Effects of supplementation on production of beef cattle grazing tropical pastures in Brazil during the wet and dry seasons: a meta-analysis

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ABSTRACT - A meta-analysis was undertaken to examine the effects of different supplementation strategies on production of beef cattle grazing tropical pastures during the wet and dry seasons in Brazil. The database was built with 132 studies published from 1999 to 2010, which accounted for 6,275 individual animals. The supplements assessed were classified into three groups: energy supplement containing <20% crude protein (CP), protein supplement containing ≥20% CP, and urea mineral supplement. The supplementation levels ranged from 0 to 1.6% body weight (BW), and the effects of type and level of supplementation were examined during both dry and wet seasons. The meta-analysis was performed using mixed models. Cattle grazing tropical pastures during the wet season had higher average daily gain (ADG) than that in the dry season (0.81 vs. 0.56 kg/day). In response to supplementation, cattle receiving >1.0% BW of energetic supplement in the wet season had the greatest gain per hectare (GPH; 8.16 kg/ha per day) and daily stocking rate (DSR; 2045 kg BW/ha/day). In the dry season, protein supplementation at rates >0.5% BW provided higher GPH (on average 2.33 kg/ha per day). Neither level nor type of supplement altered the DSR in the dry season (on average 883 kg/ha per day). Estimated regression showed that the ADG of beef cattle increased by 0.308 kg for each 1% of supplement intake. Increased supplementation intake by beef cattle grazing tropical pastures resulted in greater ADG in the warm season, whereas offering energy supplementation at rates >1.0% BW during the wet season as well as protein supplementation at rates >0.5% BW during the dry season increased gain per area.

Keywords: animal performance, dry season, grassland, supplement, wet season

1. Introduction

Cattle production in tropical regions of South America is highly dependent on forage production and quality, which vary throughout the year (Millen et al., 2011). During the late spring and summer (i.e., wet season), forage growth is favored by weather conditions (average temperature >25 °C and precipitation range of 750–1800 mm), and, consequently, there are suitable conditions for increased beef cattle production on pastures. However, the lack of rainfall during the fall, winter, and early spring (i.e., dry season; average temperature <18 °C and/or precipitation <300 mm), provides limited growth of plants, which often has poor nutritive value (Carvalho, 2006). Decreased forage allowance...
combined with its low nutritive value limits cattle production (Moore et al., 1999), and several strategies such as the use of supplementation have been used to minimize this negative scenario in the dry season (Barbero et al., 2017). Supplementation has also been used during the wet season as a strategy to improve the individual animal performance, aiming to decrease the time to slaughter and increase productivity per area (Reis et al., 2009; Resende et al., 2013).

Nevertheless, the type and level of supplementation may vary markedly throughout the year depending on the season and forage attributes, which potentially affects animal response (Boval et al., 2015; Reis et al., 2009). Commonly, nitrogen-mineral energetic, and protein supplements are used mostly to enhance cattle productivity (Barbero et al., 2015). During the dry season, the protein concentration of forage is often below 7% of dry matter (DM), and the supplementation has the goal to increase protein supply (Moretti et al., 2013; Reis et al., 2009). During the wet season, the use of energetic supplements is predominant, but protein supplementation is also offered depending on forage attributes, farm objectives, and supplement cost and availability (Resende et al., 2013). However, although the supplementation level reported in literature varies from 0 to about 1.0% of body weight (BW; Resende et al., 2013), there is still not an overall recommendation of which supplementation type and/or level would be most suitable throughout the seasons.

In addition, some studies on protein supplementation of grazing cattle have been also focused on the efficiency of nitrogen utilization (Detmann et al., 2014) and on the interactions between forage attributes and supplements (Moore et al., 1999). However, the impact of the usual seasonal fluctuations on forage allowance and nutritive value on cattle response to supplementation has not been previously considered. Then, our hypothesis is that a meta-analytical study will be able to identify the most suitable supplement and supplementation level for improving cattle performance in tropical pastures in the wet and dry seasons. Therefore, our objective was to identify the impact of supplementation on average daily gain (ADG), gain per hectare (GPH), and daily stocking rate (DSR) in tropical beef cattle systems during both dry and wet seasons using a meta-analytical approach.

2. Material and Methods

2.1. Database

All data were obtained from studies (peer-reviewed and indexed journals, meeting abstracts, conference proceedings, thesis, and dissertation of public domain) conducted with cattle grazing C4 grasses in Brazil during the wet (i.e., September to April) and dry (i.e., May to August) seasons. The final database used for the meta-analysis included 132 studies (Table 1) published on a timeline of 11 years (1999 to 2010), assessing a total of 6,275 individual animals with average initial age of 480±188 d. The database included 83.8% males and 16.2% females from different husbandry phases (i.e., 1.4% pre-weaning, 55% growing, and 43.6% finishing) and breeding purposes (i.e., 64% beef cattle, 1.1% dairy cattle, and 21% dual-purpose; 14% not defined). Most animals (60.6%) received some concentrate supplementation, whereas others (39.4%) did not receive concentrate supplementation. Database was composed mainly by studies carried out in Southeast [40.4% (65.3% from Minhas Gerais, 30.3% from São Paulo, and 4.4% from Rio de Janeiro states)], Midwest [30.7% (58.1% from Mato Grosso, 39.3% from Mato Grosso do Sul, and 2.6% from Goiás states)], South [26.0% (81.5% from Paraná and 18.5% from Rio Grande do Sul states)], Northeast (1.45%), and North (0.48%) Brazilian regions; 0.96% were not referenced. Moreover, 50.7% of data were taken from experiments conducted during the wet season and 49.3% during the dry season. Most database was obtained from studies carried out in regions with tropical climate, which are hot and semi-humid, with a rainy (summer) and a dry (winter) season. Data from Rio Grande do Sul state, however, are only from studies conducted in the summer period in which the weather and pastures species are similar to those in the wet season in Southeast and Midwest regions. The predominant grass species grazed by beef cattle in the studies were *Brachiaria brizantha* (48.7%), followed by *Brachiaria decumbens* (20.1%) and *Cynodon dactylon* (12.1%).
Table 1 - Summary of the references used in this meta-analysis on cattle grazing tropical pastures

| Study   | Reference                  | Forage genus | Supplementation | Type of supplement |
|---------|----------------------------|--------------|-----------------|--------------------|
| 1       | Alexandrino et al. (2005)  | Panicum maximum | No              | -                  |
| 2       | Barbero et al. (2009a)     | Cynodon dactylon | No              | -                  |
| 3       | Barbero et al. (2009b)     | Cynodon dactylon | No/Yes          | Energy             |
| 4       | Barbosa et al. (2006)      | Panicum maximum | No              | -                  |
| 5       | Barbosa et al. (2007)      | Brachiaria brizantha | No/Yes        | Protein            |
| 6       | Barbosa et al. (2008)      | Brachiaria brizantha | No/Yes        | Protein            |
| 7       | Baroni et al. (2010a)      | Brachiaria brizantha | No/Yes        | Urea mineral supplement |
| 8       | Baroni et al. (2010b)      | Brachiaria brizantha | No/Yes        | Urea mineral supplement |
| 9       | Baroni et al. (2010c)      | Brachiaria brizantha | No/Yes        | Urea mineral supplement |
| 10      | Barreto et al. (2009)      | Brachiaria brizantha | No              | -                  |
| 11      | Benatti et al. (2009a)     | Brachiaria brizantha | No/Yes        | Protein            |
| 12      | Benatti et al. (2009b)     | Brachiaria brizantha | No/Yes        | Protein            |
| 13      | Bomfim et al. (2001)       | Brachiaria decumbens | Yes          | Energy             |
| 14      | Brito et al. (2008)        | Brachiaria brizantha | Yes            | Protein            |
| 15      | Cabral et al. (2008)       | Panicum maximum | No/Yes         | Protein            |
| 16      | Camargo et al. (2009)      | Panicum maximum | No              | -                  |
| 17      | Cândido et al. (2005a)     | Panicum maximum | No              | -                  |
| 18      | Cândido et al. (2005b)     | Panicum maximum | No              | -                  |
| 19      | Cândido et al. (2005c)     | Panicum maximum | No              | -                  |
| 20      | Canesin et al. (2006)      | Brachiaria brizantha | Yes           | Energy/protein     |
| 21      | Canesin et al. (2007)      | Brachiaria brizantha | Yes           | Energy/protein     |
| 22      | Canesin et al. (2009)      | Brachiaria brizantha | Yes           | Urea mineral supplement |
| 23      | Canto et al. (2001)        | Panicum maximum | Yes            | Urea mineral supplement |
| 24      | Canto et al. (2002)        | Panicum maximum | Yes            | Urea mineral supplement |
| 25      | Carloto et al. (2009)      | Brachiaria brizantha | No            | -                  |
| 26      | Carvalho et al. (2009)     | Brachiaria brizantha | Yes           | Protein            |
| 27      | Cavalcanti Filho et al. (2004) | Brachiaria decumbens | No            | -                  |
| 28      | Climaco et al. (2006)      | Brachiaria brizantha | No/Yes        | Energy             |
| 29      | Costa (2007)               | Brachiaria brizantha | No/Yes        | Energy             |
| 30      | Coutinho Filho et al. (2005) | Brachiaria decumbens | No/Yes        | Urea mineral supplement |
| 31      | Cruz et al. (2009)         | Cynodon dactylon | No/Yes         | Energy             |
| 32      | Detmann et al. (2004)      | Brachiaria decumbens | Yes           | Energy/urea mineral supplement |
| 33      | Detmann et al. (2005a)     | Brachiaria decumbens | Yes           | Energy/urea mineral supplement |
| 34      | Detmann et al. (2005b)     | Brachiaria decumbens | Yes           | Energy/urea mineral supplement |
| 35      | Difante et al. (2009)      | Panicum maximum | No              | -                  |
| 36      | Difante et al. (2010)      | Panicum maximum | No              | -                  |
| 37      | El-Memari Neto et al. (2003) | Brachiaria decumbens | Yes           | Protein            |
| 38      | Erbesdöbler et al. (2002)  | Pennisetum purpureum | No            | -                  |
| 39      | Euclides et al. (2001)     | Brachiaria decumbens | No/Yes        | Energy/protein     |
| 40      | Euclides et al. (2009a)    | Brachiaria brizantha | No              | -                  |
| 41      | Euclides et al. (2009b)    | Brachiaria brizantha | Yes            | Protein/urea mineral supplement |
| 42      | Fernandes et al. (2008)    | Brachiaria brizantha | Yes            | Urea mineral supplement |
| 43      | Fernandes et al. (2010)    | Brachiaria brizantha | No/Yes        | Protein            |
| 44      | Figueiredo et al. (2008)   | Brachiaria decumbens | No/Yes        | Protein            |
| 45      | Flores et al. (2008)       | Brachiaria brizantha | No              | -                  |
| 46      | Franco et al. (2001)       | Brachiaria brizantha | Yes            | Protein            |
| 47      | Garcia et al. (2004)       | Brachiaria decumbens | Yes            | Protein            |
| 48      | Goes et al. (2003)         | Brachiaria radicans | No/Yes        | Urea mineral supplement |
| 49      | Goes et al. (2005a)        | Brachiaria brizantha | No/Yes        | Protein            |
| 50      | Goes et al. (2005b)        | Brachiaria brizantha | No/Yes        | Protein            |
| 51      | Goes et al. (2005c)        | Brachiaria brizantha | No/Yes        | Protein            |
| 52      | Goes et al. (2009)         | Brachiaria brizantha | No/Yes        | Protein            |
| 53      | Gomes Júnior et al. (2002) | Brachiaria decumbens | No/Yes        | Urea mineral supplement |
| 54      | Gomide et al. (2007)       | Panicum maximum | No              | -                  |

Continues...
Table 1 (Continued)

| Study | Reference                  | Forage genus       | Supplementation | Type of supplement      |
|-------|----------------------------|--------------------|-----------------|-------------------------|
| 55    | Gonçalves et al. (2004)    | Brachiaria brizantha | Yes             | Urea mineral supplement |
| 56    | Itavo et al. (2007a)       | Brachiaria brizantha | Yes             | Energy                  |
| 57    | Itavo et al. (2007b)       | Brachiaria brizantha | Yes             | Urea mineral supplement |
| 58    | Itavo et al. (2008)        | Brachiaria brizantha | No/Yes          | Urea mineral supplement |
| 59    | Jung et al. (2009)         | Brachiaria brizantha | Yes             | Protein/urea mineral supplement |
| 60    | Kabeya et al. (2002)       | Brachiaria brizantha | Yes             | Protein                 |
| 61    | Leão et al. (2005)         | Brachiaria brizantha | No/Yes          | Energy                  |
| 62    | Lima et al. (2004)         | Brachiaria decumbens| No/Yes          | Protein                 |
| 63    | Machado et al. (2008)      | Brachiaria brizantha | No              | -                       |
| 64    | Machado et al. (2009a)     | Brachiaria brizantha | No/Yes          | Protein                 |
| 65    | Machado et al. (2009b)     | Brachiaria brizantha | No/Yes          | Protein                 |
| 66    | Manella et al. (2002)      | Brachiaria brizantha | No/Yes          | Protein                 |
| 67    | Manella et al. (2003)      | Brachiaria brizantha | No/Yes          | Protein                 |
| 68    | Mello et al. (2008)        | Brachiaria brizantha | Yes             | Urea mineral supplement |
| 69    | Meneses et al. (2008)      | Pennisetum purpureum| Yes             | Energy                  |
| 70    | Missio et al. (2006)       | Pennisetum purpureum| No              | -                       |
| 71    | Montagner et al. (2008)    | Pennisetum glaucum | No              | -                       |
| 72    | Moojen et al. (1999)       | Pennisetum glaucum | No              | -                       |
| 73    | Moraes et al. (2004)       | Brachiaria decumbens| Yes             | Protein                 |
| 74    | Moraes et al. (2006a)      | Brachiaria brizantha | Yes             | Protein                 |
| 75    | Moraes et al. (2006b)      | Panicum maximum     | Yes             | Urea mineral supplement |
| 76    | Moreira et al. (2003a)     | Cynodon plectostachyus| No/Yes        | Urea mineral supplement |
| 77    | Moreira et al. (2003b)     | Cynodon plectostachyus| No/Yes        | Urea mineral supplement |
| 78    | Moreira et al. (2004)      | Cynodon plectostachyus| No/Yes        | Urea mineral supplement |
| 79    | Moreira et al. (2006)      | Panicum maximum     | No/Yes          | Urea mineral supplement |
| 80    | Moreira et al. (2008)      | Panicum maximum     | No/Yes          | Urea mineral supplement |
| 81    | Moretti et al. (2009)      | Brachiaria brizantha| No/Yes          | Protein                 |
| 82    | Nascimento et al. (2003)   | Brachiaria decumbens| Yes             | Energy                  |
| 83    | Nascimento et al. (2009)   | Brachiaria decumbens| No/Yes          | Protein                 |
| 84    | Nascimento et al. (2010)   | Brachiaria decumbens| No/Yes          | Protein                 |
| 85    | Neumann et al. (2005)      | Pennisetum purpureum| Yes             | Protein                 |
| 86    | Oliveira et al. (2004)     | Brachiaria brizantha| No/Yes          | Urea mineral supplement |
| 87    | Paris et al. (2004)        | Cynodon dactylon   | No              | -                       |
| 88    | Paris et al. (2005)        | Cynodon dactylon   | No/Yes          | Energy                  |
| 89    | Paris et al. (2008)        | Cynodon dactylon   | No              | -                       |
| 90    | Paris et al. (2009a)       | Cynodon dactylon   | No              | -                       |
| 91    | Paris et al. (2009b)       | Cynodon dactylon   | No              | -                       |
| 92    | Paula et al. (2009)        | Brachiaria brizantha| No              | -                       |
| 93    | Paula et al. (2010)        | Brachiaria brizantha| Yes             | Protein                 |
| 94    | Paulino et al. (2002)      | Brachiaria decumbens| Yes             | Protein                 |
| 95    | Paulino et al. (2005)      | Brachiaria decumbens| No/Yes          | Urea mineral supplement |
| 96    | Paulino et al. (2006)      | Brachiaria decumbens| No/Yes          | Protein                 |
| 97    | Paziani et al. (1999)      | Brachiaria brizantha| Yes             | Energy                  |
| 98    | Pellegrini et al. (2006)   | Pennisetum purpureum| Yes             | Energy                  |
| 99    | Pereira (2006)             | Brachiaria brizantha| Yes             | Urea mineral supplement |
| 100   | Pessoa (2008)              | Brachiaria brizantha| No/Yes          | Urea mineral supplement |
| 101   | Porto et al. (2008)        | Brachiaria decumbens| No/Yes          | Protein                 |
| 102   | Porto et al. (2009)        | Brachiaria brizantha| No/Yes          | Protein                 |
| 103   | Prado et al. (2002)        | Cynodon plectostachyus| No/Yes        | Urea mineral supplement |
| 104   | Prado et al. (2003)        | Cynodon plectostachyus/ Avena strigosa| No| - |
| 105   | Prizov et al. (2009)       | Panicum maximum    | No              | -                       |
| 106   | Prohmann et al. (2004a)    | Cynodon dactylon   | No/Yes          | Protein                 |
| 107   | Prohmann et al. (2004b)    | Cynodon dactylon   | No/Yes          | Energy                  |

Continues...
Forage attributes described in the individual studies and considered in the present study were: DM, organic matter (OM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), total digestible nutrients (TDN), in vitro dry matter digestibility (IVDMD), forage DM allowance, green:dead matter ratio, leaf:stem ratio, and leaf percentage. Furthermore, the composition of different supplements (i.e., DM, OM, CP, NDF, ADF, TDN, and IVDMD) and supplement intake was also considered.

Supplementation level, calculated as % of BW, was divided into the following ranges: 0 (not supplemented), from 0.1 to 0.49%, from 0.5 to 0.99%, and above 1%. Supplement type was set as energy (with <20% CP), protein (with ≥20% CP), and urea mineral supplement (MAPA, 2004; Instrução Normativa 12/2004).

2.2. Calculations

Where possible, calculations were performed to estimate relevant response variables when data were lacking in the publication. The ADG was calculated as: ADG (kg/day) = (final BW (kg) − initial BW (kg)) / period (days). When the DSR (kg BW/ha/day) was not given in the study, it was calculated according to either of the following equations: DSR = total BW in each paddock (kg) / (area of each paddock (ha) / period (days)); DSR = stocking rate in animal unit (AU/day) × 450; DSR = animals per day × average BW (kg); or DSR = [(available forage mass (kg) / forage allowance (kg DM/100 kg BW) × 100] / period (grazing days). In a system with

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Table 1 (Continued)

| Study | Reference | Forage genus | Supplementation | Type of supplement |
|-------|-----------|--------------|----------------|-------------------|
| 108   | Resende et al. (2009) | Panicum maximum | No/Yes | Protein |
| 109   | Restle et al. (2002) | Brachiaria plantaginea/ Pennisetum glaucum | No | - |
| 110   | Rezende et al. (2009) | Brachiaria brizantha | No/Yes | Urea mineral supplement |
| 111   | Ribeiro et al. (2008a) | Pennisetum purpureum/ Panicum maximum | No | - |
| 112   | Ribeiro et al. (2005) | Brachiaria brizantha | No/Yes | Energy |
| 113   | Ribeiro et al. (2008b) | Cynodon dactylon | No | - |
| 114   | Sales et al. (2008a) | Brachiaria brizantha | Yes | Energy/protein |
| 115   | Sales et al. (2008b) | Brachiaria brizantha | No/Yes | Energy/protein |
| 116   | Santos et al. (2004) | Brachiaria decumbens | No/Yes | Protein |
| 117   | Santos et al. (2005) | Pennisetum glaucum | No/Yes | Energy |
| 118   | Saraiva et al. (2002) | Cynodon dactylon | No/Yes | Energy |
| 119   | Saran Netto et al. (2004) | Brachiaria decumbens | Yes | Urea mineral supplement |
| 120   | Silva et al. (2008) | Brachiaria brizantha | No/Yes | Urea mineral supplement |
| 121   | Silva et al. (2009) | Brachiaria brizantha | No/Yes | Energy/protein |
| 122   | Silva Filho et al. (2007) | Brachiaria brizantha | Yes | Urea mineral supplement |
| 123   | Simioni et al. (2009) | Brachiaria decumbens | No/Yes | Protein |
| 124   | Sousa (2007) | Brachiaria brizantha | No/Yes | Protein |
| 125   | Teixeira et al. (2009) | Cynodon nlemfuensis | No | - |
| 126   | Villela and Ajarza (2002) | Brachiaria decumbens | No | - |
| 127   | Villela et al. (2008) | Brachiaria decumbens | No/Yes | Protein |
| 128   | Villela et al. (2009a) | Brachiaria decumbens | No/Yes | Urea mineral supplement |
| 129   | Villela et al. (2009b) | Brachiaria decumbens | Yes | Protein/urea mineral supplement |
| 130   | Zervoudakis et al. (2001) | Brachiaria decumbens | No/Yes | Protein |
| 131   | Zervoudakis et al. (2002) | Brachiaria brizantha | No/Yes | Protein |
| 132   | Zervoudakis et al. (2008) | Brachiaria decumbens | No/Yes | Urea mineral supplement |

1 Supplement type was set as protein (with ≥20% CP), urea mineral supplement (mixture of salt, minerals, and urea), and energy (with <20% CP).
varied stocking, the DSR in each evaluation period was the arithmetic mean of the stocking rate at the beginning and end of the period. The GPH (kg BW/ha/day) was calculated as: GPH = ADG × animal unit (AU) per ha/day. The AU per ha/day was calculated as: [(AU allocated in each experimental paddock × BW gain in the period) / area of each paddock (ha)] / period (grazing days).

2.3. Statistical analysis

The meta-analysis was performed as mixed models regressing the response variables (i.e., ADG, DSR, and GPH) against the fixed effect of season (dry or wet), supplementation (supplemented or not supplemented), supplement type (energy, protein, or urea mineral), or supplementation level. The MIXED procedure of SAS (Statistical Analysis System, version 9.4) was used for the mixed model analysis, in which the study was included as a random factor in the model using the RANDOM statement (St-Pierre, 2001). Once the standard error of the means was lacking in several studies, the number of replicates (animals) by treatment was used as a weighing factor in the model. Covariates (i.e., average BW, supplement intake (% BW), cattle age (months), and forage content of CP and NDF) were kept in the model when their effects were significant (P<0.05). Distribution of random effects was assumed to be normal, and the restricted maximum likelihood was used as the estimation method (SAS, 2008). When the likelihood ratio test indicated significant heterogeneity of residual variances between treatments, the different residual variances for each treatment were modeled using the REPEATED statement of the GROUP option of SAS, and preferably the Variance Components was used as variance-covariance matrix structure. Outliers were identified and deleted if absolute values of Studentized residuals exceeded ±3. Differences between means were determined using the P-DIFF option of the LSMEANS statement, which is based on Fisher’s F-protected least significant difference test. Significant differences were declared at P≤0.05.

Based on the means estimated from the analyses described above, the effect of season and supplement type on the regressions of ADG, GPH, and DSR against the level of supplement intake was determined using the MIXED procedure of SAS. Regressions were performed by including the study as a random effect and by weighting for the number of replicates per treatment. Cattle age and average BW were tested as covariates in this analysis. When season or supplement type were significant, the intercepts and slopes were compared using the CONTRAST statement of the MIXED procedure. The slopes and intercepts of each equation were estimated using the ESTIMATE statement of the MIXED procedure of SAS. Unless otherwise indicated, P<0.05 was considered statistically significant.

3. Results

3.1. Database description

The amplitude between the minimum and maximum values of the response variables in the database and the range by each of them were influenced by season and supplementation (Table 2). The number of cattle supplemented was greater than those without supplementation during the dry season. In general, the values of ADG (~0.25 to 1.38 kg/day), GPH (~0.57 to 13 kg/ha per day), and DSR (144 to 4050 kg/ha per day) were broadly variable across the treatments and studies, indicating the high representativeness of the database that covered a large part of practical situations found on different grasslands and supplementation strategies for grazing cattle in Brazil.

3.2. Forage attributes

Most chemical attributes were significantly different (P<0.05) between seasons and were also affected by supplementation (Table 3). Although there was a significant interaction (P<0.05) between supplementation and season for some variables (i.e., DM, CP, IVDMD, and leaf:stem ratio), the forage in the wet season showed lower concentrations of DM, NDF (69.6 vs. 72.0% DM), and
ADF (37.9 vs. 40.4% DM) and higher concentrations of OM, CP (9.81 vs. 7.64% DM), TDN (59.8 vs. 51.4% DM), and IVDMD (55.7 vs. 59.0% DM) than in the dry season. On average, the green:dead matter ratio of the forage was higher in the wet season (P<0.05; 3.77 vs. 1.38 in dry season), whereas forage DM availability was higher in the dry season (P<0.05; 29.3 vs. 24.5 kg/100 kg BW in the wet season). There was an interaction between season and supplementation on leaf:stem ratio of forage, in which the forage in the wet season in systems without supplementation showed lower leaf:stem ratio (P<0.05; 0.758). The leaf proportion in forage was not affected by season or supplementation (P>0.05). In general, in both seasons, the supplementation was associated with higher (P<0.05) forage contents of both NDF (71.8 vs. 69.8% DM) and ADF (39.8 vs. 38.5% DM) and lower content of CP (8.09 vs. 9.36% DM). The interaction between season and supplementation showed that the greatest IVDMD of the forage occurred in the wet season (P<0.01), regardless of supplementation. However, in the dry season, forage IVDMD under supplementation was lower than without supplementation (P<0.01).

3.3. Supplement characteristics

The different supplements assessed in our database had similar concentrations of DM (88.7% as fed), NDF (26.7% DM), ADF (10.4% DM), and IVDMD (79.0% DM; Table 4). The greatest CP concentration (P<0.01) was observed in urea mineral supplement (39.0% DM), followed by protein and energy...
### Table 3 - Forage composition (% DM) and availability (±SEM) for both supplemented and not supplemented cattle during the wet and dry seasons

| Variable                             | n   | Dry | Wet | Dry | Wet | Supplementation | Season | Interaction |
|--------------------------------------|-----|-----|-----|-----|-----|-----------------|--------|-------------|
| DM matter (DM % as fed)              | 234 | 44.1±2.41c | 28.7±2.41c | 91.6±4.03 | 29.1±2.41c | <0.001 | <0.001 | <0.001 |
| Chemical composition (% of DM)       |     |     |     |     |     |                 |        |             |
| Organic matter                       | 44.2 | 90.7±4.00 | 86.2±3.79 | 91.3±4.03 | 86.3±3.79 | <0.001 | <0.001 | <0.001 |
| Protein                              | 44.2 | 73.2±7.76 | 70.3±7.90 | 92.8±2.77 | 68.9±2.77 | <0.001 | <0.001 | <0.001 |
| NDF                                  | 301 | 4.1±0.38 | 4.0±0.36 | 59.0±1.39 | 57.9±1.37 | <0.001 | <0.001 | 0.007 |
| Acetate                              | 301 | 51.6±1.38 | 50.9±1.38 | 59.0±1.39 | 57.9±1.37 | <0.001 | <0.001 | 0.007 |
| IVDMD (%)                            | 140 | 65.7±2.14 | 61.4±2.12 | 59.0±1.39 | 57.9±1.37 | <0.001 | <0.001 | 0.007 |
| Available DM (kg/100 kg BW)          | 162 | 2.1±0.307 | 2.4±0.317 | 24.9±2.51 | 24.9±2.51 | <0.001 | <0.001 | 0.007 |
| Leaf (%                               | 286 | 0.87±0.144a | 0.87±0.144a | 57.7±1.49 | 57.7±1.49b | <0.001 | <0.001 | 0.007 |
| Leaf:stem ratio                      | 186 | 1.3±0.137 | 1.3±0.137 | 3.7±0.134 | 3.7±0.134 | <0.001 | <0.001 | 0.007 |
| IVDMD - in vitro dry matter digestibility (%) | 14  | 76.5±5.47 | 76.5±5.47 | 86.4±5.47 | 86.4±5.47 | <0.001 | <0.001 | 0.007 |
| Available DM (kg/100 kg BW)          | 556 | 2.1±0.307 | 2.4±0.317 | 24.9±2.51 | 24.9±2.51 | <0.001 | <0.001 | 0.007 |
| Green:dead matter ratio              | 265 | 0.87±0.144a | 0.87±0.144a | 57.7±1.49 | 57.7±1.49b | <0.001 | <0.001 | 0.007 |
| Leaf (%)                             | 186 | 1.3±0.137 | 1.3±0.137 | 3.7±0.134 | 3.7±0.134 | <0.001 | <0.001 | 0.007 |

**a–c** - Means in the same row with different letters differed significantly (Fisher's test; *P*<0.05).

### Table 4 - Supplement composition (% DM, mean±SEM) during the wet and dry seasons

| Variable                             | n   | Dry | Wet | Dry | Wet | Dry | Wet | DM (%) | Protein | Urea mineral | P-value |
|--------------------------------------|-----|-----|-----|-----|-----|-----|-----|--------|---------|-------------|---------|
| Dry matter (DM % as fed)             | 192 | 89.5±0.20 | 88.8±0.21 | 87.4±0.67 | 88.7±0.67 | <0.001 | <0.001 | 0.381 |
| Chemical composition (% of DM)       |     |     |     |     |     |     |     |        |         |             |         |
| OM                                   | 85  | 92.5±1.12 | 92.5±1.12 | 90.7±0.99 | 90.7±0.99 | <0.001 | <0.001 | 0.033 |
| CP                                   | 347 | 19.1±1.48 | 14.3±1.14 | 29.4±2.32 | 29.4±2.32 | <0.001 | <0.001 | 0.159 |
| NDF                                  | 145 | 9.0±2.92  | 12.9±3.98 | 13.2±2.63 | 13.2±2.63 | <0.001 | <0.001 | 0.125 |
| ADF                                  | 102 | 9.4±2.92  | 10.7±2.35 | 13.2±2.63 | 13.2±2.63 | <0.001 | <0.001 | 0.125 |
| TDN                                  | 173 | 9.4±2.92  | 10.7±2.35 | 13.2±2.63 | 13.2±2.63 | <0.001 | <0.001 | 0.125 |
| IVDMD (%)                            | 14  | 76.5±5.48 | 76.5±5.48 | 76.5±5.48 | 76.5±5.48 | <0.001 | <0.001 | 0.033 |
| SI (%)                                | 377 | 0.77±0.08 | 0.74±0.06 | 0.84±0.08 | 0.84±0.08 | <0.001 | <0.001 | 0.033 |

**DM** - dry matter; **OM** - organic matter; **CP** - crude protein; **NDF** - neutral detergent fiber; **ADF** - acid detergent fiber; **TDN** - total digestible nutrients; **IVDMD** - in vitro dry matter digestibility; **SI** - supplement intake; **BW** - body weight; **n** - number of treatment means comprising all experiments; **SEM** - standard error of the mean.

**1** - Energy = <20% CP; **2** - Protein = with ≥20% CP; **3** - Urea mineral = mixed of mineral supplement with urea (MAPA, 2004; Instrução Normativa 12/2004).

**a–c** - Means in the same row with different letters differed significantly regarding the type of supplement fed (Fisher's test; *P*<0.05).
supplements (30.1 and 14.2% DM, respectively). The TDN concentration in energy and protein supplements averaged 73.7% DM. Comparing the supplements, cattle consumed greater amounts of energy (0.76% BW), followed by protein and urea mineral supplements (0.54 and 0.18% BW, respectively; P<0.05). As average of all supplement types, supplement intake was 13% greater during the dry season than during the wet season (0.52 vs. 0.46% BW; P<0.05).

3.4. Effect of supplementation and season on cattle production

The ADG of grazing cattle in the wet season was 44.6% higher (P<0.001) than that observed in the dry season (0.81 vs. 0.56 kg/day; Figure 1). The ADG of grazing cattle increased at the same rate by increasing the supplementation level when seasons were compared (P<0.001; Figure 1). There was a triple interaction among supplement level, supplement type, and season for GPH and DSR. In the wet season, the higher GPH (8.16 kg/ha per day) and DSR (2045 kg/ha per day) were obtained for cattle receiving more than 1.0% BW of energy supplementation (P<0.001; Figures 2 and 3, respectively). In the dry season, protein supplementation >0.5% of BW provided greater GPH (P<0.001; on average 2.33 kg/ha per day). Neither supplementation level nor supplement type affected DST in the dry season (P>0.05), which was on average 883 kg/ha per day.

Based on estimated means of observed values (Figure 4), regression equations were developed to estimate the impact of supplement intake on cattle production in the wet and dry seasons. The intercept of the regression between ADG and supplement intake was different between seasons (P<0.05; 0.081 and 0.221 in the dry and wet season, respectively), whereas the slope was similar for both seasons (0.308; Figure 4). The slope of the equations indicated that, on average, for both seasons, the ADG increased by 0.308 g/day for each 1.0% BW of increase in the supplement intake, regardless of supplement type. In the wet season, GPH and DSR increased by 5.1 kg/day/ha and 981 kg/day/ha, respectively, for each 1% BW increase in the intake of energy supplement (P<0.05; Figure 5). In the dry season, GPH increased by 1.07 kg/day/ha for each 1% BW increase in the intake of protein supplement (P<0.05; Figure 6).

Bars with different letters differed based on Fisher’s F-protected least significant difference test (P≤0.05).

**Figure 1** - Average daily gain of cattle grazing tropical pastures according to supplementation level (% body weight) during the wet and dry seasons.
**Figure 2** - Gain per hectare of cattle grazing tropical pastures according to supplementation type (energetic, protein, and urea mineral supplement) and level (% BW) during the wet and dry seasons.

**Figure 3** - Daily stoking rate of cattle grazing tropical pastures according to supplementation type (energetic, protein, and urea mineral supplement) and level (% BW) during the wet and dry seasons.
Cattle age and body weight (BW) were used as covariates in the regression. Effect of season on intercept (P<0.05); SC slope (P>0.05).

ADG (dry season) = 0.0811 (±0.0245) + 0.308 (±0.0182) SC - 0.00039 (±0.00013) Age + 0.00139 (±0.00030) BW.
ADG (wet season) = 0.221 (±0.0285) + 0.308 (±0.0182) SC - 0.00039 (±0.00013) Age + 0.00139 (±0.00030) BW.

Figure 4 - Average daily gain (ADG) of cattle grazing tropical pastures as a function of supplement consumed (SC) in wet and dry seasons.

Figure 5 - Gain per hectare (GPH; a) and daily stocking rate (DSR; b) of cattle grazing tropical pastures as a function of energetic supplement consumed (SC) in the wet season.
4. Discussion

4.1. Influence of season on cattle production

Cattle in the tropical and sub-tropical regions are in face of large seasonal fluctuations in feed supply and quality (Poppi and McLennan, 1995), with better productive performance expected during the wet season than in the dry season. The wet season provides favorable weather conditions for plant growth (i.e., increased temperature and rainfall accompanied by change of luminosity by daylength), leading to enhanced forage mass and nutritive value (Boval et al., 2015; Sollenberger and Vanzant, 2011). As expected, in the current meta-analysis, we found better nutritive value of forage grazed during the wet season. In such conditions, CP and TDN contents in forage were on average 2.2 and 8.4% higher, respectively, whereas the NDF content was 2.4% lower than in forages of dry season. The NDF concentration is usually inversely related to forage intake (Van Soest, 1994), and the voluntary feed intake by grazing cattle is directly related to the digestibility of consumed forage (Poppi et al., 1987). Moreover, the low CP concentration in tropical pastures during the dry season limits rumen microbial growth, fiber digestion, and the absorbed nutrients in cattle (Detmann et al., 2014). Therefore, it was expected that TDN intake from forage and, consequently, ADG of cattle grazing in the wet season, were higher than those of cattle grazing in the dry season. Results of the present study were partially similar to those previously obtained by Boval et al. (2015), performing a meta-analysis of studies with cattle grazing in tropical grasslands, which showed a positive and quadratic relationship between ADG and digestible DM intake.

Furthermore, our study showed that forage availability (i.e., kg DM/100 kg BW) was higher in the dry season, probably as consequence of the lower DSR observed in this period (789 vs 1157 kg/ha per day). In fact, it is usual to allow the pasture biomass to accumulate at the end of the wet season to be used as forage reserve during the dry season. Moreover, the current database contained data from both unsupplemented and supplemented grazing cattle and, thus, the substitution effect of supplementation (i.e., decreased forage intake at increased supplement intake) may have also contributed for the higher forage allowance during the dry season.
4.2. Influence of supplementation on cattle production

It has been suggested that cattle response to supplementation under tropical conditions is usually inversely related to forage nutritive value (Poppi and McLennan, 2007). However, despite the discrepancy in forage quality along the seasons, we found that increased supplementation level resulted in the same slope (0.308) on ADG of cattle grazing tropical pasture in both wet and dry seasons. A previous study on the effect of supplementation on performance of cattle grazing tropical pastures also reported no effect of season when this factor was used as a class variable in the statistical model (Detmann et al., 2014). In the present study, the impact of forage content of either CP or NDF on equation parameters for predicting ADG were not significant (P>0.05) and, thus, we opted to maintain the season as a fixed factor in the model. However, the intercept of the equation predicting ADG was significantly higher in the wet season, as a consequence of the improved forage quality in that period. In turn, the current meta-analysis indicated that, in both seasons, the individual BW gain of cattle grazing tropical pastures may be increased by 112 kg/animal per year with supplementation at a rate of 1% BW/day, regardless of supplement type (Figure 4). At this level of supplementation during the dry (210 days) and wet (155 days) periods, GPH can potentially be increased by 1015 kg/ha per year. For this animal production performance, a total of 790 kg of energy (Figure 5) plus 225 kg of protein (Figure 6) supplementation would be offered during the wet and dry seasons, respectively. However, the supplementation strategy must also consider the economic viability. For example, a study by Romanzini et al. (2020) simulating different economic scenarios based on several strategies of supplementation (ranging in supplementation type and level) of cattle in tropical conditions reported the highest profitability when cattle received a mineral supplement (0.3% BW) in the rearing phase and multiple supplement types (different combinations of a mixture of energy and protein concentrates plus urea and minerals; 1.0% BW) in the finishing phases. However, all tested scenarios indicated that supplementation is a consistent strategy aiming to increase livestock profitability (Romanzini et al., 2020). Nevertheless, the farmer option for either supplementation strategy should consider economic costs and financial return at each specific scenario (Romanzini et al., 2020).

The GPH and DSR responses to supplementation were dependent on the supplementation level and season. The GPH was greater in the wet season with energy supplementation and was associated with an increased DSR in this period. In turn, the increased DSR obtained in the wet season with energy supplementation was probably a consequence of the substitution effect of forage DM intake (Horn and McCollum, 1987; Dixon and Stockdale, 1999; Machado et al., 2019), allowing increased allocation of animals per area without compromising growth performance (Moore et al., 1999).

In the dry season, DSR was not affected by supplement type whereas GPH was improved with protein supplementation at a rate of >0.5% BW. Once DSR was not increased, it is probable that there was no substitutive effect of protein supplementation on forage intake. In fact, CP is the most limiting nutrient for grazing cattle production in the dry season in the tropics (Reis et al., 2009) and, thus, protein supplementation is considered an efficient strategy to increase the N availability for fiber-degrading bacteria in the rumen, allowing an increase in forage intake, digestibility, and nutrient supply to the animal (Resende et al., 2013; Detmann et al., 2014). However, the true protein supplementation during the dry season resulted in higher GPH than that observed for cattle supplemented with urea mineral supplement. The CP concentration in protein supplements was on average lower than in urea mineral supplements. Therefore, the best GPH obtained under protein supplementation was probably a consequence of increased DM intake and/or due to an improved availability of branched-chain volatile fatty acids to rumen microorganisms originated from deamination of branched-chain amino acids present in the true protein supplements (Kozloski, 2011). Moreover, as energy availability in forage is limited in the dry season, it is probable that the true protein supplements were also used as energy source allowing a better GPH in the dry season. In fact, a of 515 g/day of protein supplement in the dry season provided increased growth of cellulolytic bacteria in cattle supplemented than in those not supplemented or supplemented with urea-based N supplements (Silva-Marques et al,
2019). The utilization of urea mineral supplements resulted in lower GPH (~820 g/ha per day; Figure 2) compared with protein supplements, which corresponds to 123 kg/ha less gain during the dry period. On the other hand, urea mineral supplements are less expensive than protein supplements and, thus, the decision of using either depends on other factors besides the productive response of cattle.

5. Conclusions

This meta-analysis provided an overview on the different supplementation strategies used in Brazil, and our findings revealed that the individual performance of cattle grazing tropical pastures is dependent on season and supplementation level regardless of supplement type. In this situation, high levels of supplement intake (more than 1% body weight) resulted in the highest individual gain. Conversely, gain per area was more dependent on supplement type. Maximum gain per hectare was reached by using energy supplementation at a rate over 1.0% body weight in the wet season and protein supplement at a rate over 0.5% body weight in the dry season. The findings of this study will enable a comprehensive overview of supplementation strategies for beef cattle grazing tropical pastures.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: A.A.C. Tambara and G.V. Kozloski. Data curation: A.A.C. Tambara and G.V. Kozloski. Formal analysis: A.A.C. Tambara, C.J. Härter and C.H.S. Rabelo. Funding acquisition: G.V. Kozloski. Investigation: A.A.C. Tambara, C.J. Härter and G.V. Kozloski. Methodology: A.A.C. Tambara, C.H.S. Rabelo and G.V. Kozloski. Project administration: A.A.C. Tambara and G.V. Kozloski. Supervision: G.V. Kozloski. Writing-original draft: C.J. Härter, C.H.S. Rabelo and G.V. Kozloski. Writing-review & editing: C.J. Härter, C.H.S. Rabelo and G.V. Kozloski.

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