UNIVERSIDADE ESTADUAL PAULISTA JÚLIO DE MESQUITA FILHO

CÂMPUS DE JABOTICABAL

MACROMINERAL REQUIREMENTS IN MALE AND FEMALE SAANEN GOATS

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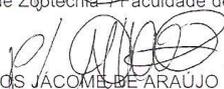
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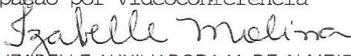
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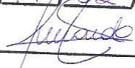
DADOS CURRICULARES DO AUTOR

José Mauricio dos Santos Neto é filho de João Batista do Nascimento Santos e Célia Maria Ferreira Portela. Nasceu em 09/07/1990, na cidade de Areia, Paraíba, Brasil. Iniciou o curso de graduação em Zootecnia em 2009, na Universidade Federal da Paraíba (UFPB) - Centro de Ciências Agrárias (CCA). Desenvolveu, sob a orientação do Dr. Ariosvaldo Nunes de Medeiros, a monografia intitulada: "Composição tecidual e características qualitativas da carne de cabritos Canindé submetidos à restrição alimentar". Colou grau no ano de 2013, sendo, naquele momento, agraciado com o prêmio honorífico "Jaime Coelho de Moraes", láurea que é concedida ao estudante que obteve o melhor desempenho acadêmico dentre os formandos do período. Em 2014 iniciou o curso de mestrado no Programa de Pós-Graduação em Zootecnia da UNESP - FCAV, Câmpus de Jaboticabal, sob a orientação do Dr. Kléber Tomás de Resende e coorientação da Dra. Márcia Helena Machado da Rocha Fernandes. No ano de 2015 realizou estágio de pesquisa no exterior, por um período de cinco meses, na Texas A&M University, College Station, Texas. Foi aprovado na seleção de doutorado, para ingresso em 2016, no Programa de Pós-Graduação em Zootecnia da UNESP - FCAV, Câmpus de Jaboticabal e no Programa de Pós-Graduação em Ciência Animal e Pastagens da USP - Esalq, Câmpus de Piracicaba.

"O homem começa a morrer na idade em que perde seu entusiasmo."
Balzac

Nunca aja como o porco Napoleão ou como o cavalo Sansão, personagens icônicos do livro: "A revolução dos bichos", de George Orwell. O primeiro é cruel e o segundo é um tolo.

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SUMMARY

THESIS STRUCTURE

This thesis is organized in three chapters:

-Chapter 1 is a literature review of the effects of sex on the net macromineral requirements of goats. The format of this chapter is according to the guidelines of the Graduate Program in Animal Science of the UNESP Jaboticabal Campus.

-Chapter 2 is an evaluation of the effects of sex on the net macromineral requirements of goats. The format of this chapter is according to the guidelines of the Journal of Animal Science (JAS), except for letter style and table positions.

-Chapter 3 describes the main implications of this study.

EXIGÊNCIAS DE MACROMINERAIS EM CAPRINOS SAANEN DE DIFERENTES CATEGORIAS SEXUAIS

RESUMO – Objetivou-se determinar as exigências de Ca, P, Mg, K e Na em machos inteiros, machos castrados e fêmeas da raça Saanen. Foram realizados dois experimentos: um para determinar as exigências líquidas para mantença (Exp. 1) e outro para determinar as exigências líquidas para crescimento (Exp. 2). Setenta e cinco caprinos (26 machos inteiros, 25 machos castrados e 24 fêmeas) foram utilizados para determinar as exigências líquidas para mantença. Desses, 21 caprinos (8 machos inteiros, 7 machos castrados e 6 fêmeas) foram abatidos com peso médio de 16,6 ± 0,40 kg e foram utilizados como grupo referência para estimar a composição corporal inicial. Os 54 caprinos restantes (18 machos inteiros, 18 machos castrados e 18 fêmeas) foram alocados em seis blocos ao acaso, no quais foram incluídos três caprinos do mesmo sexo distribuídos em um dos três níveis de alimentação: *ad libitum* e ingestão de 75% ou 50% em relação aos animais alimentados *ad libitum*. Quando os animais alimentados *ad libitum* atingiram 30 kg de PC foram abatidos juntamente com os outros caprinos do mesmo grupo. Os dados das categorias sexuais e dos níveis de alimentação foram analisados em parcelas subdivididas. A parcela principal foi composta pelas três categorias sexuais e as subparcelas pelos três níveis de alimentação. Os requerimentos líquidos para mantença não diferiram entre as categorias sexuais ($P > 0.05$), resultando em valores de: 35,4 mg de Ca; 24,7 mg de P; 2,5 mg de Mg; 5,0 mg de K e 3,3 mg de Na/kg PC·d. As exigências líquidas para crescimento foram obtidas a partir de 58 caprinos (20 machos inteiros, 20 machos castrados e 18 fêmeas) com peso inicial de 15,8 ± 0,11 kg de PC alimentados *ad libitum*. Os animais foram distribuídos em um delineamento experimental inteiramente casualizado e alocados em três pesos ao abate: 16,6 ± 0,40 kg de PC; 23,1 ± 1,33 kg de PC; e 31,2 ± 0,58 kg de PC. Os dados utilizados para determinar as exigências líquidas para crescimento foram analisados em um esquema fatorial 3 × 3 (categorias sexuais × níveis de alimentação). As exigências líquidos de Ca, P e Mg para crescimento foram similares entre machos inteiros, machos castrados e fêmeas ($P > 0.05$). Houve efeito da categoria sexual sobre as exigências líquidas de K e Na para crescimento ($P < 0,05$). As exigências líquidas de K (g/kg de PC ganho) para crescimento foram superiores nos machos inteiros, sendo verificado um aumento de aproximadamente 16% conforme o PC aumentou de 15 para 30 kg de PC. Já nas fêmeas e nos machos castrados, para a mesma faixa de peso, observou-se redução nos requerimentos líquidos de K para crescimento em aproximadamente 11%. Machos inteiros aumentaram os requerimentos líquidos de Na para crescimento em 9,5%, enquanto as fêmeas diminuíram em 22%. Em caprinos Saanen dos 15 aos 30 kg de PC, a categoria sexual afeta as exigências de líquidas de K e Na para crescimento, mas não influencia as exigências líquidas para mantença.

Palavras chave: abate comparativo, caprinos Saanen, equações alométricas, exigência de macrominerais, nível de ingestão, retenção mineral

MACROMINERAL REQUIREMENTS IN MALE AND FEMALE SAANEN GOATS

ABSTRACT – Our study estimated Ca, P, Mg, K, and Na requirements of intact male, castrated male, and female Saanen goats. Two experiments were performed: one to determine the net macromineral requirements for maintenance (Exp. 1), and another to determine net macromineral requirements for growth (Exp. 2). In Exp. 1, 75 goats (26 intact males, 25 castrated males, and 24 females) with initial BW (iBW) of 15.76 ± 0.10 kg were used. These animals were divided in two groups: baseline animals and pair-fed animals. Twenty-one goats (8 intact males, 7 castrated males, and 6 females) were slaughtered at the beginning of the experiment (16.6 ± 0.40 kg BW) to be used as the baseline group. The 54 remaining goats (18 intact males, 18 castrated males, and 18 females) were pair-fed in 6 blocks of 3 goats per sex. The goats within each block were then randomly allocated to one of 3 different levels of intake: ad libitum, restricted-fed to 75% of the ad libitum intake, and restricted-fed to 50% of ad libitum intake. When the animal fed ad libitum reached 31.2 ± 0.58 kg BW, it and the other goats from the same block were slaughtered. The effects of sex and level of intake were evaluated in a split-plot design, where sex was the main plot observation and level of intake was the sub-plot. Daily net macromineral requirements for maintenance did not differ among the sexes ($P >$ 0.05), and the average values obtained were 35.4 mg Ca, 24.7 mg P, 2.5 mg Mg, 5.0 mg K, and 3.30 mg Na per kg BW. The net requirements for growth in Exp. 2 were obtained using 58 goats (20 intact males, 20 castrated males, and 18 females) with 15.8 ± 0.11 kg iBW, all fed ad libitum. These animals were assigned in a completely randomized design and allocated in three slaughter weight groups: 16.6 ± 0.40, 23.1 ± 1.33, and 31.2 ± 0.58 kg BW. The net Ca, P, and Mg requirements for growth were similar among the sexes ($P > 0.05$). There was a sex effect on net K and Na requirements for growth ($P < 0.05$). The net K requirements for growth (g/kg ADG) of intact males was greater and increased approximately 16%, whereas females and castrated males decreased approximately 11% as BW increased from 15 to 30 kg BW. The net Na requirements for growth increased 9.5% for intact males and decreased 22% for females when the goats grew from 15 to 30 kg BW. Sex thus affects net K and Na requirements for growth, but it does not affect net macromineral requirements for maintenance in Saanen goats.

Keywords: comparative slaughter, Saanen goats, allometric equations, macromineral requirements, level of intake, mineral retention

LIST OF ABBREVIATIONS

ADF	Acid detergent acid
ADG	Average daily gain
ADP	Adenosina difosfato
AMP	Adenosina monofosfato
ATP	Adenosina trifosfato
BL	baseline
BW	Body weight
Ca	Calcium
Cl	Chlorine
Co	Cobalt
CP	Crude protein
Cu	Copper
d	Day
df	Degree of freedom
DM	Dry matter
DMI	Dry matter intake
EBW	Empty body weight
EWG	Empty body weight gain
fBW	Final body weight
Fe	Ferrum
GE	Gross energy
HCl	Hydrochloric acid
I	Iodine
iBW	Inicial body weight
K	Potassium
Mg	Magnesium
Mn	Manganese
Na	Sodium
NaCl	Sodium chlorine

NDF   Neutral detergent acid

P   Phosphorus

RMSE   Root mean square error

S   Sulfur

Se   Selenium

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Zn   Zinc

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CHAPTER 1 – GENERAL CONSIDERATIONS

1. INTRODUCTION

The goat was one of the first domesticated animals in the world with a strong presence in all sectors of ancient societies, including religion, economy, nutrition, and tradition. Nowadays, goats are still important animals in many regions of the world, especially in developing countries, where the demand for food products increases with population growth and associated needs (BOYAZOGLU et al., 2005).

A better understanding of the nutritional requirements of goats, especially in terms of minerals, is crucial for improving production (MCDOWELL, 1999). Minerals are essential for the physiological function, since they are structural components of body tissues and participate in acid-base balance, osmotic pressure, cellular permeability, and several energy reactions as enzymatic cofactors. Minerals are classified in two categories, according to consumption requirements: microminerals, or trace elements, which are required in amounts less than 100 ppm; and macrominerals, which are required in amounts higher than 100 ppm. In animal nutrition, macrominerals are calcium (Ca), phosphorous (P), magnesium (Mg), potassium (K), sodium (Na), chlorine (Cl), and sulfur (S) (MCDOWELL, 1992; NRC, 2007; SUTTLE, 2010).

The macromineral requirements for goats are mainly based on data from sheep and cattle (CSIRO, 2007; NRC, 2007; AFRC, 1998). However, goats have metabolic and adaptation features that differ from other ruminant species (VAN SOEST, 1994). Therefore, more studies are needed to better understand the factors that affect macromineral requirements in goats. Sex can be one of these factors, because it is involved in animal physiology and metabolism and has effects on growth, body composition, and productive and reproductive functions.

Previous studies evaluated the effect of sex on macromineral requirements of Saanen goats (COSTA, 2013; MENDONÇA, 2013), but not all the related factors, whereas other studies did not compare the sexes (ARAÚJO et al., 2010; GOMES et al., 2011; FERNANDES et al., 2012; TEIXEIRA et al., 2015).

The objectives of this chapter were thus to present the main factors related to the effect of sex on macromineral requirements of goats and review the most recent related studies.

2. LITERATURE REVIEW

2.1. Macromineral requirements

Minerals are inorganic elements, essentials in animal nutrition, since they are structural components of body tissues and participate in acid-base balance, osmotic pressure, cellular permeability, and several energy reactions as enzymatic cofactors. Mineral deficiencies reduce animal performance below the average potential and cause serious or even fatal health problems (SUTTLE, 2010).

Minerals are classified into microminerals or macrominerals, according to consumption requirements; the former are required in amounts less than 100 ppm, whereas the latter in amounts greater than 100 ppm. In animal nutrition, the macrominerals are Ca, P, Mg, K, Na, Cl, and S. Of these, Ca, P, Mg, K, and Na have the lowest concentrations in ruminant diets (MCDOWELL, 1992; MORAES et al., 1999; NRC, 2007; SUTTLE, 2010).

The factorial approach proposed by ARC (1980) is the most frequently method used in animal feeding systems for determining the net macromineral requirements, which are divided into the following components: (1) net macromineral requirements for maintenance, which is the amount of a macromineral necessary for counterbalancing the endogenous losses; (2) net macromineral requirements for growth, which is equivalent to the deposition of a macromineral in the weight gain; (4) net macromineral requirements for lactation, which is the amount of a macromineral secreted in the milk; and (5) net macromineral requirements for pregnancy, which is equivalent to the amount of a macromineral in the fetus, placenta, uterus, and fetal fluids. The total net macromineral requirements are the summation of these components (SUTTLE, 2010). For example, the total net Ca requirement (TCR) for a growing goat, non-pregnant and non-lactating is:

$$TCR = M + G$$

where M and G are the net Ca requirements for maintenance and growth, respectively. The dietary requirements are estimated when TCR is divided by the absorption coefficient for Ca (SUTTLE, 2010).

The most common feeding systems for goats follow the recommendations of AFRC (United Kingdom), NRC (USA), INRA (France), and CSIRO (Australia), which are mainly based on sheep and cattle nutritional requirements; therefore, these recommendations may not be accurate because goats have metabolic and adaptation features that differ from other ruminant species (VAN SOEST, 1994).

Because of this non-specific information, data were obtained from different goat breeds, such as Moxotó, Saanen, and Boer, in the growing phase (ARAÚJO et al., 2010; GOMES et al., 2011; FERNANDES et al., 2012; TEIXEIRA et al., 2015) or Saanen during pregnancy (COSTA et al., 2003; RESENDE et al., 1999). Disparities among these studies have resulted in a greater divergence from the specifications of feeding systems, suggesting that more studies are required to better understand the factors that affect macromineral requirements of goats.

Sex is a factor that probably affects nutritional requirements, since it is involved in physiology and metabolism and influences animal growth, body composition, and productive and reproductive functions. Previous studies have evaluated the effect of sex on the net macromineral requirements of Saanen goats from 5 to 15 kg BW and from 30 to 45 kg BW (MENDONÇA, 2013; COSTA, 2013), but not all the related factors.

2.2. Ca and P

Ca is the most abundant macromineral in the body, mainly located in the bones. The remaining Ca is located in extracellular fluids and other tissues. Ca participates in structural function, nerve impulse transmission, contraction and relaxation of muscles and blood vessels, insulin release, and regulation of blood clotting (MCDOWELL, 1992; UNDERWOOD and SUTLLE, 1999; NRC, 2007).

P is the second most abundant macromineral in the body, mainly located in the bones, where it is bound to Ca, forming hydroxyapatite crystals. P is a component of DNA and RNA and participates in cell growth as well as in ATP, ADP, and AMP

formation (UNDERWOOD and SUTLLE, 1999). Severe P deficiency causes bone and tooth abnormalities, appetite depression, low feeding efficiency, and decreased fertility (MCDOWELL, 1992). Usually, Ca and P are studied together due to the constant Ca:P ratio in the bones, and because an inadequate absorption in one of these macrominerals increases the risks of urolithiasis. To ensure prophylaxis against this disease, the Ca:P ratio in the diet needs to be at least 2:1 (NRC, 2007; RIET-CORREA et al., 2008).

Both Ca and P participate in several physiological functions, which can be affected by several factors, including sex. Testosterone is the main sex hormone of intact males and estrogen the main sex hormone of females. Testosterone acts on bone metabolism, stimulating epiphyseal growth and hastening bone development through the increment of mineralization, which is essential for the maintenance of bone mass (SISSONS, 1971; MAURAS et al., 1994). Estrogen does not affect bone mineralization, but maintains bone mass through the induction of osteoclast apoptosis (BLYTHE and BURCHSBAUM, 1976; HUGHES et al., 1996). In addition, estrogen has a retarding effect on bone growth and promotes the premature epiphyseal fusion (SILBERBERG and SILBERBERG, 1971). Although other glands also produce testosterone and estrogen, they are mainly synthesized in the testicles and ovaries. Therefore, castrated males have low levels of testosterone and estrogen compared with intact males, which delay the epiphyseal fusion and decrease bone thickness. The epiphyseal fusion occurs earlier in females, followed by intact males, and castrated males (SILBERBERG and SILBERBERG, 1971; DAVIS, 2000).

Sex directly affects bone development and, consequently, Ca and P requirements, since approximately 90% of Ca and 80% of P are located in the bones as structural components (SHUTTLE, 2010). In Saanen goats from 5 to 15 kg BW, the net Ca requirements for growth are higher in intact and castrated males than in females, whereas the net P requirements for growth are similar between sexes. Already Saanen goats from 30 to 45 kg BW have the same net Ca and P requirements for growth, regardless of sex (Table 1).

Other studies on goat net macromineral requirements for growth reported that castrated male Saanen goats from 15 to 30 kg BW require 10.1–9.3 g Ca/kg BW gain and 8.51–7.27 g P/kg BW gain; intact male F1 Boer x Saanen goats from 5 to 25 kg

BW require 9.70–7.03 g Ca/kg BW gain and 6.51–4.70 g P/kg BW gain; and castrated male Moxotó goats from 15 to 25 kg BW require 9.53–10.65 g Ca/kg BW gain and 7.41–8.65 g P/kg BW gain (ARAÚJO et al., 2010 GOMES et al, 2011; TEIXEIRA et al., 2015). NRC (2007), based on data from sheep and cattle, reported that goats require 11 g Ca/kg BW gain and 6.5 g P/kg BW gain regardless of sex.

Regarding net requirements for maintenance, Saanen goats from 30 to 45 kg BW require 13.6 mg Ca/kg BW·d and 23.5 mg P/kg BW·d, regardless of sex; intact male ¾ Boer × ¼ Saanen goats from 20 to 35 kg BW require 27.4 mg Ca/kg BW·d and 26.2 mg P/kg BW·d; whereas intact male F_1 Boer × Saanen goats from 15 to 25 kg BW require 38.3 mg Ca/kg BW·d and 42.3 mg P/kg BW·d (FERNADES et al., 2012; COSTA, 2013; TEIXEIRA et al., 2015)

Table 1. Net Ca and P requirements for growth of intact male, castrated male and female Saanen goats from 5 to 15 kg BW and from 30 to 45 kg BW

	BW, kg[2]		Equations[3]
Mendonça (2013)[1]	5	15	
Ca, g/kg EWG			
Intact and castrated male	15.36	18.78	$11.45 \times EBW^{0.20}$
Female	13.70	12.02	$16.57 \times EBW^{-0.13}$
P, g/kg EWG	11.65	13.82	$9.08 \times EBW^{0.17}$
	BW, kg		Equations
Costa (2013)	30	45	
Ca, g/kg EWG	6.58	5.73	$17.25 \times EBW^{-0.302}$
P, g/kg EWG	2.98	2.25	$21.56 \times EBW^{-0.620}$

[1]EWG = empty body weight gain
[2]BW = body weight
[3]EBW = empty body weight

2.3. Mg

Mg participates in more than 300 metabolic reactions associated with energy production, molecular synthesis, ion transportation, cell signaling, and enzymatic and neuromuscular activities. It also has an important structural role, since approximately 70% of Mg is located in the bones (MCDOWELL, 1992; MCDOWELL 1999; NRC,

2007; SUTTLE, 2010). Because of this, the aforementioned effects of sex on bone development may also affect Mg requirements.

In addition, the remaining Mg is in the extracellular fluid (1%) and the cells (29%), where it actively participates in metabolism as an important controller of glycolysis and the Krebs cycle (GARFINKEL and GARFINKEL, 1984). As the maintenance of protein turnover is an energetically expensive process (WANG et al., 2009; LOBLEY et al., 1994), it is possible that Mg requirements increase with muscle development. In this regard, male goats, which have great proportion of muscle in their carcass, probably have greater Mg requirements than females.

Indeed, the net Mg requirements for growth in Saanen goats from 5 to 15 kg BW are higher in males than in females (Table 2). However, no differences were identified between sexes in the net Mg requirements for growth in Saanen goats from 30 to 45 kg BW (COSTA, 2013; Table 2).

Table 2. Net Mg requirements for growth of intact male, castrated male and female Saanen goats from 5 to 15 kg BW and from 30 to 45 kg BW

Mendonça (2013)[1]	BW, kg[2]		Equations[3]
	5	15	
Mg, g/kg EWG			
Intact and castrated male	0,58	0,77	$0,386 \times EBW^{0,28}$
Female	0,54	0,53	$0,544 \times EBW^{0,01}$
Costa (2013)	BW, kg		Equations
	30	45	
Mg, g/kg EWG	0,34	0,29	$0,938 \times EBW^{-0,314}$

[1]EWG = empty body weight gain
[2]BW = body weight
[3]EBW = empty body weight

Other studies reported that intact male ¾ Boer × ¼ Saanen goats from 20 to 35 kg BW require 0.29–0.30 g Mg/kg BW gain; and castrated male Moxotó goats from 15 to 25 kg BW require 0.018–0.043 g Mg/kg BW gain (FERNANDES et al., 2012; ARAUJO et al., 2010). According to NRC (2007), the net Mg requirements for growth in goats are 0.4 g kg/BW gain, regardless of sex and breed.

Previous studies on the net Mg requirements for maintenance have shown that Saanen goats from 30 to 45 kg BW require 1.59 mg Mg/kg BW·d, regardless of sex; intact male ¾ Boer × ¼ Saanen goats from 20 to 35 kg BW require 1.1 mg Mg/kg BW·d; whereas intact male F_1 Boer × Saanen goats from 15 to 25 kg BW require 1.6 mg Mg/kg BW·d (COSTA, 2013; FERNANDES et al., 2012; TEIXEIRA et al., 2015).

2.4 Na and K

Na is the primary extracellular cation in the body, found at concentrations of 0.2%. It participates in the maintenance of osmotic pressure, the regulation of acid-base balance and water metabolism, the absorption of nutrients, and the transmission of nerve impulse (MCDOWELL, 1992). Along with Cl, Na forms NaCl, which is the most important and common supplement for ruminants. NaCl is important for bile formation and the presence of HCl in the gastric fluid. Deficiencies in NaCl decrease appetite, soil intake, milk production, and also cause hair thickening (NRC, 1981; RIBEIRO 1997).

Na is excreted in the urine, feces, and sweat; therefore, animals with a relatively high capacity of sweating have higher Na requirements (MCDOWELL, 2003; NRC, 2007). In cattle, intact males produce more sweat than females (KASA et al., 1997), probably due to hormonal differences, which suggest that intact males may require more Na than females. Aldosterone regulates electrolytic balance and acts by increasing Na reabsorption by the kidneys and small intestine, resulting in higher Na body retention (SCHRIER, 2006; SQUIRES, 2010). Previous studies reported that intact male rats have higher aldosterone levels than females, which may be associated with the androgen effect (KIENITZ and QUINKLER, 2008; SPYROGLOU et al., 2012). Thus, aldosterone may act similarly in goats, inducing greater Na retention and, as a result, intact males have higher Na requirements than females.

K is the third most abundant macromineral in the body and the primary intracellular cation with a relatively high concentration in the muscles. Along with Na, it maintains cell membrane potential through the Na-K pump (ARC, 1980; UNDERWOOD and SUTTLE, 1999; NRC, 2007). Due to its intense metabolic rate, K

is not stored in the body and the daily intake of K is necessary (NRC, 2007). However, excessive K intake in ruminants has toxic effects. Aldosterone promotes the re-absorption of Na and excretion of K, maintaining a constant Na:K ratio and, consequently, osmotic equilibrium (UNDERWOOD and SUTTLE, 1999; SHUTTLE, 2010; GOMES et al., 2011). A Na:K ratio of 0.6 has been reported to be adequate for goats (PFEFFER and RODEHUTSCORD, 1998; GOMES et al., 2011).

Due to the important role of hormones in Na and K metabolism, sex probably affects Na and K requirements of goats. Previous studies have demonstrated that in Saanen goats from 30 to 45 kg BW, net Na requirements for growth are higher in males than in females, and the net K requirements are the same among sexes. In Saanen goats from 5 to 15 kg BW, net Na and K requirements for growth are the same among sexes (COSTA, 2013; MENDONÇA, 2013; Table 3).

Table 3. Net Na and K requirements for growth of intact male, castrated male and female Saanen goats from 5 to 15 kg BW and from 30 to 45 kg BW

Mendonça (2013)[1]	BW, kg[2]		Equations[3]
	5	15	
Na, g/kg EWG	2.01	1.88	$2.374 \times EBW^{-0.07}$
K, g/kg EWG	2.95	2.92	$2.989 \times EBW^{-0.01}$
Costa (2013)	BW, kg		Equations
	30	45	
Na, g/kg EWG			
Intact and castrated male	1.18	1.12	$1.728 \times EBW^{-0.118}$
Female	1.05	0,99	$1.529 \times EBW^{-0.118}$
K, g/kg EWG	1.86	1.88	$1.718 \times EBW^{0.026}$

[1]EWG = empty body weight gain
[2]BW = body weight
[3]EBW = empty body weight

Other studies have shown that castrated Moxotó goats from 15 to 25 kg BW require 1.31–1.41 g Na/kg BW gain and 1.47–1.70 g K/kg BW gain, whereas intact male F_1 Boer × Saanen goats from 5 to 25 kg BW require 0.88–0.50 g Na/kg BW gain and 1.94–1.17 g K/kg BW gain (ARAUJO et al., 2010; TEIXEIRA et al., 2015). According to ARC (1980), the net Na requirements for growth in goats are 1.10 g/kg

BW gain, similar to those in sheep, as well as to net K requirement for growth (2.4 g kg/BW gain) suggests by NRC (2007).

Previous studies have demonstrated that the net Na and K requirements for maintenance are 3.27 mg Na/kg BW·d and 4.73 mg K/kg BW·d in Saanen goats from 30 to 45 kg BW, regardless of sex; 4.36 mg Na/kg BW·d and 7.13 mg/K BW·d in intact male ¾ Boer × ¼ Saanen goats from 20 to 35 kg BW; and 4.98 mg Na/kg BW·d and 19.3 mg/K BW·d in intact male F_1 Boer × Saanen goats from 15 to 25 kg BW (COSTA, 2013; FERNANDES et al., 2012; TEIXEIRA et al., 2015).

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CHAPTER 2 – Net macromineral requirements in male and female Saanen goats

ABSTRACT: Our study estimated Ca, P, Mg, K, and Na requirements of intact male, castrated male, and female Saanen goats. Two experiments were performed: one to determine the net macromineral requirements for maintenance (Exp. 1), and another to determine net macromineral requirements for growth (Exp. 2). In Exp. 1, 75 goats (26 intact males, 25 castrated males, and 24 females) with initial BW (iBW) of 15.76 ± 0.10 kg were used. These animals were divided in two groups: baseline animals and pair-fed animals. Twenty-one goats (8 intact males, 7 castrated males, and 6 females) were slaughtered at the beginning of the experiment (16.6 ± 0.40 kg BW) to be used as the baseline group. The 54 remaining goats (18 intact males, 18 castrated males, and 18 females) were pair-fed in 6 blocks of 3 goats per sex. The goats within each block were then randomly allocated to one of 3 different levels of intake: ad libitum, restricted-fed to 75% of the ad libitum intake, and restricted-fed to 50% of ad libitum intake. When the animal fed ad libitum reached 31.2 ± 0.58 kg BW, it and the other goats from the same block were slaughtered. The effects of sex and level of intake were evaluated in a split-plot design, where sex was the main plot observation and level of intake was the sub-plot. Daily net macromineral requirements for maintenance did not differ among the sexes ($P > 0.05$), and the average values obtained were 35.4 mg Ca, 24.7 mg P, 2.5 mg Mg, 5.0 mg K, and 3.30 mg Na per kg BW. The net requirements for growth in Exp. 2 were obtained using 58 goats (20 intact males, 20 castrated males, and 18 females) with 15.8 ± 0.11 kg iBW, all fed ad libitum. These animals were assigned in a completely randomized design and allocated in three slaughter weight groups: 16.6 ± 0.40, 23.1

± 1.33, and 31.2 ± 0.58 kg BW. The net Ca, P, and Mg requirements for growth were similar among the sexes ($P > 0.05$). There was a sex effect on net K and Na requirements for growth ($P < 0.05$). The net K requirements for growth (g/kg ADG) of intact males was greater and increased approximately 16%, whereas females and castrated males decreased approximately 11% as BW increased from 15 to 30 kg BW. The net Na requirements for growth increased 9.5% for intact males and decreased 22% for females when the goats grew from 15 to 30 kg BW. Sex thus affects net K and Na requirements for growth, but it does not affect net macromineral requirements for maintenance in Saanen goats.

Keywords: allometric equations, comparative slaughter, level of intake, macromineral requirements, mineral retention, Saanen goats

INTRODUCTION

Minerals are an essential part of animal diets, and they are needed to adequately support growth and physiological functioning. Excessive or insufficient supply of these inorganic nutrients can result in poor performance and poor production in farm animals (Araújo et al., 2010; Sutlle, 2010). Feeding systems worldwide therefore recommend ideal levels of dietary minerals, but these recommendations may not always be accurate.

The most recent report of the National Research Council (NRC, 2007) specified mineral requirements for small ruminants that were based on data not only from goats, but also from sheep and cattle. Because of this non-specific information, some researchers have designed experiments to collect data on macromineral requirements for different breeds of goats, such as Moxotó, Saanen, and Boer crossbreeds (Araújo et al., 2010; Gomes et al., 2011; Fernandes et al. 2012; Teixeira et al., 2015). Nonetheless, disparities among these experiments have resulted in greater divergence from the NRC specifications, suggesting that more studies are needed to better understand the factors that affect macromineral requirements in goats. Sex can be one of these factors, because it is involved in animal physiology and metabolism and has effects on growth, body composition, and productive and reproductive functions. In general, current feed systems do not take into account any sex effects on macromineral requirements.

Previous studies with cattle weighing from 250 to 300 kg BW reported that females have lower macromineral requirements than intact males (Marcondes et al., 2009). Additionally, heifers have lower body ash content when compared to bulls, as a result of their lower percentage of bone and higher proportion of fat (Paulino et al.,

2009). Experiments on goat macromineral requirements are still insufficient, however, and the current data are not yet clear enough to estimate the effect of sex on the mineral requirements of growing goats.

Our objective was thus to determine the macromineral requirements for maintenance and growth in intact male, castrated male, and female Saanen goats from 15 to 30 kg BW.

MATERIAL AND METHODS

Animal Care

Humane animal care and handling procedures were followed as required by the Committee on Ethics and Animal Welfare (Comissão de Ética e Bem Estar Animal, protocol #008919-08), Faculty of Agricultural and Veterinary Sciences, Jaboticabal Campus, Universidade Estadual Paulista, São Paulo, Brazil (UNESP).

General Procedures

This study was conducted at the Goat Facility of the UNESP Jaboticabal Campus, São Paulo, Brazil (21°14′05″ S and 48°17′09″ W). During the pre-experimental period, animals were adapted to the diet, the housing, and daily handling. Animals were housed in individual pens measuring 0.5 m × 1.0 m, equipped with feeders and water troughs. During the experiment, the mean daily minimum and maximum air temperatures were 20.7°C ± 1.86 and 35.7°C ± 3.24, respectively, and the minimum and maximum relative humidity was 36.1% ± 11.21 and 83.4% ± 6.72, respectively.

Two experiments were performed, one to determine the macromineral requirements for the maintenance of intact male, castrated male, and female Saanen goats from 15 to 30 kg BW (Exp. 1), and the other to determine the macromineral requirements for their growth (Exp. 2). The macrominerals examined were Ca, P, Mg, K, and Na. In both experiments, the experimental diet (Table 1) was formulated to meet the requirements of growing goat kids according to the NRC (2007), and it was offered twice daily (0700 and 1700 h). Feeds and orts were weighed daily, sampled, and frozen. The feed intake was calculated by subtracting orts from the offered diet. The goats had free access to water. The water intake was estimated over five consecutive days by comparing the difference between offered, refused, and evaporated water. The evaporated water was obtained as the mass difference over a 24-h period in a separated drinker.

The dietary ingredients and orts were dried in an oven at 60°C for 72 h. After drying, the samples were ground to pass a 1 mm screen using a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA). Concentrations of DM, ash, NDF, ADF, CP, crude fat, and GE in the ingredients were determined, and DM was also determined in the orts. The DM concentration was determined by drying the material in an oven at 105°C for 24 h (AOAC, 1990; method 930.15), and the ash content was measured by complete combustion in a muffle furnace at 600°C for 3 h (AOAC, 1990; method 942.05). The concentration of NDF was measured in an Ankom 220 Fiber Analyzer (Ankom Technology Corp., Fairport, NY) using heat-stable α-amylase without sodium sulfite (Mertens et al., 1982). The ADF concentration also was measured (Goering and Van Soest, 1970). The nitrogen concentration was determined using Dumas's combustion method, and CP was calculated as nitrogen × 6.25 (LECO FP-528;

LECO Corp., St. Joseph, MI) (AOAC, 1990; method 990.03). The crude fat content was determined by extraction with petroleum ether in a Soxhlet apparatus for 6 h (AOAC, 1990; method 930.15). Gross energy was determined using a bomb calorimeter (IKA Calorimeter system C 2000 basic/control)

Table 1. Water, ingredient and chemical composition of the diet

Item	Value
Dietary ingredient, % DM	
Dehydrated corn plant[1]	45.3
Cracked corn	26.6
Soybean meal	22.4
Soybean oil	1.6
Limestone	1.0
Mineral supplement[2]	2.2
Ammonium chloride	0.9
Diet composition, % DM	
DM, % as fed	85.6
Ash	6.5
CP	20.5
Crude fat	8.0
GE, Mcal/ kg DM	4.46
NDF	35.3
ADF	18.3
Ca	1.01
P	0.45
Mg	0.18
K	1.53
Na	0.43
Water composition, %	
Ca	0.002
P	-
Mg	0.0001
K	0.0002
Na	0.002

[1] Whole corn plants (60 to 70% moisture) chopped when the kernel milk line was approximately two-thirds of the way down the kernel. Chopped material was air dried for approximately 72 h on until it reached 8 to 10% moisture and then ground to pass through a 4-mm screen. [2] Composition, per kg: 109 g of Ca; 60 g of P; 10 g of Mg; 175 g of Na; 4000 mg of Zn; 1200 mg of Fe; 600 mg of Cu; 600 mg of F; 600 mg of Mn; 130 mg of I; 100 mg of Co; 30 mg of S; 12 mg of Se.

Exp. 1: Net Macromineral Requirements for Maintenance

Maintenance requirements were calculated using the comparative slaughter technique of Lofgreen and Garrett (1968). For this purpose, we used 75 animals with 15.76 ± 0.10 kg iBW, and we divided them in two groups: baseline (BL) animals (n = 21), and pair-fed animals (n = 54).

Among the 54 pair-fed animals, we used 18 intact males (15.6 ± 0.54 kg iBW, 106 ± 16 d old), 18 castrated males (15.5 ± 0.34 kg iBW, 112 ± 21 d old), and 18 females (15.2 ± 0.24 kg iBW, 106 ± 19 d old). Six blocks of 3 goats per sex with equal iBW were randomly formed. The goats within each block were then randomly allocated to one of 3 different levels of intake: ad libitum, restricted-fed to 75% of the ad libitum intake, and restricted-fed to 50% of the ad libitum intake. The intake of the animals fed ad libitum was daily adjusted to ensure 10% of orts from the offered diet, and the intake levels of 75% and 50% were determined daily based on the DMI of the goats in the ad libitum group. The effects of sex and level of intake were evaluated in a split-plot design, where sex was the main plot observation and level of intake was the sub-plot.

The goats were weighed once a week before morning feeding, and when the animal in each block that was fed ad libitum reached 30 kg BW, it was slaughtered along with the other goats from the same block. Immediately before slaughter the body weight was measured. At slaughter, the animals were stunned with a captive bolt pistol followed by severing of the jugular vein and carotid artery. The blood was weighed and collected. After that, the animals were skinned and eviscerated. Skin and non-carcass constituents were weighed. The digestive tract was weighed before and after emptying and flushing with water to determine the empty BW (EBW), which

was calculated as the BW at slaughter minus the digestive tract contents. The carcasses, non-carcass constituents, and skins were initially frozen at –6°C. These components were individually cut into small pieces, ground with a large screw grinder (Grinder CAF 114DS inox NR 12; CAF Máquinas, Rio Claro, São Paulo, Brazil) through a plate with 0.32 cm holes, and mixed by two additional passes through the grinder. After grinding and homogenization, representative samples of 100 g were collected, frozen again, and freeze-dried during 96 h for DM determination. Approximately 30 g of these components was individually analyzed for water, CP, crude fat, and ash as previously described, and these values were used to estimate body composition.

Macrominerals were extracted from the body, feed ingredients, and orts by means of nitric-perchloric acid wet digestion (AOAC, 1990; method 935.13). The concentrations of Ca, Mg, Na, and K were determined by atomic absorption (AOAC, 1990; method 935.13), and the P content was determined by colorimetric method (AOAC, 1990; method 965.17).

The BL group was slaughtered at the beginning of the experiment, following the procedures described previously. This group was composed of 8 intact males (slaughtered at 16.6 ± 0.7 kg BW and 112 ± 28 d old), 7 castrated males (slaughtered at 16.4 ± 0.9 kg BW and 97 ± 10 d old), and 6 females (slaughtered at 16.9 ± 1.3 kg BW and 136.8 ± 10 d old). A regression equation was developed from the BL group to determine the initial EBW (kg) from the BW (kg). The BL animals were similarly used to estimate the initial macromineral composition from which the averages of the macromineral concentrations in the EBW were calculated (Table 2). Macromineral body retention in tissues was obtained from the difference between the final

macromineral body composition of the pair-fed animals and the initial macromineral body composition estimated from the BL animals. The net macromineral requirements for maintenance were estimated from regression equations obtained between the retention of a macromineral in the EBW (g/kg EBW·d) and the intake of the macromineral from DMI and water (g/kg EBW·d). The net macromineral requirements for maintenance were estimated as the estimated mineral loss when macromineral intake was set at zero.

Exp. 2: Net Macromineral Requirements for Growth

Net macromineral requirements for growth were obtained using 58 goats (20 intact males, 20 castrated males, and 18 females) with 15.8 ± 0.11 kg iBW that were fed ad libitum. These animals were assigned in a completely randomized design, with an initial group (7 castrated males, 8 intact males, and 6 females) slaughtered at 16.6 ± 0.40 kg BW and 114.2 ± 25 d old, an intermediate group (7 castrated males, 6 intact males, and 6 females) slaughtered at 23.1 ± 1.33 kg BW and 165.5 ± 33 d old, and a final group (6 animals of each sex) slaughtered at 31.2 ± 0.58 kg BW and 202.0 ± 27 d old. Data were analyzed in a 3 × 3 factorial treatment structure (3 sexes × 3 slaughter weight groups). The procedures adopted for slaughter, sampling, and analysis of body composition were the same as in Exp. 1.

An allometric equation (Eq. 1) was developed to predict body macromineral concentration from the EBW (kg) (ARC, 1980):

$$\text{Macromineral amount (g)} = a' \times [\text{EBW (kg)}]^{b'} \tag{1}$$

Equation 1 was differentiated on EBW to compute estimates of the composition of the gain at various EBW values (Eq. 2):

$$[\text{Mineral, g}] = b' \times a' \times EBW^{(b'-1)} \tag{2}$$

where [Mineral, g] is the nutrient concentration per unit of empty BW gain (EWG) in g/kg, and a' and b' are parameters determined from a nonlinear regression (Eq. 2).

Statistical Analysis

Data on the net macromineral requirements for maintenance, retention, and intake were analyzed as split-plot design using a mixed model (PROC MIXED, SAS Inst. Inc., Cary, NC; version 9.4) that considered the fixed effects of sex (main plot; df = 2), level of intake (sub-plot; df = 2), their interactions (df = 4), and the random effect of the level of intake nested within sex (block; df = 15). The residual was the random effect assuming i.i.d. N(0, σ^2_{ij}). Sex effects were compared using Fisher's test in the LSMEANS statement. Regression analyses were performed using the restricted maximum likelihood estimation method and the model was fitted through the REPEATED statement with the GROUP regarding sex. The CONTRAST statements were used for testing whether a regression parameter differed among the three sexes. Studentized residuals were plotted against predicted values to verify model assumptions. Significance was declared at $P \le 0.05$.

The data on net macromineral requirements for growth were analyzed using a completely randomized design in a 3 × 3 factorial treatment structure (3 sexes × 3 slaughter weight groups) with the fixed effects of sex (df = 2), slaughter group (df =

2), and their interactions (df = 4). The residual was the random effect assuming i.i.d. $N(0, \sigma^2_{ij})$. The allometric equations were fitted according to a nonlinear mixed model methodology using the SAS macro %NLINMIX% (SAS Inst. Inc., Cary, NC; version 9.4). Restricted maximum likelihood was used as the method of estimation, and the zero-order expansion method was used to fit the model (Littell et al., 2006). Three dummy variables ($z1$, $z2$, and $z3$) were created to assess the effect of sex on the regression parameters. For intact males, $z1 = 1$, $z2 = 0$, and $z3 = 0$; for females, $z1 = 0$, $z2 = 1$, and $z3 = 0$; and for castrated males, $z1 = 0$, $z2 = 0$, and $z3 = 1$. Using these dummy variables, we estimated separate regression parameters for each of the 3 sexes. CONTRAST statements were used for testing whether a regression parameter differed among the three sexes. Significance was declared at $P \leq 0.05$.

RESULTS

Exp. 1: Net Macromineral Requirements for Maintenance

Body Composition of Baseline Animals. The BL body composition was similar among the sexes, except for K and Na concentrations, wherein intact males had lower values for EBW and defatted EBW than females and castrated males (Table 2).

Table 2. Body composition of baseline intact male, castrated male and female Saanen goats

Item[1]	Sex			SEM	*P*-value
	Intact	Castrated	Females		
BW, kg	16.6	16.4	17.0	0.40	0.558
EBW, kg	13.6	13.6	14.4	0.29	0.010
% EBW					
Water	67.2	65.2	64.4	1.08	0.165
CP	16.4	17.0	17.8	0.62	0.279
Crude fat	12.5	14.0	13.9	0.77	0.294
Ash	3.9	3.9	3.9	0.25	0.993
Ca	0.89	1.10	1.06	0.11	0.402
P	0.85	0.91	0.94	0.06	0.495
Mg	0.02	0.03	0.03	0.003	0.136
K	0.16^b	0.18^a	0.17^a	0.05	0.010
Na	0.11^b	0.13^a	0.14^a	0.006	0.020
% of defatted EBW					
Ca	1.03	1.28	1.23	0.13	0.385
P	0.99	1.07	1.10	0.07	0.477
Mg	0.03	0.04	0.04	0.003	0.075
K	0.18^b	0.21^a	0.22^a	0.009	<0.01
Na	0.13^b	0.15^a	0.16^a	0.006	<0.01

[a-c] Means within sex at the same row with different superscripts differ ($P \leq 0.05$) for sex.

[1] EBW = empty BW.

Animal Performance, Body Composition, and Macromineral Retention in Tissues According to Level of Intake. There was an observed interaction effect between sex and level of intake for final BW (fBW) and EBW (Table 3). Animals fed ad libitum had higher fBW and EBW, followed by animals in the 75% and 50% intake levels. When fed ad libitum, intact males had higher fBW than females. The EBW values of intact males were higher than those of females and castrated males (25.6 kg BW) when the animals were fed ad libitum (Table 3). When fed 75% of the ad libitum intake, castrated males had lower fBW and EBW values than intact males and females. No significant interactions between sex and level of intake were observed for macromineral composition (Table 3). When the effect of sex on macromineral composition is observed individually, castrated males (1.0% of defatted EBW) had greater percentage of P in the defatted EBW than intact males and females (0.9% of defatted EBW; Table 3).

We also observed a significant interaction (sex × level of intake) for DMI, wherein castrated males fed ad libitum ingested 10.7% more than intact males and females (Table 4). Consequently, castrated males fed ad libitum also had greater macromineral intake when compared to intact males and females (Table 4). At the 75% and 50% intake levels, there was no difference in DMI and macromineral intake among the sexes (Table 4). The water intake did not differ among the sexes nor among levels of intake ($P > 0.05$; average of 3174.10 ± 320.42 g/d), nor did the macromineral intake by water ($P > 0.05$; averages of 0.06 ± 0.005 g/d Ca, 0.003 ± 0.0003 g/d Mg, 0.008 ± 0.0008 g/d K, and 0.06 ± 0.006 g/d Na; the P concentration in the water was negligible).

The interaction between sex and level of intake was not significant for macromineral retention ($P > 0.05$), so each factor will be described individually (Fig. 1). Body Ca and Mg retention in the tissues of animals fed ad libitum (average of 1.60 ± 0.21 g Ca and 0.04 ± 0.004 g Mg daily) was greater than in those fed restrictively (average of 0.76 ± 0.22 g Ca and 0.01 ± 0.005 g Mg daily) ($P = 0.007$), but did not differ among the sexes ($P = 0.54$; general average of 1.04 ± 0.22 g Ca and 0.02 ± 0.005 g Mg daily). Body P retention decreased with decreasing levels of intake ($P < 0.01$; average of 0.89 ± 0.06, 0.53 ± 0.06, and 0.24 ± 0.05 g/d for ad libitum, 75%, and 50% of ad libitum intake, respectively), and it was greater for intact and castrated males (0.65 ± 0.07 g/d) than for females (0.34 ± 0.07 g/d) ($P < 0.01$). Similarly, K retention decreased with decreasing levels of intake ($P < 0.01$; averages of 0.20 ± 0.01, 0.15 ± 0.01, and 0.04 ± 0.01 g/d for ad libitum, 75%, and 50% of ad libitum intake, respectively), and it also was affected by sex ($P = 0.02$), wherein body K retention of intact males (0.17 ± 0.02 g/d) was greater than that of castrated males and females (0.11 ± 0.02 g/d). Body Na retention of females (0.06 ± 0.01 g/d) was lower than that of intact and castrated males (0.11 ± 0.01 g/d) ($P = 0.006$). In addition, body Na retention decreased with decreasing levels of intake ($P < 0.01$; average of 0.14 ± 0.008, 0.09 ± 0.009, and 0.03 ± 0.009 g/d for ad libitum, 75%, and 50% of ad libitum intake, respectively).

Table 3. Performance and body composition of intact male, castrated male and female Saanen goats subjected to different levels of intake

Item[1]	Level of intake (%)[2]									SEM	P-value		
	Intact			Castrate			Female						
	AL	75%	50%	AL	75%	50%	AL	75%	50%		LI	S	LI*S
Days on feed	105	105	105	91	91	91	104	104	104	-	-	-	-
iBW, kg	15.7	15.4	15.6	15.6	15.5	15.3	15.3	15.1	15.2	-	-	-	-
fBW, kg	32.6^{aA}	28.0^{bA}	21.0^{c}	31.2^{aAB}	25.0^{bB}	20.2^{c}	29.8^{aB}	27.2^{bA}	20.1^{c}	0.68	<0.01	0.010	0.041
EBW, kg	27.7^{aA}	23.64^{bA}	17.02^{c}	26.08^{aB}	19.76^{bC}	16.8^{c}	25.24^{aB}	22.06^{bB}	16.50^{c}	0.50	<0.01	<0.01	<0.01
% EBW													
Water	64.7	64.6	66.7	59.1	62.0	64.7	57.9	61.3	62.0	1.28	<0.01	<0.01	0.297
CP	17.5	17.7	17.8	17.2	18.2	17.7	16.7	16.5	17.0	0.42	0.380	0.110	0.530
Crude fat	13.9	13.6	11.1	20.3	16.4	13.5	21.6	18.8	16.8	0.92	<0.01	<0.01	0.174
Ash	3.94	4.08	4.23	3.40	4.00	4.03	3.73	3.45	4.09	0.23	<0.01	0.233	0.104
Ca	0.95	0.77	0.97	1.16	1.26	1.27	1.21	0.83	1.18	0.16	0.292	0.072	0.624
P	0.83	0.76	0.85	0.80	0.92	0.84	0.74	0.73	0.78	0.06	0.692	0.095	0.424
Mg	0.031	0.030	0.020	0.031	0.031	0.030	0.029	0.026	0.033	0.003	0.732	0.444	0.108
K	0.158	0.187	0.153	0.160	0.161	0.142	0.157	0.167	0.144	0.01	0.014	0.291	0.670
Na	0.124	0.125	0.114	0.122	0.118	0.123	0.105	0.108	0.116	0.006	0.988	0.205	0.248
% of defatted EBW													
Ca	1.10	0.89	1.10	1.47	1.52	1.27	1.55	1.05	1.43	0.19	0.343	0.054	0.429
P	0.90	0.89	0.96	1.08	1.04	0.92	0.94	0.85	0.95	0.05	0.497	0.047	0.119
Mg	0.036	0.035	0.023	0.039	0.037	0.035	0.037	0.033	0.040	0.004	0.426	0.187	0.180
K	0.184	0.217	0.186	0.189	0.191	0.165	0.201	0.196	0.174	0.01	0.017	0.275	0.348
Na	0.145	0.129	0.129	0.153	0.141	0.142	0.135	0.135	0.132	0.007	0.053	0.217	0.581

[a-c] Means within sex at the same row with different superscripts differ ($P \leq 0.05$) for the level of intake.
[A-C] Means within level of intake at the same row with different superscripts differ ($P \leq 0.05$) for sex.
[1] iBW = initial BW; fBW = final BW; EBW = empty BW.
[2] Ad libitum (AL) or 75% or 50% levels of the AL intake. [3] LI = level of intake, S = sex and LI*S = their interaction.

Table 4. Dry matter and macromineral intake of intact male, castrated male and female Saanen goats subjected to different levels of intake

Item, g/d	Level of intake (%)[1]									SEM[3]	P-value[2]		
	Intact Males			Castrated males			Females				LI	S	LI*S
	AL	75%	50%	AL	75%	50%	AL	75%	50%				
Days on	105	105	105	91	91	91	104	104	104				
DMI	789.9^{aB}	563.0^b	386.4^c	867.8^{aA}	571.9^b	414.3^c	777.3^{aB}	591.8^b	389.7^c	16.36	<0.01	0.107	<0.01
Ca	9.4^{aB}	5.9^b	4.0^c	10.8^{aA}	6.1^b	4.3^c	9.8^{aB}	6.1^b	4.1^c	0.17	<0.01	0.03	<0.01
P	3.3^{aC}	2.5^b	1.8^c	4.1^{aA}	2.5^b	1.9^c	3.7^{aB}	2.7^b	1.8^c	0.09	<0.01	0.03	<0.01
Mg	1.3^{aB}	1.0^b	0.7^c	1.6^{aA}	1.0^b	0.7^c	1.4^{aB}	1.0^b	0.7^c	0.03	<0.01	0.04	<0.01
K	13.0^{aB}	8.7^b	6.0^c	14.3^{aA}	8.8^b	6.4^c	12.9^{aB}	8.9^b	5.9^c	0.27	<0.01	0.07	0.02
Na	3.6^{aB}	2.5^b	1.7^c	4.2^{aA}	2.5^b	1.8^c	3.6^{aB}	2.6^b	1.7^c	0.06	<0.01	0.01	<0.01

$^{a-c}$ Means within sex at the same row with different superscripts differ ($P \le 0.05$) for the level of intake.
$^{A-C}$ Means within level of intake at the same row with different superscripts differ ($P \le 0.05$) for sex.
[1]Ad libitum (AL) or 75% or 50% levels of the AL intake.
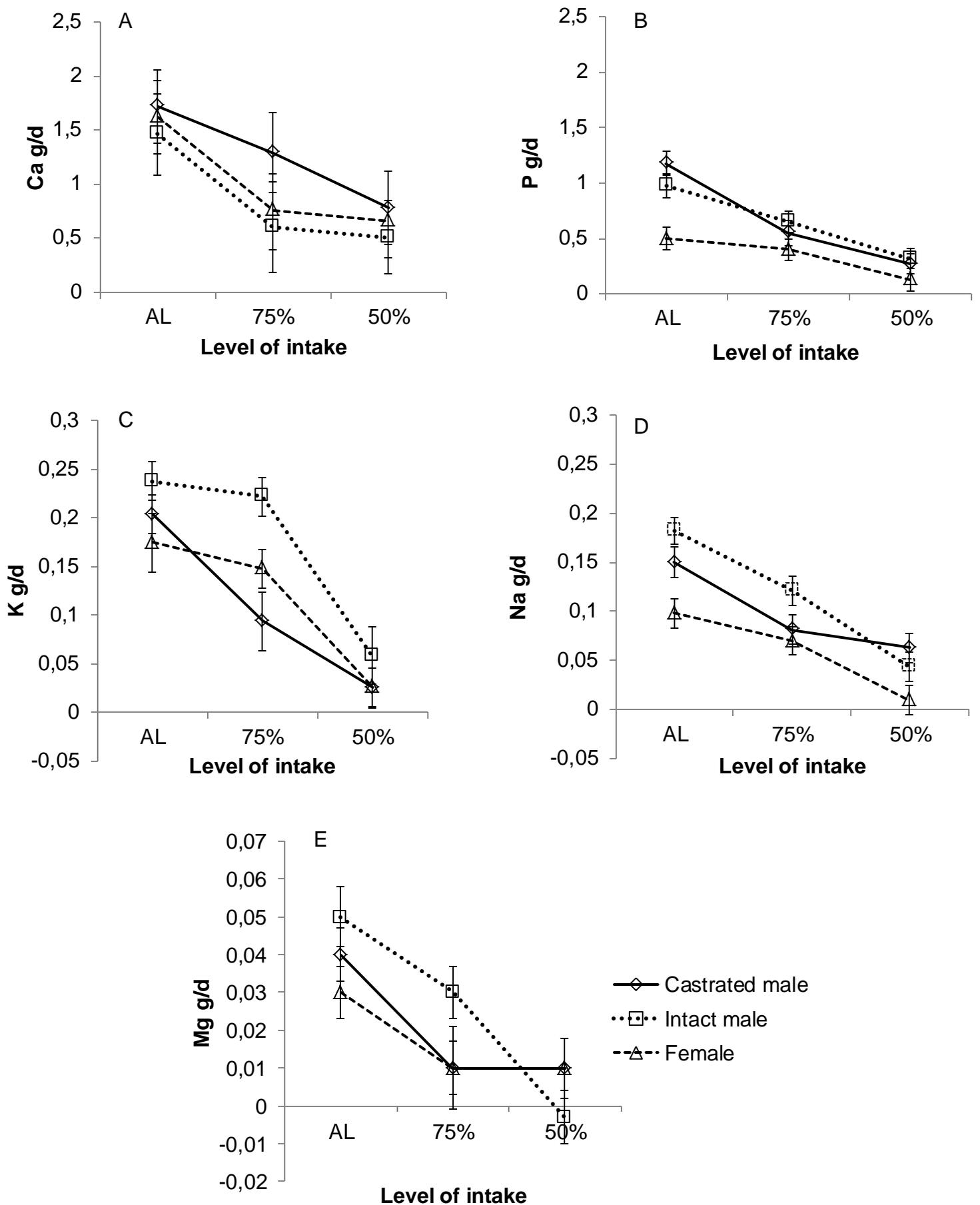[2]LI = level of intake, S = sex and LI*S = their interaction.

Figure 1. Body macromineral retention in tissues of intact male, castrated male and female Saanen goats fed ad libitum (AL) and restricted to 75% or 50% of the AL intake.

Net Macromineral Requirements for Maintenance. A regression equation was developed (Eq. 3) from BL animals to estimate initial EBW from BW. This regression equation was generated without considering sex, because no effect of sex was observed ($P = 0.88$). Additionally, as the intercept was not significant ($P = 0.37$), only the slope was estimated ($P < 0.01$; Eq. 3):

EBW, kg = 0.824 (± 0.005) × BW　　　　　　　　　　　　　　　　　[3]

Regression equations were used to calculate the relationship between daily macromineral intake and daily macromineral retention proportional to EBW, in which the negative intercept was considered as the net requirement for maintenance. The slope and the intercept of these regression equations did not differ among the sexes ($P > 0.05$), so equations were generated without regard to sex for each macromineral (Table 5).

Table 5. Regression equations to estimate the net macromineral requirements for maintenance of intact male, castrated male and female Saanen goats from 15 to 30 kg BW

Item[1]	Equation[1]	RMSE[2]	Net requirement mg/(kg EBW·d)	Net requirement[3] mg/(kg BW·d)
Ca Ret.	− 0.043 (± 0.018) + 0.249 (± 0.047) × Ca Int.	0.038	43.0	35.4
P Ret.	− 0.030 (± 0.008) + 0.396 (± 0.054) × P Int.	0.013	30.0	24.7
Mg Ret.	− 0.003 (± 0.0005) + 0.058 (± 0.007) × Mg Int.	0.001	3.00	2.50
K Ret.	− 0.006 (±0.002) + 0.023 (±0.004) × K Int.	0.004	6.00	5.00
Na Ret.	− 0.004 (±0.001) + 0.058 (±0.008) × Na Int.	0.002	4.00	3.30

[1] Ret = retained, g/kg empty body weight (EBW); Int = intake, g/kg EBW.
[2] RMSE = root mean square error.
[3] Conversion of EBW to BW (EBW = 82.4% of BW).

Exp. 2: Net Macromineral Requirements for Growth

Net Macromineral Requirements for Growth. Sex did not affect the relationship between BW and EBW ($P > 0.13$), so the regression equation was developed without regard to sex (Table 6). The intercept was not significant ($P = 0.13$), and only the slope was estimated ($P < 0.01$; Table 6). Likewise, the allometric equations for Ca, P, and Mg body composition also were not affected by sex ($P > 0.05$; Table 6), which resulted in similar net requirements for growth among the sexes. As a consequence, equations were generated for each macromineral without regard to sex, and these equations showed that the net Ca and Mg requirements for growth (g/kg ADG; Table 7) remained relatively constant, whereas the net P requirements for growth (g/kg ADG) decreased by approximately 14% when the goats grew from 15 to 30 kg BW.

The allometric equations for K body composition were different among the sexes ($P < 0.05$; Table 6), revealing that K body composition of intact males was different from females and castrated males. One allometric equation was therefore generated for intact males, and the data of castrated males and females were pooled to generate another equation. As a result, the net K requirements for growth of intact males (g/kg ADG) were greater and increased by approximately 16%, whereas the values for females and castrated males decreased by approximately 18.7% as BW grew from 15 to 30 kg BW (Table 7).

Regarding the allometric equations for Na body composition (Table 6), intact males were different from females ($P < 0.05$), and castrated males were similar both to intact males and to females ($P > 0.05$). We generated an allometric equation for each sex, which revealed that intact males increased their Na body composition for

growth by 9.5% and females decreased by 21.6% when the goats grew from 15 to 30 kg BW (Table 6). The same pattern was observed in their net requirements for growth (g/kg ADG) (Table 7). Additionally, intact males had a greater concentration of Na in the skin than females ($P < 0.01$; 0.3 ± 0.07% versus 0.2 ± 0.07%; data not shown).

Table 6. Allometric equations to estimate the macromineral body composition of intact male, castrated male and female Saanen goats from 15 to 30 kg BW

Item[1]	BW, kg			Allometric equation
	15	22	30	
EBW, kg	12.4	18.2	24.8	EBW, kg = 0.825 ± 0.00293 × BW
Ca, g/kg EBW	10.7	10.6	10.5	$11.35 ± 5.45 × EBW^{0.98 ± 0.157}$
P, g/kg EBW	8.94	8.22	7.68	$15.45 ± 4.08 × EBW^{0.78 ± 0.086}$
Mg, g/kg EBW	0.33	0.33	0.33	$0.37 ± 0.10 × EBW^{0.96 ± 0.096}$
K, g/kg EBW				
Intact Male	1.57	1.70	1.82	$0.92 ± 0.30 × EBW^{1.21 ± 0.107}$
Castrated and Females	1.87	1.67	1.52	$4.02 ± 0.92 × EBW^{0.69 ± 0.076}$
Na, g/kg EBW				
Intact Male	1.13	1.18	1.23	$0.81 ± 0.27 × EBW^{1.13 ± 0.108}$
Castrated Male	1.24	1.22	1.21	$1.39 ± 0.47 × EBW^{0.96 ± 0.113}$
Female	1.38	1.20	1.08	$3.33 ± 1.24 × EBW^{0.65 ± 0.127}$

[1] EBW = empty BW

Table 7. Gain macromineral composition (g/kg EWG) and net macromineral requirements for growth (g/kg ADG) of intact male, castrated male, and female Saanen goats from 15 to 30 kg BW

Item	BW, kg			Equations of net requirements for growth[1]
	15	22	30	
Mineral composition in empty body weight gain (EWG)				
Ca, g/kg EWG	10.5	10.4	10.3	$11.09 \times EBW^{-0.023}$
P, g/kg EWG	6.98	6.43	6.00	$12.10 \times EBW^{-0.218}$
Mg, g/kg EWG	0.32	0.32	0.31	$0.355 \times EBW^{-0.038}$
K, g/kg EWG				
Intact Male	1.90	2.07	2.21	$1.11 \times EBW^{0.214}$
Castrated and Female	1.30	1.16	1.06	$2.79 \times EBW^{-0.303}$
Na, g/kg EWG				
Intact Male	1.27	1.34	1.39	$0.917 \times EBW^{0.129}$
Castrated Male	1.19	1.17	1.16	$1.33 \times EBW^{-0.043}$
Female	0.90	0.78	0.70	$2.16 \times EBW^{-0.352}$
Net requirements for gain[2]				
Ca, g/kg ADG	8.63	8.55	8.49	
P, g/kg ADG	5.77	5.30	4.96	
Mg, g/kg ADG	0.27	0.26	0.26	
K, g/kg ADG				
Intact Male	1.57	1.70	1.82	
Castrated and Female	1.07	0.96	0.87	
Na, g/kg ADG				
Intact Male	1.05	1.10	1.15	
Castrated Male	0.98	0.97	0.95	
Female	0.74	0.64	0.58	

[1] First derivative of equations from Table 6; EBW = empty body weight
[2] Conversion of EBW to BW based on equation from Table 6 (EBW = 82.5% of BW).

DISCUSSION

There are have been few studies on macromineral retention and requirements in goats, so the effect of sex has not previously been investigated. We therefore tested for an effect of sex on macromineral retention and net macromineral requirements for maintenance and growth. Our results indicated that sex did not affect net maintenance requirements, but it did influence mineral retention and the net requirements for growth of K and Na.

Macrominerals have several functions in the animal body, acting as structural components, in energetic reactions, and in osmotic pressure maintenance and acid-base balance (Suttle, 2010). However, no previous research has suggested that the role of Ca, P, Mg, K, and Na in maintenance activities is influenced by sex during the growth phase, and this agrees with our results, in which net macromineral requirements for maintenance did not differ among the sexes.

Nonetheless, the net Ca and Mg maintenance requirements observed in our study were greater than those reported for intact males ¾ Boer × ¼ Saanen growing from 20 to 35 kg BW (27.4 and 1.31 mg/kg BW·d for net Ca and Mg, respectively; Fernandes et al., 2012), presumably because the Saanen goat is a dairy breed whose skeleton is more protuberant, and so it has more intense bone remodeling when compared to a meat breed, like Boer, and its crossbreds. Bone remodeling serves to maintain the mechanical integrity of the adult skeleton (Compston, 2001). On the other hand, even though P also acts in the bone structure, the net maintenance requirement for P that we found (24.7 mg/kg BW·d) was 6% lower than that reported by those authors (26.2 mg/kg BW·d). Saanen goats have lower muscle deposition than Boer × Saanen crossbreeds, which may explain this slight disparity

because ATP is the main energy source for muscle protein turnover, an essential component of basal metabolism involving protein synthesis and degradation (Lobley et al., 1994; Saraiva et al., 2009; Wang et al., 2009).

According to the NRC (2007), a goat with 30 kg BW and eating approximately 811.6 g DM/d would require for maintenance 4.0 g K and 0.6 g Na daily. Those recommendations are greater than the estimated maintenance requirements in this study (0.15 and 0.1 g/d of K and Na, respectively). More recently, Teixeira et al. (2015) evaluated macromineral requirements in Saanen × Boer crossbreeds, from 15 to 25 kg BW, and they also found a large discrepancy when they used the equation proposed by the NRC (2007) to calculate the K maintenance requirement. According to these authors, this may indicate that growing goats have different requirements for maintenance than mature cattle and sheep, from which a large part of the NRC data were obtained. Additionally, these recommendations were based in the minimum endogenous losses from balance trials, which estimate macromineral losses from feces and urine. However, they cannot take into account other inevitable losses, e.g., through the skin, sweat, and so forth (Teixeira et al., 2015). In our study the maintenance requirements were assessed, by contrast, using the comparative slaughter technique. Previous studies concluded that equations for macromineral maintenance that were derived from the comparative slaughter technique fit the data better than those derived from balance trials (Duncan, 1958; Fernandes et al., 2012).

Our findings show that net Ca, P, and Mg requirements for growth do not differ among the sexes. Our data were therefore pooled, and they demonstrated that the net requirements for growth of these macrominerals decreased as BW increased. Because approximately 90% of Ca, 80% of P, and 70% of Mg are located in the

bones as structural components (Shuttle, 2010), the deposition of these minerals is directly related to skeletal development, and the decrease in the net requirements for growth may indicate that Saanen goats growing from 15 to 30 kg BW are approaching bone maturity. With bone maturity, the requirements for these macrominerals tend to stabilize, so that differences among the sexes cannot be identified in this phase. Similarly to our study, net macromineral requirements for growth of Nellore × Red Angus bulls, steers, and heifers decrease as BW increases, and do not change among the sexes (Chizzotti et al., 2009). Contrary to our study, an increase in the Ca and P components of body composition, as well as in their net requirements for growth, were found in younger Saanen goats growing from 5 to 20 kg BW (Gomes et al., 2011), probably because of the high demand for minerals during the bone growth phase.

We observed that intact males retained more Na in the body than females; consequently, intact males had greater net Na requirements for growth than females. Aldosterone regulates electrolytic balance and acts by increasing Na reabsorption by the kidneys and small intestine, resulting in higher Na body retention (Schrier, 2006; Squires, 2010). Previous studies reported that intact male rats have higher aldosterone levels than females, which may be associated with the androgen effect (Kienitz and Quinkler, 2008; Spyroglou et al., 2012). We speculate that aldosterone may acts similarly in goats, inducing greater Na retention, and, consequently, higher Na requirements in intact males than in females. However, future studies are needed to determine plasma aldosterone levels in goats and its mechanism of action in both sexes. In addition to the effects of aldosterone, Na requirements are directly correlated with losses through sweat (McDowell, 2003). In the present study, intact

males had a greater concentration of Na in the skin than did females, so it is possible that the differences in Na requirements may also result from greater sweating in intact male goats. In cattle, for example, it is known that intact males produce more sweat than females (Kasa et al., 1997).

With respect to K, intact males had greater net requirements for growth than females and castrated males, as well as a similar trend to that observed in Na, which increased in intact males and decreased in females and castrated males. As K and Na are the primary intracellular and extracellular cations, respectively, these parallel trends probably occur because the organism needs to ensure a constant Na:K ratio in order to maintain osmotic equilibrium (Shuttle, 2010; Gomes et al., 2011). Throughout this study, the Na:K ratio remained constant at approximately 0.98 for females and castrated males and 0.70 for intact males. A similar Na:K ratio, approximately 0.60, was found in intact Saanen males growing from 5 to 25 kg BW (Pfeffer and Rodehutscord, 1998; Gomes et al., 2011).

The macromineral requirements for growth given in established feeding systems are not necessarily accurate. For example, the NRC (2007), using sheep and cattle data, as well as data from older studies with goats, reported 11 g Ca/kg BW gain. The same applies with respect to P, where the value of 6.5 g P/kg BW gain was based on cattle data and adjusted for the high concentration and recycling of P in goat saliva. With respect to K and Mg, goat data were also limited, so that cattle and sheep data were necessary to obtain the values of 2.4 g K/kg BW gain and 0.4 g Mg/kg BW gain (NRC, 2007). The ARC (1980) treated goat Na requirements as similar to sheep, with a value of 1.10 g/kg BW gain. We found, however, lower net macromineral requirements for growth than those specified in the aforementioned

feeding systems, with the exception of Na requirements in intact goats from 22 to 30 kg BW. At this point, it is important to emphasize that these feeding systems have generally not taken into account the sex differences discussed above in our study. Moreover, other studies of goat macromineral requirements using different breeds, husbandry systems, and weight ranges reported different results (Araújo et al., 2010; Gomes et al., 2011; Fernandes et al., 2012; Teixeira et al., 2015), indicating that macromineral requirements in goats are dynamic and estimates from cattle and sheep may not provide a good surrogate measure for goats. Thus, more research utilizing goats could contribute to adjustments and improvements in feeding systems.

A great knowledge gap exists concerning macromineral requirements in goats. We have contributed to the body of work on this subject by providing an important description of sex differences in net macromineral requirements during the growth phase. Future studies can now focus on the mechanisms underlying these differences.

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CHAPTER 3 – IMPLICATIONS

These findings are useful to meet the net macromineral requirements of growing goats and, consequently, protect animal health, increase productivity, and avoid any environmental impacts due to excessive excretion of nutrients. Additionally, these results contribute to adjustments and improvements in feeding systems by providing an important description of sex differences in net macromineral requirements during the growth phase.