Dorper × Santa Ines F1 crossbred lambs under different grazing times and supplement levels in tropical regions: performance and macromineral requirements

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ABSTRACT

The objective of this study was to evaluate the performance and net requirements for calcium (Ca), phosphorus (P), magnesium (Mg), potassium (K) and sodium (Na) in Dorper × Santa Ines F1 crossbred lambs under different grazing times and supplement levels. We used 36 uncastrated male lambs with initial body weights (BW) of 15.5 ± 1.9 kg. Twelve animals were used as a reference group, and the remaining 24 animals were divided into three treatments according to grazing time and supplement level: 9 h × 1.2% BW, 6 h × 0.84% BW and 3 h × 0.48% BW. There were increases in the final BW, average daily gain (ADG) and dry matter intake (DMI) of pasture (p < .05) in lambs that grazed longer (9 h × 1.2% BW). Feed efficiency (G/F ratio) was similar between the 9 h × 1.2% BW and 6 h × 0.84% BW groups and both the groups were greater than the 3 h × 0.48% BW. However, there was a reduction in the DMI of concentrate, total DMI, and Ca, P, Mg and K intake (p < .05) for lambs that grazed longer. However, pasture DMI and sodium intake increased (p < .05) in animals that grazed for less time (3 h). The chemical composition of the empty bodies in DM, fat, ash, Ca and P showed the greatest values (p < .05) in groups with animals grazing 9 h with a supplement level of 1.2% BW. Net maintenance requirements were 0.101–0.202 g Ca/day, 0.204–0.408 g P/day, 0.053–0.105 g Mg/day, 0.386–0.771 g K/day and 0.105–0.211 g Na/day for crossbred lambs between 15 and 30 kg BW. For the same group, net requirements to gain 100/200 g/day BW were 1.711/2.341–1.667/3.333 g Ca/day, 0.694/1.398–0.998/1.995 g P/day, 0.027/0.054–0.032/0.063 g Mg/day, 0.098/0.195–0.091/0.182 g K/day and 0.315/0.629–0.311/0.621 g Na/day. Lambs grazing longer (9 h × 1.2% BW) displayed increased ADG and concentrate intake and reduced forage intake, which increased intake and body retention of Ca, P, Mg and K.

INTRODUCTION

Efficient farming of sheep in tropical regions requires reliable estimates of the mineral requirements for growth (Pereira Filho et al., 2013). Determination of the nutritional requirements of sheep under local conditions of the Caatinga biome is particularly important for crosses between native and adapted strains (Teixeira et al., 2015).

Caatinga vegetation consists of primarily small woody species and herbs, usually endowed with thorns and deciduous with leaf loss at the beginning of the dry season, in addition to cacti and bromeliads (da Silva et al., 2011; Pereira Filho et al., 2013).

Phytosociological characteristics, density and species frequency and dominance are determined by topographical variation, soil type and rainfall. In terms of forage, the Caatinga is very rich and diverse (Rodal and Sampaio, 2002; da Silva et al., 2011). However, over the course of the year, vegetation becomes sparse, which reduces the grazing time in animals and increases the need for supplementation (Zhang et al., 2015). Further, the concentrated supplements are generally formulated based on tables that are generated by international committees; these tables do not address the expected results, lack of nutrients or waste affecting productivity and economic efficiency.

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Inappropriate provision of trace elements may damage animal health and productivity. Thus, there is a need to determine the nutritional requirements for hair sheep by considering different farming systems, breeds and geographic regions.

Strategies should be adapted to better meet the nutrient requirements, including mineral intake, of animals (Beede 1991). Because minerals are involved in almost all metabolic pathways of animal body functions, they are particularly important in reproductive performance, growth maintenance/energy metabolism and immune function, among many other physiological functions, not only for the maintenance of life but also for increasing the animal population (NRC 2007). In addition, if the mineral requirements of animals are not met, then several changes may occur, including metabolic changes that are directly related to production performance (Suttle 2010). Therefore, appropriate mineral supplementation is of paramount importance because soil impoverishment results in forage that is poor in minerals such as that observed in Caatinga most of the year (Pereira Filho et al. 2013), and this mineral-poor forage is directly responsible for animal weight loss, among other problems (McDowell 1992).

There is a general paucity of literature concerning the nutritional requirements of crossbred hair sheep, and in Brazil, few studies on this subject have been conducted (Costa et al. 2013; Regadas Filho et al. 2013; Zhang et al. 2015; Pereira et al. 2016), and most describe protein and energy requirements (Nie et al. 2015). All animal tissues and feeds have varying quantities and proportions of mineral elements (Pereira et al. 2016). Although the majority of natural mineral elements can be found in animal tissues, several of these minerals are purely derived from the diet and serve no essential functions in animal metabolism (McDonald et al. 2010).

This study determined the performance and net requirements of crossbred hair sheep for Dorper × Santa Ines F1 crossbred lambs created in tropical conditions under different grazing times and supplement levels.

Animals, treatments and management

Thirty-six male young unastratized (3 months) Dorper × Santa Ines F1 crossbred lambs with an average initial body weight (BW) of 15.6 ± 1.98 kg were used in this study. Twenty animals with 15.4 ± 0.30 kg BW were slaughtered at the beginning of the experiment; this BW value represented the initial body composition (baseline group, BL). Twenty-four lambs were randomly allocated to three treatments that consisted of combinations of grazing time and supplement level (9 h × 1.2% BW; 6 h × 0.84% BW and 3 h × 0.48% BW). Lambs were pair-fed in eight slaughter groups. When the animals reached 30 kg body weight, their lot was slaughtered. A slaughter group consisted of one lamb from each treatment and was slaughtered when one treatment lamb reached 30 kg BW.

Immediately after birth, the lambs ingested colostrum (6 h) and then remained with the sheep until weaning. During the suckling period, the sheep and lambs remained in a feedlot and were supplied with a diet for growing lamb based on ground corn/soybean meal and Buffel grass hay offered in a forage:concentrate ratio (20:80%) and the diet was offered ad libitum in creep feeding system. At a pre-established age of 45 days, the lambs were weaned, weighed, dewormed (Ivermectin, Ivomec®, Merial, Duluth, GA) and placed in feedlots with collective bays of 6.3 m × 4.0 m until 75 days of age where the lambs collectively received the same diet as creep feeding. The animals were then acclimated to pasture during a pre-trial period of 15 days. The experimental period was 85 days in total.

Grazing

The total area of the experiment was three hectares, bounded by screens and divided into three paddocks of one hectare each. The predominant vegetation was hyperxerophilic savanna, and soil in the experimental area was classified as Planossolic Luvisol.
Chemical properties of the soil in the experimental area were as follows: pH, 6.7; P, 96 mg/kg; K, 0.55 mg/kg; Ca, 3.3 mg/kg; Mg, 1.1 mg/kg and Na, 0.25 mg/kg.

At the beginning of the experiment, there was a predominance of the following species in the Caatinga area: Mimosa tenuiflora, Cróton sonderianos, Caesalpinia bracteosa, Spondias sp., Ziziphus joazeiro, Tabebuia carába, Prosopis juliflora, Walteria albicans, Calotropis procera, Aristida setifolia, Cenchrus ciliaris, Hyptis suaveolens, Senna obtusifolia and Borreria sp. At the end of the experiment, there was a predominance of Aristida setifolia, Ziziphus joazeiro and Tabebuia caribbean.

Forage availability was estimated in two assessments, on days 3 and 81 of the experiment. The first assessment was shortly after the entry of animals to the experimental area, and the second was at the end of the experiment. A rectangular, iron frame with dimensions of 1.00 × 0.25 m was used to mark one sampling unit (Araújo Filho et al. 2002). Every day the lamb changed paddocks to reduce differences due forage availability. During the experiment, the average availability of dry matter was 1904.96 kg/10,000 m².

**Feed intake**

In addition to the nutritional requirements assessment, we also performed an experimental trial to estimate the dry matter intake (DMI) of pasture-grazed animals. Three Dorper × Santa Ines F1 crossbred lambs uncastrated male sheep with an average age of two years old and average BW of 35 ± 5.15 kg were cannulated in the rumen. Lambs were fed by same as grazing time and supplement level (9 h × 1.2% BW; 6 h × 0.84% BW and 3 h × 0.48% BW).

Grass intake was determined over the 85-day experimental period by determining the chemical composition of extrusa (Goes et al. 2003). The rumen content (extrusa) of the fistulated animals was removed before entering the pasture area. The fistulated animals were allowed to browse, and after 20 min in the field, the total content of the rumen was collected, stored in a container with ice and analysed according to the methods of AOAC (1990) to determine nutrient concentrations and indicators in the forage (extrusa).

Supplement intake was determined directly from the difference between the amount of feed offered and the number of refusals. The estimated grass dry matter intake was calculated according to the following equation: $\text{DMI (kg/day)} = \frac{[(\text{FP} \times \text{CIF}) \times \text{ISI}]}{\text{CIFO}}$, where $\text{DMI}$ = dry matter intake (kg/day), $\text{FP}$ = faecal production (kg/day), $\text{CIF}$ = iNDF concentration (kg/day as DM) in faeces, $\text{IS} = \text{iNDF in the supplement (kg/day)}$ and $\text{CIFO} = \text{iNDF forage (kg/day as DM)}$.

To estimate the faecal output, chromic oxide was offered to three fistulated animals as an external indicator. A single 10.0 g dose was provided daily at 9 h for 12 days, seven days for adaptation and regulation of flow excretion and five days for stool collection. Faeces were collected directly from the rectum once a day for indicator management and were stored in a cold chamber at −10°C. Stool samples were analysed by atomic absorption spectrophotometry for chromium dosage as described in Williams et al. (1962).

For determination of the internal indicator, indigestible neutral detergent fibre (iNDF), samples of fodder concentrate and faeces were incubated in the rumen of three fistulated animals for 144 h, and the residue was assumed to be indigestible. Dry matter intake (DMI) was estimated from the faecal production and verified using chromium oxide (Cr₂O₃) as an external marker and indigestible neutral detergent fibre (iNDF) as an internal marker (Forbes 1995).

The concentrate supplement was prepared from corn meal, soybean meal, limestone and mineral mixture and adjusted according to analysis of the collected extrusa. The diets were formulated to contain approximately 16% crude protein and to promote gains of 200 g/day according to the NRC (2007) (Table 1).

**Chemical analysis**

Ingredients were sampled from faeces and extrusa for chemical analysis. Samples were predried at 55°C for 72 h, ground with a Willey mill (Tecnal, Piracicaba City, São Paulo State, Brazil) through a 1 mm sieve, and stored in airtight plastic containers (ASS, Ribeirão Preto City, São Paulo State, Brazil) that were sealed properly until laboratory analysis following the methods of the Association of Official Analytical Chemists (AOAC) (1990) for dry matter (DM – method 967.03), ash (method 942.05) and crude protein (CP – method 981.10) (Table 1).

The analyses for determining the mineral content in feed, faeces and animal bodies were performed by acid digestion as recommended by Tedesco et al. (1995). A mixture of nitric acid (HNO₃), perchloric acid (HClO₄) and hydrogen peroxide (H₂O₂) was used to decompose the samples, resulting in a mineral extract. Ca and Mg contents were determined by atomic absorption spectrophotometry (AOAC 2000, official method 968.08). Na and K contents were determined by flame spectrophotometry (AOAC 2000, method 985.35), while P content was determined by colorimetry (AOAC 2000, method
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The empty body weight (EBW) was estimated using the regression of log empty body weight (EBW) on the log body weight (BW) of the reference animals (ARC 1980):

\[
\log y = a + b \log x,
\]

where \(y\) = mineral content of the EBW (kg), \(a\) = intercept, \(b\) = slope and \(\log x\) = logarithm of EBW (kg).

The composition of the weight gain was determined by the difference between the total content of each mineral in the empty bodies of the animals that were slaughtered at the end of the experiment and the total content of each mineral in the empty bodies of the reference animals (ARC 1980).

After applying the antilog of Equation (1), its derivation regarding EBW was used to determine the daily net requirements of each mineral per kilogram of EBW gain, as shown in Equation (2):

\[
y' = b10^aEBW^{(b-1)}
\]

where \(y'\) = net requirement for the gain of each mineral (g or mg/kg EBW) and \(a\) and \(b\) = intercept and slope, respectively, of Equation (1).

The net mineral requirements for BW gain were obtained through the conversion of EBW into BW. To transform the values of the EBW estimates, the BW adjustment was calculated by the ratio between the average BW divided by the EBW of all experimental animals. Thus, we obtained the value (1.23), which provides the BW when multiplied by the estimated EBW.

A linear regression of the retained minerals (g or mg/kg EBW) during mineral intake (g or mg/kg EBW)
was used to calculate the net mineral requirements for maintenance (Lofgreen and Garrett 1968). The intercepts of the regression were considered endogenous and representative of metabolic losses of minerals, which were then assumed to represent the net mineral maintenance requirements.

### Statistical analysis

Data analysis was performed using PROC GLM in SAS© (Statistical Analysis System, version 9.1, SAS 2003). We utilised a completely randomised design (CRD) with three treatments and eight repetitions following the statistical model in Equation (3):

$$Y_i = \mu + a_i + e_i,$$

where $Y_i$ = the value observed in the plot that received treatment $i$, $\mu$ = the overall constant, $a_i$ = the fixed effect of treatment $i$ and $e_i$ = random error $\sim$ NID ($0, \sigma^2$).

For regression analysis, we adopted the logarithmic model $y = a + b \times x$, which indicates the behaviour of the dependent variable $y$ in response to the independent variable $x$.

### Results

The final BW ($p < .001$), EBW ($p = .003$) and ADG ($p = .023$) were greater in lambs that grazed for 9 h and received 1.20% BW supplement level compared to animals $6 \times 0.84\%$ BW and $3 \times 0.48\%$ BW time grazing × supplementation (Table 2). Feed efficiency (G/F ratio) was similar between the $9 \times 1.2\%$ BW (0.26 g/g) and $6 \times 0.84\%$ BW (0.26 g/g) groups and both groups were greater than $3 \times 0.48\%$ BW (0.13 g/g). The mean final value for BW was 27.5 kg; for EBW 20.6 kg and for ADG 190 g/d. Animals that grazed for 9 h with a concentrate supplement intake of 1.2% BW presented a 63% increase in ADG (g/d) compared with animals that grazed 3 h with a concentrate supplement intake of 0.48% BW.

Lambs with a longer grazing time (9 h) and higher supplementation level (1.20% BW) had the highest concentrate DMI ($p = .021$), total DMI ($p = .033$) and intake of Ca ($p = .014$), P ($p = .011$), Mg ($p = .018$) and K ($p = .021$), followed by animals with 6 h of grazing time and a supplementation level of 0.84% BW and finally animals with 3 h of grazing time and a supplementation level of 0.48% BW. The mean final value for BW was 27.5 kg; for EBW 20.6 kg and for ADG 190 g/d. Animals that grazed for 9 h with a concentrate supplement intake of 1.2% BW presented a 63% increase in ADG (g/d) compared with animals that grazed 3 h with a concentrate supplement intake of 0.48% BW.

### Table 2. Performance and body trace element content of Dorper × Santa Ines F1 crossbred lambs that were fed different levels of supplements and that had different grazing times.

| Variables                      | BLb | 9 h × 1.2% BW | 6 h × 0.84% BW | 3 h × 0.48% BW | SEMb | p Value |
|-------------------------------|-----|---------------|---------------|---------------|------|---------|
| No. of lambs                  | 12  | 8             | 8             | 8             | –    | –       |
| Days on feed                  | –   | 85            | 85            | 85            | –    | –       |
| Initial BW, kg                | 15.4| 15.8          | 15.7          | 15.7          | –    | –       |
| Final BW, kg                  | 15.4| 31.9a         | 28.8b         | 21.7c         | 1.12 | <.001   |
| EBW, kg                       | 11.1| 24.6a         | 21.5b         | 15.5c         | 0.56 | .003    |
| ADG, g/day                    | –   | 190a          | 154b          | 70.8c         | 3.22 | .023    |
| Feed efficiency, g/g          | 0.26| 0.26          | 0.13          | 0.01          | <.001|
| Daily intake, g/day           |     |               |               |               |      |         |
| Concentrate                   | 286a| 187b          | 89.1c         | 8.06          | .021 |
| Forage                        | 432b| 416c          | 472a          | 13.87         | .012 |
| Total                         | 718a| 603b          | 562c          | 27.21         | .033 |
| Ca                            | 10.9a| 9.19b        | 8.61c         | 2.12          | .014 |
| P                             | 4.12a| 3.35b        | 2.94c         | 1.10          | .011 |
| Mg                            | 6.33a| 5.77c        | 6.10b         | 0.45          | .018 |
| K                             | 4.99a| 3.55b        | 2.27c         | 0.87          | .021 |
| Na                            | 12.4b| 11.9c        | 13.6a         | 0.91          | .035 |
| Empty body composition        |     |               |               |               |      |         |
| Dry matter                    | 32.9a| 32.6a        | 31.1b         | 0.31          | .006 |
| Fat                           | 10.3a| 9.45a        | 6.63b         | 0.54          | .005 |
| Ash                           | 5.54a| 5.45a        | 4.99b         | 0.27          | .044 |
| Ca                            | 1.53a| 1.52a        | 1.22b         | 0.37          | .028 |
| P                             | 0.88a| 0.88a        | 0.73b         | 0.11          | .034 |
| Mg                            | 0.03 | 0.03         | 0.03          | 0.02          | .758 |
| K                             | 0.11 | 0.12         | 0.11          | 0.11          | .547 |
| Na                            | 0.36 | 0.39         | 0.35          | 0.41          | .434 |

Means followed by different letters in the same row differ by F test at 5% significance.

bSEM = standard error of the mean.

bBL = baseline group.

BW: body weight; EBW: empty body weight; ADG: average daily gain.
However, pasture DMI (p = .012) and sodium intake (p = .035) were higher in animals that grazed for less time (3 h) and received 0.48% BM supplement concentrate.

Analysis of chemical composition of empty bodies showed that values for DM (p = .006), fat (p = .005), ash (p = .044), Ca (p = .028) and P (p = .034) were higher in the groups with animals with 9 h of grazing time and a supplementation level of 1.20% BW and animals with 6 h of grazing time and a supplementation level of 0.84% BW compared with animals with 3 h of grazing time and a supplementation level of 0.48% BW. There was no effect of grazing time or concentrate supplement level on the body content of Mg (p = .758), K (p = .547) and Na (p = .434).

Logarithmic allometric equations were used to calculate the relationships between macromineral quantities and EBW; these relationships were significant and provided a R² value between 0.51 and 0.98 (Table 3).

The body composition of Ca, P, Mg, K and Na in the EBW of Dorper x Santa Ines F1 crossbred lambs was estimated according to the EBW. There were increases in Ca, P and Mg levels of 30%, 30% and 15%, respectively, and there were decreases of approximately 7.0% for K and 1.0% for Na. Trace element content varied from 14.40 to 20.50 g Ca/kg EBWG, 8.54 to 12.27 g P/kg EBWG and 0.33 to 0.39 g Mg/kg EBWG. There was a reduction from 1.20 to 1.12 g K/kg EBWG and 3.87 to 3.82 g Na/kg EBWG in animals with BW varying from 15 to 30 kg.

The equations used to predict the amount of macrominerals deposited per kilogram of empty body weight (EBWG) gain in Dorper x Santa Ines F1 crossbred lambs (g/kg EBWG) that were fed different levels of supplements and that had different grazing times and that had different grazing times is described in Table 5.

From the equations, the initial, final and retained body micromineral contents were calculated, and initial content showed no differences in the studied mineral content (p > .05) or final contents (p < .05) among
grazing and supplement groups. Retained contents ($p < .05$) of the macroelements Ca, P, Mg, K and Na were greater in the group with 9 h grazing time (1.2% BW supplement) and 6 h grazing time (0.84% BW supplement) compared to animals with 3 h of grazing time (0.48% BW supplement) (Table 6).

The net macromineral requirements for body weight gain in Dorper × Santa Ines F1 crossbred lambs increased with increasing BW and ADG (Table 7). Net maintenance requirements were 0.101–0.202 g Ca/day, 0.204–0.408 g P/day, 0.053–0.105 g Mg/day, 0.386–0.771 g K/day and 0.105–0.211 g Na/day for crossbred lambs between 15 and 30 kg BW. Net requirements to gain 100 g/day BW were 1.171–1.667 g Ca/day, 0.694–0.998 g P/day, 0.027–0.032 g Mg/day, 0.098–0.091 g K/day and 0.315–0.311 g Na/day for crossbred lambs from 15 to 30 kg BW. Net requirements to gain 200 g/day BW were 2.341–3.333 g Ca/day, 1.398–1.995 g P/day, 0.054–0.063 g Mg/day, 0.195–0.182 g K/day and 0.629–0.621 g Na/day for crossbred lambs between 15 and 30 kg BW.

**Table 6.** Estimates of initial, final and retained body content of macrominerals in Dorper × Santa Ines F1 crossbred lambs (g/kg EBW) that were fed different levels of supplements and that had different grazing times.

| Grazing time × Supplementation | Body content (g) | 9 h × 1.2% BW | 6 h × 0.84% BW | 3 h × 0.48% BW | SEM | p Value |
|-------------------------------|-----------------|----------------|----------------|----------------|-----|---------|
| Ca                            |                 |                 |                |                |     |         |
| Initial                       | 140             | 143             | 113            | 18.4           | .088|         |
| Final                         | 416a            | 365ab           | 204b           | 23.3           | .039|         |
| Retained                      | 276a            | 222ab           | 91.3b          | 8.22           | .022|         |
| P                             |                 |                 |                |                |     |         |
| Initial                       | 82.0            | 83.8            | 70.1           | 8.02           | .094|         |
| Final                         | 241a            | 210ab           | 123b           | 5.11           | .001|         |
| Retained                      | 159a            | 126ab           | 53.2b          | 3.01           | .012|         |
| Mg                            |                 |                 |                |                |     |         |
| Initial                       | 3.77            | 3.82            | 2.85           | 0.21           | .051|         |
| Final                         | 8.42a           | 7.57a           | 5.04b          | 0.34           | .037|         |
| Retained                      | 4.65a           | 3.75ab          | 2.19b          | 0.11           | .042|         |
| K                             |                 |                 |                |                |     |         |
| Initial                       | 15.8            | 16.1            | 13.1           | 0.42           | .097|         |
| Final                         | 30.5a           | 28.9a           | 18.3b          | 0.49           | .009|         |
| Retained                      | 14.7a           | 12.8a           | 5.13b          | 0.18           | .016|         |
| Na                            |                 |                 |                |                |     |         |
| Initial                       | 51.5            | 50.9            | 54.5           | 2.95           | .092|         |
| Final                         | 96.6a           | 90.9a           | 60.9b          | 1.89           | .011|         |
| Retained                      | 45.2a           | 40.1a           | 6.47b          | 0.37           | .036|         |

Means followed by different letters in the same line differ by F test at 5% significance.

aSEM, standard error of the mean.

**Table 7.** Macromineral net requirements for maintenance (NRm) and body weight gain (NRg) in Dorper × Santa Ines F1 crossbred lambs.

| BW, kg | ADG, g/day | NRm Ca, g/day | NRg Ca, g/day | NRm P, g/day | NRg P, g/day | NRm Mg, g/day | NRg Mg, g/day | NRm K, g/day | NRg K, g/day | NRm Na, g/day | NRg Na, g/day |
|--------|------------|---------------|---------------|--------------|--------------|---------------|---------------|--------------|--------------|---------------|---------------|
| 15     | 100        | 0.101         | 1.171         | 0.204        | 0.694        | 0.053         | 0.027         | 0.386        | 0.098        | 0.105         | 0.315         |
| 20     | 200        | 0.101         | 2.341         | 0.204        | 1.389        | 0.053         | 0.054         | 0.386        | 0.195        | 0.105         | 0.629         |
| 25     | 200        | 0.134         | 2.725         | 0.272        | 1.624        | 0.070         | 0.029         | 0.514        | 0.094        | 0.140         | 0.313         |
| 30     | 200        | 0.168         | 3.049         | 0.340        | 1.821        | 0.088         | 0.060         | 0.643        | 0.185        | 0.176         | 0.626         |

NRm: net requirements for maintenance; NRg: net requirements for gain.

**Discussion**

Grazing times and supplement levels influenced intake, ADG and EBW. Animals that grazed for shorter periods (3 h) increased forage intake relative to animals that spent more time in the pasture (9 h), which consequently reduced performance and feed efficiency at 50%. Growing lambs present lower fermentation capacity ruminal, therefore with less capacity of fibre digestion (Keady and Hanrahan 2015). Therefore, diets with great concentrations of energy and protein are necessary to meet BW gains high (Rezaei et al. 2015). Thus, lambs 3 h grazing increased the pasture intake.
because to the percentage of concentrate offered was lower (0.48%) as a function of the BW.

Body fat content increased in animals grazing for longer periods, which is possibly reflected in the concentration of energy available for grazing animals over time when offered dietary supplements (Girard et al. 2015). There was a positive interaction between the EBW, animal age and body fat; as the animal approaches physiological maturity, adipose tissue forms and deposits, which leads to increased EBW.

International committees have reported variation in mineral requirements according to genotype, sex, age and environment factors (AFRC 1991; NRC 2001; CSIRO 2007; NRC 2007). In the present study, as BW increased, there was an increase in the concentration and mineral requirement due to higher fat content in animals. Fat is a component directly related to age and weight of the animal (NRC 2007); thus, as BW increases during physiological development, muscle tissue deposition and fat content also increase (Owens et al. 1993).

The ARC (1980) suggests that the deposition of minerals in EBW gain is constant and recommends values of 11.0, 6.0, 0.41, 1.10 and 1.80 g/kg EBW gain for Ca, P, Mg, Na and K, respectively, which are higher than those observed in the present study. Ca and P in Dorper × Santa Ines F1 crossbred lambs increased from 10.6 to 15.4 g/kg EBW and 5.93 to 9.18 g/kg EBW, respectively, representing 53% and 35% increases, respectively. However, the values recommended by the NRC (2007) are 11.0 g Ca/kg EBW and 6.0 g P/kg EBW. Body tissues do not grow uniformly, resulting in differences in body composition and tissue deposition in groups of animals with different weight ranges (Suttle 2010). Consequently, there is reduced mineral deposition with weight gain due to greater fat deposition, leading to smaller depositions on bone and muscle tissue.

Mineral requirements in animals can be influenced by inherent characteristics of the feed or diet, such as organic or inorganic mineral fractions and element availability and chemical form in ingredients, as well as inherent factors of the animal, such as rate of production and previous nutrition, as well as factors related to antagonistic and agonistic interactions among minerals (Pereira et al. 2016). Among the minerals, approximately 99% of calcium and 80% of phosphorus are found in bones, and the net requirements for gain are highly related to skeletal growth. Ca and P are also absorbed in the small intestine by practically the same transporters, and thus have interrelated pathways (Ahmed et al. 2000). This relationship affects the absorption of these two minerals in the body; therefore, it is necessary to supply lambs with adequate levels of Ca and P. In this study, the average Ca:P ratios in animal bodies were 1.74:1, 1.73:1 and 1.69:1 in the 9 h × 1.20% BW; 6 h × 0.84% BW and 3 h × 0.48% BW grazing time × supplementation treatments, respectively. These values are near those recommended by the AFRC (1991), which ranges from 1.71 to 1.76:1 and is lower than the 1.80:1 ratio recommended by the ARC (1980).

There was an increase in estimated values of Ca and P most likely as result of increased feeding efficiency in animals and resulting in weight gain and body growth, indicating that the animals had not yet reached physiological maturity. According to Nóbrega et al. (2009), the increase in estimated body composition of minerals can be explained by the fact that minerals are present mostly in the bones, indicating that the lambs studied in the experiment showed growth independent of bone tissue or greater fat deposition. Dorper × Santa Ines F1 crossbred lambs weighting 25 kg BW increased Ca and P by 18.7 and 11.2 g/kg EBW, respectively (Table 4). In fully grown animals, deposition of Ca and P decreases, and calculations should taking the dilution factor into account; however, for the present study, there was no such decrease most likely because the animals were still in the initial growth phase, which increased the need for further deposition of Ca and P for growth.

There was an increase of 34.7% and 35.5% in net requirements for a gain of 200 g/day for Ca and P, respectively, in Dorper × Santa Ines F1 crossbred lambs. These two minerals promote animal growth, as observed in the estimation of body composition and gain (Table 5). One of the factors that affects body mineral composition is the proportion of minerals in fat, that is, when the deposition of fat increases, the proportion of minerals decreases (Araújo et al. 2010; Pereira et al. 2016).

The ranges of values for Na, K and Mg were 0.28–0.34 g/kg EBW, 1.29–1.20 g/kg EBW and 3.93–3.87 g/kg EBW, respectively. The net requirements for gain of these minerals are related to corporal gains as a whole, with continuous addition as the animal grows. However, in this study, we observed decreases in Na and K concentrations that can be attributed to the reduction of extracellular content. The concentrations of Na and K in Dorper × Santa Ines F1 crossbred lambs found in this study are similar to those reported by the NRC (2007). The decrease in K is mainly due to higher accumulation of fat and reduction in muscle tissue (Pereira et al. 2014; Pereira et al. 2016). The estimated macromineral concentrations in this study are less than those recommended by the ARC (1980),
which are fixed gain compositions of 0.41 g Mg/kg EBW, 1.8 g K/kg EBW and 1.1 g Na/kg EBW, respectively. Comparing the results of Mg, K and Na contents deposited per kg gain in body weight of the empty body with the proposed ARC (1980), the difference to Mg was 4.87%, while that of K was 36.7% for Dorper × Santa Ines F1 crossbred lambs.

The retained and final body content was similar for most of the macrominerals between 9 h × 1.20% BW and 6 h × 0.84% BW and both presented greater body content comparing to the 3 h × 0.48% (gra- zing × supplementation). The lower mineral intake and lower Ca, P and Mg retained for 3 h grazing is related with grazing time (3 h × 6 h × 9 h). Consequently, lambs presented lower BW final content and retention of Ca and P compared to animals grazing during 9 h (Table 6). The P requirements estimated in this study were similar to those obtained by Louvandini et al. (2008) in a study of P kinetics at different intake levels in male sheep. The authors concluded that 13.0 mg P/kg BW/day is sufficient for the maintenance of these animals.

Na concentration usually decreases with age partly because of the decrease in extracellular content, in which Na is the main cation, from birth to puberty (Ahmed et al. 2000). Reduction in K content can be attributed to a reduction in the ratio of muscle tissue to skin because most of this element is located in these tissues (McDowell 1992).

Conclusions

Final BW, ADG, total DMI and intake of Ca, P Mg and K increased when lambs were grazed longer (9 h) and received concentrate supplementation of 1.20% BW; lambs grazing (3 h) and received lower concentrate supplementation (0.84% BW), presented greater forage intake, however feed efficiency was reduced. Net maintenance requirements were 0.101–0.202 g Ca/day, 0.204–0.408 g P/day, 0.053–0.105 g Mg/day, 0.386–0.771 g K/day and 0.105–0.211 g Na/day for crossbred lambs between 15 and 30kg BW. For the same group, net requirements to gain 100/200 g/day BW were 1.171/2.341–1.667/3.333 g Ca/day, 0.694/1.398–0.998/1.995 g P/day, 0.027/0.054–0.032/0.063 g Mg/day, 0.098/0.195–0.091/0.182 g K/day and 0.315/0.629–0.311/0.621 g Na/day.

Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.
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