando Panicum maximum cv. Colonião incrementa o desempenho e não impacta a performance na fase subsequente de confinamento

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ABSTRACT

To evaluate the influence of supplementation strategies on the average daily gain (ADG) of cattle in a rotational grazing system of Guinea grass (*Panicum maximum* cv. Coloniao) pastures during the rainy season. It was further evaluated the residual effects in the feedlot finishing phase. Seventy-five 8 month-old crossbred bull calves averaging 200.1 ± 2.5 kg of body weight (BW) were stratified and grouped in three into 25 blocks according to BW, and then randomly assigned to one of three supplementation treatments: control (no supplement), energy supplement [65 g crude protein (CP)/kg dry matter (DM)] or protein supplement (200 g CP/kg DM) both fed as 6 g/kg BW. All animals composed a single herd and were separated daily according to treatment groups for supplementation. After the grazing phase, all animals were moved to a feedlot and received the same diet up until slaughter. Guinea grass was subjected to rotational stocking with pre- and post-grazing heights of 76 and 43 cm, respectively. Energy and protein supplements provided similar ADG ($P > 0.05$; 0.94 kg/day) which was greater than for non-supplemented animals during the grazing phase ($P \leq 0.05$; 0.74 kg/day), but there was no difference in the subsequent feedlot phase ($P > 0.05$; 1.45 kg/day). The protein supplement had no incremental effects over the energy supplement on ADG and carcass traits of growing crossbreed bulls during the grazing phase, indicating that either source could be used, and

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that an energy supplement would lead to more efficient nutrient use coming from the grass.

Keywords: concentrate, energy, Guinea grass, protein, tropical forage

RESUMO

Objetivou-se avaliar estratégias de suplementação sobre o ganho médio diário (GMD) de bovinos pastejando capim-colonião (*Panicum maximum*) sob lotação rotacionada na estação chuvosa. Também foi avaliado o efeito residual na fase de terminação em confinamento. Setenta e cinco bezerros mestiços não-castrados de oito meses com peso corporal (PC) médio de 200,1 ± 2,5 kg foram estratificados e agrupados de acordo com PC, distribuídos em 25 blocos, e aleatorizados entre três tratamentos: controle (sem suplementação), suplemento energético [65 g de proteína bruta (PB)/kg matéria seca (MS)] ou suplemento proteico (200 g PB/kg MS) ambos fornecidos a 6 g/kg PC. Os animais compuseram um único rebanho sendo separados diariamente de acordo com o tratamento para suplementação. Após a fase de pastejo, esses foram movidos para um confinamento onde receberam a mesma dieta até o abate. O capim-colonião foi pastejado sob lotação rotacionada com altura média pré- e pós-pastejo de 76 e 43 cm, respectivamente. Os suplementos proporcionaram GMD semelhante (P > 0,05; 0,94 kg/dia) e superior ao dos animais não suplementados na fase de pastejo (P < 0,05; 0,74 kg/dia) e sem diferença na fase de confinamento (P > 0,05; 1,45 kg/dia). O suplemento proteico não proporciona ganho adicional sobre o energético, sem diferenças sobre o GMD e as características de carcaça de tourinhos mestiços durante a fase de pastejo, indicando que ambas as fontes de suplementação podem ser utilizadas baseado no custo e na disponibilidade, e indicando que o suplemento energético poderia proporcionar uso mais eficiente dos nutrientes contidos na forragem.

Palavras-chave: Concentrado, confinamento, energia, forragem tropical, proteína

INTRODUCTION

The growth of the world's population is not decreasing in the near future, and if we are to continually meet the larger demand for food, it becomes obvious that there is a need to focus on ways to increase farming efficiency. Improvements in herbage nutritive value and grazing efficiency through strategic grazing management of temperate grasses (Hodgson, 1990), were further supported by research conducted with a wide range of tropical forages (Da Silva et al., 2015). Despite the countless benefits of these strategically grazed and fertilized pastures, the herbage crude protein (CP) usually reaches values greater than 15% whilst the non-fibrous carbohydrate (NFC) content remains lower than 7% (Congio et al., 2018). Johnson et al. (2001) showed that the concentration of CP in tropical forages increases considerably with nitrogen (N) fertilization, which may result in CP in excess of the requirements for growing cattle (NASEM, 2016). An overfeeding of CP would increase not only the feed costs, but also the energy required to metabolize the excess of N (Silva et al., 2019). Furthermore, excessive N excretion may potentially result in environmental issues such as greenhouse gas emissions (Congio et al., 2019). The use of supplements for grazing animals could potentially improve the average daily gain (ADG), allowing animals to reach heavier weights in the finishing phase, and decrease the animals' slaughter age (Roth et al., 2019). However, an ideal supplementation strategy must be considered to meet the animal requirements in order to optimize the nutrient use efficiency (Delevatti et al., 2019). Costa et al. (2019) evaluated the performance of beef cattle subjected to strategic grazing management of Marandu palisade grass (*Uruchloa brizantha*) associated with the use of an energy supplement, finding positive synergistic effects on animal performance and productivity. The objectives of the current work were to evaluate the influence of energy or protein supplementation on the performance of cattle grazing Guinea grass (*Panicum maximum*) that has been rotationally stocked, and to evaluate the impacts of both strategies in the following feedlot phase. The first hypothesis was that cattle performance would be improved by the use of supplementation and would be no different between the sources utilized. A second hypothesis was that cattle supplemented in the grazing phase would not have deleterious effects on ADG in the feedlot phase.

MATERIAL AND METHODS

All procedures were conducted in accordance with the guidelines of the Animal and Environment Ethics Committees at the University of São Paulo, College of Agriculture "Luiz de Queiroz" (USP/ESALQ).

Study site and experimental set up

The grazing phase of the experiment was carried out at the Department of Animal Science of USP/ESALQ in Piracicaba, SP, Brazil (22°42′S, 47°38′W and 546 m) from the 16th December 2004 until the 23rd May 2005, being 21 days used for adaptation of the animals and 137 days used for animal and forage data collections on a 22-ha area of rainfed Guinea grass pastures divided into eight paddocks (≈ 2.75 ha). The perennial grass was established (1988) in an Eutroferric Red Nitossol soil sampled in July 2003 with chemical properties (0-20 cm) as follows: pH in $CaCl_2$ = 5.4, OM = 30.5 g dm^{-3}, P (ion-exchange resin extraction method) = 10.5 mg dm^{-3}, K = 3.5 mmolc dm^{-3}, Ca = 56 mmolc dm^{-3}, Mg = 21 mmolc dm^{-3}, H+Al = 28 mmolc dm^{-3}, sum of bases = 80.5 mmolc dm^{-3}, cation exchange capacity = 108.5 mmolc dm^{-3}, base saturation = 74%. For the C4 grasses, such as Guinea grass, in group 1, it is recommended a base saturation between 60 to 70% (Santos et al., 2010); therefore, no pH corrections were required with the use of lime. In November 2004, prior to the commencement of the experiment, the area was fertilized with 40 kg P_2O_5/ha and a trace mineral mixture (i.e. 3.9% S, 1.8% B, 0.85% Cu, 2.0% Mn, and 9.0% Zn) at 50 kg/ha. The experimental animals arrived on 16th December, and then 45 kg N/ha were applied between grazing cycles until the end of the experiment. The average maximum and minimum air temperatures and the accumulated rainfall during the grazing period were 29.8 °C, 17.8 °C, 713 mm, respectively.

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Animals and treatments

Seventy-five crossbred (½ Brown Swiss × ¼ Angus × ¼ Nellore) weaned bull calves averaging 200.1 ± 2.5 kg BW (mean ± SD) and 8 months of age were stratified according to shrunk BW and then completely randomly assigned to one of three supplementation treatments: control (no supplement); energy supplement (65 g CP/kg DM, fed as 6 g/kg BW) and protein supplement (200 g CP/kg DM, fed as 6 g/kg BW). All animals had free access to a complete mineral mix and were managed as a single herd in order to exclude some possible effects of the grazing management as indicated by Fisher (2000). The animals were separated daily at 07:00 h according to the treatment group for supplementation. The supplement was offered in two concrete bunks, fed as a group, and weighed in on an as-fed basis. Adjustments on the total amount of supplement offered were made every 28 days between the BW weighing intervals as in Costa et al. (2019). After the grazing phase, all bulls were kept in three groups as in the grazing phase, and then lot fed until slaughter. The ingredients and chemical composition of the supplements and finishing diet are shown in Table 1.

Table 1. Ingredients (g/kg DM, unless specified otherwise) and chemical composition (g/kg DM) of experimental concentrates and finishing diet.

Item	Energy	Protein	Finishing diet
Ingredient			
Citrus pulp	950.0	580.0	640.0
Cotton meal	-	370.0	40.0
Corn silage	-	-	190.0
Cottonseed	-	-	90.0
Urea	-	-	20.0
Mineral mix[1]	50.0	50.0	-
Mineral and vitamin mix[2]	-	-	20.0
Monensin, ppm	98	98	
Chemical composition			
Crude Protein	65.0	206.0	140.0
Neutral detergent fibre	230.0	254.0	327.0
Total digestible nutrients	758.0	709.0	700.0

[1]Provided the following per kilogram of product (DM basis): 110 g Ca; 60 g P; 10 g Mg; 40 g S; 160 g Na; 1500 mg Cu; 4500 mg Zn; 150 mg I; 70 mg Co; 20 mg Se; 600 mg F

[2]Provided the following per kilogram of product (DM basis): 100 g Ca; 80 g P; 50 g S; 50 g Na; 6 mg Co; 550 mg Cu; 35 mg I; 800 mg Mn; 13 mg Se; 2500 mg Zn; 130000 IU vitamin A; 17000 IU vitamin E; 1500 IU vitamin D

Grazing management and herbage measurements

The experimental area was subjected to rotational stocking using the experimental animals in a single herd. Pre- and post-grazing sward heights were managed at 75 cm and 45 cm, respectively, in order to optimize the grazing efficiency and the feeding value of Guinea grass cv. Coloniao based on

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the work done with other *Panicum maximum* cultivars (Moreno, 2004). Pre- and post-grazing herbage masses were sampled in all grazing cycles using six samples collected randomly from each paddock with a rectangular frame (0.75 m^2). The herbage was clipped close to the ground (i.e. 0.5-1 cm), weighed fresh, and a sub-sample of approximately 8.0 kg was taken immediately to the laboratory for morphological composition by hand separation into leaf, stem and dead material as in Costa et al. (2019). The sward height was estimated in all grazing cycles by measuring the inflection of the curvature of the highest leaves in 30 points randomly spread across each paddock. Additionally, twenty hand-plucked sub-samples were taken per paddock at pre-grazing in order to determine the herbage chemical composition of the forage potentially consumed by animals. Both herbage mass and hand-plucked samples were placed in paper bags, weighed fresh, and dried in a forced-air drier (MA035/5, Marconi laboratory equipment, Piracicaba, SP, Brazil) at 55 °C to constant weight for approximately 72 hours.

The samples utilized for the determination of chemical composition were ground through a 1-mm screen (Wiley Mill, Thomas Scientific, Philadelphia, PA, USA). Dry matter (DM) and ash were determined at 105 °C in a forced-air drier (MA035/5, Marconi laboratory equipment, Piracicaba, SP, Brazil) for 24 hours, and at 600 °C in a muffle furnace (MA033/42I300, Marconi laboratory equipment, Piracicaba, SP, Brazil) for 4 hours, respectively (AOAC International, 2005). Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin were determined using a modified method of Van Soest et al. (1991) adapted for use with ANKOM bags (ANKOM Technology Corp., Macedon, NY, USA). The total N content was determined by the Dumas combustion method using a N analyser (Leco Instruments Inc., St. Joseph, MI, USA), and CP calculated as N × 6.25. The *in vitro* digestible organic matter (IVDOM) content was determined by the method of Tilley & Terry (1963), modified by Goering & Van Soest (1970) in a water bath (MA127, Marconi laboratory equipment, Piracicaba, SP, Brazil) at 39 °C.

Grazing animal liveweight performance and intake calculations

The liveweight gain was estimated at 28-day intervals after 16 hours of feed and water curfew. The total dry matter intake was predicted (pDMI) according to equation 2.2 fitted for crossbred cattle from BR-CORTE (Valadares Filho et al., 2016) based on the ADG and BW of each animal as follows:

$$DMI\ (kg/d) = -0.6273 + 0.06453 \times BW^{0.75} + 3.871 \times ADG - 0.614 \times ADG^2.$$

Finishing phase in feedlot

The experimental animals were moved to the feedlot facility, grouped according to the grazing treatments and fed a common restricted diet to maintenance for 28 days. After this period, animals shrunk BW was obtained, and the same finishing diet (Table 1) was fed for 125 days. The amount of feed delivered per animal was increased gradually during the first 2 weeks. During the feedlot phase, the average DMI (aDMI) was estimated daily by the difference between the diet that was offered to and refused by each group. The ADG was calculated from BW measurements at

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28-day intervals after 16 hours of feed and water curfew. At the end of the feedlot phase, animals were slaughtered, and some carcass traits were assessed. The hot carcass weight (HCW) was calculated based on the final shrunk BW assuming 55% dressing percentage for all treatments. The subcutaneous backfat thickness and *Longissimus* muscle area (LMA) were measured at the 12th rib for each carcass after a 24-hour chill at 2 °C, using a numbered grid and a digital calliper, respectively (Luchiari Filho, 2000).

Statistical Analysis

Data were analysed using PROC MIXED from SAS 9.3 (SAS Institute Inc., Cary, NC). Prior to analysis of variance, all data sets were tested to ensure that all the assumptions of analysis of variance were met. Different structures of the variance–covariance matrix were tested and the first-order autoregressive structure was chosen as the best fit for the majority of variables based on the Schwarz's Bayesian Criterion (Wolfinger, 1993). An individual animal was considered an experimental unit as proposed by Fisher (2000) for grazing animals receiving different treatments allocated in the same paddocks. The treatments and their interactions were treated as fixed effects, whilst measurement periods were treated as repeated measures (Littell et al., 2006). Means were calculated using the LSMEANS statement and compared using the Tukey's test at a significance level of $P \leq 0.05$.

RESULTS

Grazing phase

The sward characteristics of Guinea grass are shown in Table 2. The stocking and rest periods averaged 4 and 21 days, respectively. The sward height and herbage mass at pre-grazing averaged 76 cm and 10230 kg DM/ha, respectively. The pre-grazing sward condition was represented by 31% of leaves, 32% of stems and 37% of dead material (Table 2). In contrast, sward height and herbage mass at post-grazing averaged 43 cm and 8280 kg DM/ha, respectively, with only 20% of leaves, 41% of stems and 39% of dead material. The leaf:stem ratio was 1:1 and 0.5:1 at pre- and post-grazing condition, respectively.

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Table 2. Stocking period, rest period, pre- and post-grazing sward characteristics of Guinea grass subjected to rotational stocking management during the grazing phase (Dec 2004 – May 2005).

Variables	Periods					Mean
	1	2	3	4	5	
Stocking period, days	3.3	3.3	5.6	2.8	4.8	4.0
Rest period, days	21.7	22.7	18.4	22.2	20.2	21.0
Pre-grazing						
Herbage mass, kg DM/ha	10470	13610	8550	8480	10040	10230
Sward height, cm	83.2	64.2	64.2	96.0	72.5	76
Leaves, %	39.2	28.1	34.9	31.9	21.2	31
Stem, %	33.4	41.1	36.1	31.1	20.3	32
Dead material, %	27.4	30.8	29.0	37.0	58.5	37
Leaf:stem ratio	1.2:1	0.7:1	1:1	1:1	1:1	1:1
Post-grazing						
Herbage mass, kg DM/ha	7850	9290	6760	7570	9930	8280
Sward height, cm	45.1	42.0	28.6	45.0	55.5	43
Leaves, %	24.6	26.4	23.0	17.0	10.2	20
Stem, %	41.5	39.6	40.1	37.6	45.3	41
Dead material, %	33.9	34.3	36.9	45.4	44.5	39
Leaf:stem ratio	0.6:1	0.7:1	0.6:1	0.5:1	0.2:1	0.5:1

The chemical composition of the hand-plucked samples is shown in Table 3. In general, the herbage chemical composition indicates a typical well managed tropical grass under rotational stocking management and N fertilization practices. The mean CP, NDF, ADF, lignin, ether extract (EE), NFC and IVDOM contents were 163, 666, 336, 40, 17, 56 and 579 g/kg DM, respectively.

Table 3. Herbage chemical composition (g/kg DM, unless specified otherwise) of Guinea grass subjected to rotational stocking management during the grazing phase (Dec 2004 – May 2005).

Variables	Periods					Mean
	1	2	3	4	5	
Dry matter	156	217	222	220	269	217
Ash	100	101	99	91	100	98
Crude protein	185	158	181	172	119	163
Neutral detergent fibre	681	655	660	641	692	666
Acid detergent fibre	336	341	314	304	384	336
Lignin	41	26	50	43	42	40
Ether extract	19	15	18	18	13	17
Non-fibrous carbohydrates[1]	15	71	42	78	76	56
In vitro digestible organic matter	597	581	595	599	523	579

[1]Non-fibrous carbohydrates = 1000 - (Ash + CP + NDF + EE)

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The supplemented animals presented greater final BW (fBW), ADG and pDMI than non-supplemented animals ($P < 0.01$; Table 4). However, there was no difference between supplemented animals ($P > 0.05$). The ADG and pDMI were also influenced by periods ($P < 0.01$; Table 4). The pDMI was greater in the third and fourth periods, intermediate in the first and second, and considerably lower in the fifth period. The ADG was slightly lower in the second period and considerably lower in the fifth period compared to the other periods (Table 5).

Table 4. Initial and final body weight (iBW and fBW, respectively), predicted dry matter intake (pDMI) and average daily gain (ADG) of crossbred weaned bulls grazing Guinea grass subjected to rotational stocking management during the grazing phase, fed or not a 0.6% BW energy or protein supplement (Dec 2004 – May 2005).

Variables	Treatments			SEM[1]	*P*-value		
	Control	Energy	Protein		Trt[2]	Per[3]	Trt×Per
iBW, kg	212.4	209.9	212.3	4.21	0.8921	-	-
fBW, kg	313.4b	333.8a	344.4a	6.35	0.0023	-	-
pDMI, kg DM/d	6.10 b	6.55 a	6.89 a	0.109	<0.0001	<0.0001	0.6545
ADG, kg BW/d	0.74b	0.90a	0.97a	0.027	<0.0001	<0.0001	0.8384

Means followed by the same lower-case letter in rows do not differ ($P > 0.05$).
[1]Standard error of the mean, [2]Treatment effect, [3]Period effect.

Table 5. Predicted dry matter intake (pDMI) and average daily gain (ADG) of crossbred weaned bulls grazing Guinea grass subjected to rotational stocking management during the grazing phase, fed or not a 0.6% BW energy or protein supplement (Dec 2004 – May 2005).

	Periods					SEM[1]	*P*-value
	1	2	3	4	5		
pDMI, kg DM/d	6.40 b	6.35 b	7.00 a	7.38 a	5.62 c	0.122	<0.0001
ADG, kg BW/d	1.03a	0.90b	1.00a	1.06a	0.36c	0.034	<0.0001

Means followed by the same lower-case letter in rows do not differ ($P > 0.05$).
[1]Standard error of the mean.

Feedlot phase

The initial BW (iBW) of non-supplemented animals after the adaptation to the finishing diet, at the beginning of the feedlot phase, was still about 25 kg lower than both supplemented treatments ($P < 0.05$; Table 6). The final BW was also lower for non-supplemented animals ($P < 0.05$) and not different between the supplemented treatments ($P > 0.05$). The hot carcass weight was greater for both supplemented animals compared to the non-supplemented animals ($P < 0.05$). The *Longissimus* muscle area was greater for the protein supplemented animals compared to non-supplemented animals, but no different to the energy supplemented animals ($P < 0.05$; Table 6). In spite of that, no differences were found in subcutaneous backfat thickness amongst the treatments ($P > 0.05$).

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Table 6. Performance and carcass traits of crossbred weaned bulls during the 125 days of the feedlot phase after being fed or not a 0.6% BW energy or protein supplement during the grazing phase.

	Control	Energy	Protein	SEM[1]	*P*-value
Initial body weight, kg	309.9b	328.9a	339.5a	6.20	0.006
Final body weight, kg	486.6b	519.04a	518.3a	7.28	0.003
Average dry matter intake, kg DM/d	9.41	9.42	9.01	-	-
Predicted dry matter intake, kg DM/d	9.59	10.02	9.85	0.137	0.086
Average daily gain, kg BW/d	1.38b	1.51a	1.45ab	0.035	0.035
Hot carcass weight[2], kg	267.6b	285.5a	285.1a	4.87	0.003
Subcutaneous backfat thickness, mm	5.3	6.5	5.2	0.62	0.260
Longissimus muscle area, cm^2	73.8b	76.6ab	79.9a	1.7	0.043

Means followed by the lower-case letter in rows do not differ ($P > 0.05$).
[1]Standard error of the mean. [2]Hot carcass weight calculated assuming a 55% dressing yield for all treatments.

DISCUSSION

Worldwide crop-livestock production must grow 70% by 2050 whilst environmental impacts from production systems should significantly decrease to meet the world's food demand in a sustainable way (Godfray et al., 2010; Foley et al., 2011). In this context, growers must improve farming efficiency through practices with low environmental footprint that would provide profitable outcomes and enable production to continue along the years without deleterious impacts to the environment (Tilman et al., 2002; Gregorini et al., 2017). In grazing systems such as the one used in the current work, managed under tight sward monitoring and N fertilization practices during the rainy season, the herbage CP content usually reaches values greater than 15% with no proportional increase in NFC content (Congio et al., 2018). Such scenarios contribute to a decreased efficiency of forage N utilization, which is usually low in tropical grasses (Poppi & McLennan, 1995). The amount of non-protein vs. true protein in the chemical composition of the grass, protein structure, presence of disulphide bridges, and crosslinking of amino acids within them have a great influence on protein degradation in the rumen (Bach et al., 2005). The N content increases with the use of fertilizers (Johnson et al., 2001) and N losses increase when the degradation rate exceeds the use of N compounds for microbial synthesis. This leads to increased ammonia concentration in the rumen fluid that is potentially absorbed across the rumen epithelium by a passive mechanism, converted to urea in the liver and excreted in urine or recycled to the digestive tract via saliva or by passive diffusion (Silva et al., 2019). In such scenarios, energy supplementation allows for improved N and NFC balance and, consequently, increases the efficiency of the use of forage nutrients by rumen microorganisms

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and thereafter by the host animal (Costa et al., 2020).

Animals require both protein and energy for growth. According to NASEM (2016) growing animals similar to the ones in the current experiment would require approximately 130 g CP per kg of digestible organic matter (OM). However, as stated by Poppi & McLennan (1995), losses may occur in the net transfer of protein from tropical grasses to the intestines when the diet CP content exceeds 210 g CP per kg of digestible OM. The inclusion of NFC in diets with high CP content would contribute to microbial protein synthesis by supplying more energy to microbes (Owens & Goetsch, 1993), but the efficient use of N would happen as long as there is available N in pastures when the extra energy is provided. The CP of the Guinea grass in the current experiment was greater than 160 g/kg DM and showed an NFC of only about 56 g/kg DM indicating that energy content in the final diet of non-supplemented steers could be limiting performance. Danes et al. (2013) reported no effects on ruminal volatile fatty acid concentration and ruminal microbial synthesis in mid-lactation dairy cows supplemented with concentrates, with increasing levels of CP and grazing a fertilized elephant grass (*Pennisetum purpureum*) strategically managed based on optimal sward height. The supplementation of an energy supplement with 8.7% CP was enough to meet the microbial requirements, and the increased supplement CP levels to 13.4 and 18.1% did not increase milk yield and decreased the N use efficiency.

The strategic grazing management in the current experiment allowed non-supplemented animals to reach 0.74 kg BW/d. In contrast, the 6 g/kg BW supplementation provided greater pDMI and an increase of about 0.2 kg BW/d. Additionally, there were no differences on pDMI and ADG between supplemental sources indicating that the energy supplement with 6.5 % CP was enough to meet the ruminal microbial requirements in crossbred weaned bull calves and that the 20% CP supplement most likely decreased N use efficiency.

The greater ADG of supplemented grazing animals is usually associated to increased OM intake (McLennan et al., 2016). However, studies have shown that increasing levels of energy supplementation may lead to reductions in forage intake, but increase the total OM intake (Chase & Hibberd, 1987; Minson, 1990; Farmer et al., 2001). This reduction in forage intake, defined as substitution effect, if also associated to a greater OM intake resulted from the supplementation strategy, is defined as associative effect (Moore, 1980). The forage not consumed due to the substitution effect could potentially be used to increase the stocking rate and consequently obtain greater productivities that improve farming efficiency. In the current experiment, both supplemental sources provided greater pDMI and ADG; however, all animals were kept in a single herd grazing the same paddocks; therefore, the effects on the stocking rate could not

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be assessed. Nevertheless, some authors who have outlined their experiments to evaluate the variation in stocking rate due to the supplementation strategy have reported increments from the use of supplements (Fernandes et al., 2010; Costa et al., 2019). The use of a citrus pulp-based supplement at 6 g/kg BW by Costa et al. (2019) resulted in differences in ADG of about 0.4 kg BW/d greater for supplemented animals and 13% greater stocking rate capacity compared to non-supplemented animals. Fernandes et al. (2010) observed significant increments in stocking rates in Marandu palisade grass when crossbred cattle were supplemented with a high energy protein supplement at 6 g/kg BW (i.e. 6.4 vs 4.9 animal units per hectare, for supplemented and non-supplemented, respectively).

The protein supplement used in the current experiment had no incremental ADG over energy supplementation of the crossbred weaned bull calves, and according to the law of diminishing returns as indicated by Malafaia et al. (2003), the overall costs must be considered when choosing a supplementation strategy. Sources of proteins are usually more expensive than energy supplements (Danes et al., 2013) and, despite the lower feeding costs for non-supplemented bulls, their lower performance resulted in animals with lower BW at the beginning of the feedlot phase and also lower BW at the end of the finishing period, indicating no compensatory growth. Non-supplemented animals in Fernandes et al. (2010) had an ADG of 0.77 kg BW/d whilst supplemented cattle gained 1.06 kg BW/d, very similar to the performance of growing crossbred bulls in the current work, and no deleterious carryover effects from supplementation were observed in the following feedlot phase. Compensatory growth can remove any advantage in using supplements. However, the performance of energy supplemented bulls in the feedlot was 0.13 kg BW/d greater than non-supplemented bulls and no different to their protein supplemented cohort. In contrast, Lancaster et al. (2014) observed effects of supplementation during the backgrounding of animals on their performance in the finishing phase. Animals that were previously supplemented, started heavier and had higher DMI, but gained less weight and were less efficient during the finishing phase. Although, in their work, HCW and LMA were positively related with stocker-phase ADG and iBW in the finishing phase, as observed in the current experiment, they speculate that the lower efficiency may be a function of increased BW at the start of the feedlot phase, rather than stocker-phase ADG. Sharman et al. (2013) reported negative carryover effects of supplementation during the grazing period on finishing ADG, indicating that it may be related to greater deposition of visceral tissues, which would increase maintenance energy required by heavier animals. Furthermore, energy supplemented bulls had carcasses with greater LMA compared with non-supplemented bulls most likely

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linked to a greater HCW. There were no differences in LMA between supplemental sources in the current trial. It may be hypothesized that cattle supplemented during the stocker-phase may adapt easier and faster to finishing high energy diets than non-supplemented animals. The gastrointestinal tract of supplemented animals may be more adjusted anatomically, and also have a rumen microbiome more prepared to energy dense diets. However, it is important to note that animals in Lancaster et al. (2014) presented carcasses with 13 mm subcutaneous backfat thickness versus only 5.2 to 6.5 mm in the present study. Whether bringing the crossbred animals from the present study to a greater subcutaneous backfat thickness would result in feedlot performance response to stocker treatments similar to the one reported by Lancaster et al. (2014) deserves further investigation. In the current experiment, all animals were placed on restricted feeding to maintenance at the end of the grazing period for 28 days due to an unexpected drier period that interfered with forage production. To what extent this could have interfered with the subsequent feedlot phase is unknown, but despite this, the findings of the current work highlight an opportunity to increase the efficiency of tropical pasture-based livestock systems. Energy supplementation for growing yearling bulls strategically grazing tropical pastures during the rainy season, allowing greater ADG, greater BW placement at feedlot and similar or even better performance during the finishing period, could strongly decrease the age and increase the HCW of cattle produced on intensively managed tropical systems, with greater overall production efficiency.

CONCLUSIONS

Energy supplementation at 6 g/kg BW increases ADG of growing crossbreed bulls rotationally grazing Guinea grass pastures during the rainy season, most likely because of increments on the total OM intake. Protein supplement has no incremental effects over energy supplement on ADG and carcass traits of growing crossbreed bulls during the grazing phase indicating that either source could be used based on price and availability, and indicating that an energy supplement would lead to more efficient use of nutrients coming from the grass. There are apparently no compensatory growth effects on non-supplemented animals that would otherwise remove the beneficial aspects of the use of supplementation during the grazing phase.

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