MINERAL REQUIREMENTS OF ZEBU BEEF CATTLE

Mateus Pies Gionbelli[1]; Marcos Inácio Marcondes[1]; Sebastião de Campos Valadares Filho[2]; Laura Franco Prados[3]

[1]*Doutorando em Zootecnia do DZO-UFV,* [2]*Professor do DZO-UFV.Coordenador do INCT de Ciência Animal: scvfilho@ufv.br,* [3]*Bolsista IC-CNPQ,DZO-UFV*

INTRODUCTION

All animal tissues and all feeds have mineral elements, in widely amounts and proportions (Underwood, 1981), and although the majority of natural mineral elements can be found in animal tissues, several of them are present only because they are part of the consumed feeds and do not have essential functions in the animals' metabolism. The term "essential mineral element" is related only to elements that play a role in the organism (McDonald et al., 2002). This group is usually divided into macronutrient minerals and micronutrient minerals, with macrominerals being the ones that can be expressed in g/kg of animal tissue, such as calcium (Ca), phosphorus (P), magnesium (Mg), sodium (Na), potassium (K), sulfur (S) and chlorine (Cl). On the other hand, microminerals, or trace elements, are essential minerals that are usually found in concentrations lower than 50 mg/kg of the animal tissue. The most well studied microminerals in cattle are iron (Fe), zinc (Zn), copper (Cu), molybdenum (Mo), selenium (S), iodine (I), manganese (Mn) and cobalt (Co).

Although the mineral elements are present in the animal body in a lower proportion than other nutrients, such as protein and fat, they play vital functions in the organism, and their deficiency generates severe nutritional alterations that decrease the animal's productive and reproductive performance. The minerals have three basic types of functions in the animal (Underwood, 1981):

1. Structural components of body organs and tissues, such as calcium, phosphorus, magnesium, fluorine and silicon in the bones and teeth, and phosphorus and sulfur in muscle proteins. About 99% of the calcium, 80% of the phosphorus and 70% of the magnesium in the body are present in the skeleton (AFRC, 1991; Coelho da Silva, 1995; NRC, 2000);
2. Components of the body fluids and tissues responsible for the maintenance of osmotic pressure, acid-base balance, membrane permeability and tissue irritability, including sodium, potassium, chlorine, calcium and magnesium in the blood, cerebrospinal fluid and gastric juice;
3. Catalysts in enzymes and hormone systems, where this includes the microminerals.

The total requirement for each macroelement mineral corresponds to the sum of the requirements for maintenance and production, and the factorial method is the most frequently used to predict the mineral requirements for cattle (ARC, 1980). One may find the total dietary requirements of a particular mineral element by dividing the net requirement by the absorption coefficient of the inorganic element in the animal's digestive tract.

The nutritional requirements for minerals of cattle are usually expressed in amounts per day or per unit of product or in proportions of the dry matter intake. These requirements are affected by the species or breed of animal, dietary aspects, rate of production and environment in which the animal is raised (Underwood, 1981). Inherent factors of feeds or diets, such as the organic or inorganic fractions of the mineral in a given feed and the availability and chemical form of the element in the dietary ingredients, and inherent factors of the animal, such as the rate of production and previous nutrition, along with aspects related to inter-relations (antagonism and agonists) among minerals, also influence the mineral requirements (Coelho da Silva and Leão, 1979).

In this chapter, we will discuss the macromineral requirements for maintenance described by some systems of nutritional requirements that exist worldwide and also the results obtained from studies conducted in Brazil. We will also present models of the net requirements for gain, obtained from data of animals raised in Brazilian conditions. Moreover, we will present considerations on the absorption coefficients of macrominerals and on the need for the development of studies on the mineral requirements in Brazil. Finally, we will present tables of nutritional requirements for the minerals (Ca, P, Mg, Na and K) for maintenance and weight gain.

REQUIREMENTS OF MACROMINERALS FOR MAINTENANCE

The dietary maintenance requirements comprises the nutrients needed to keep intact the tissues of an animal that is not growing, working, reproducing or yielding any product. Body maintenance involves the performance of internal work in circulation, respiration and other vital processes, together with some external work in the ordinary movements of the animal,(Underwood, 1981). These requirements depend on the animal's needs in relation to the inevitable losses of the body, also called endogenous secretions (Fontes, 1995).

The differences between organic and inorganic nutrients in relation to the needs for maintenance and production result in different metabolic destinies. Organic nutrients such as protein, after being absorbed, become part of the metabolic pool of the organism and can be converted into energy or used for the synthesis of tissues or maintenance; they can be metabolized and stored, or they can be lost as final products of the metabolism through regular pathways. On the other hand, the inorganic ions released during metabolism are not changed or rendered unavailable to the tissues. These ions remain available for the reformulation of their functional combinations as are the inorganic ions absorbed from the digestive tract (Underwood, 1981)..Theoretically, this reutilization of minerals by the tissues could be complete, resulting in no maintenance requirements for these nutrients (Underwood, 1981). However, in reality, the processes of mineral conservation of the body are not very efficient, resulting in mineral losses through the kidneys, intestinal mucosa, the digestive glands and the skin; this *leakage* must be replaced, imposing a small requirement (Underwood, 1981).

To calculate the mineral requirements for maintenance, the values from the endogenous losses through feces and urine are usually estimated through regressions of the fecal or urinary excretion as a function of the a given mineral intake. The estimation of the requirements for minerals for cattle vary substantially among different committees (ARC, 1980; AFRC, 1991; NRC, 2000; CSIRO, 2007), being the main sources of variation the differences in the adopted values for the maintenance requirements and in the absorption coefficients.

In Brazil, according to Silva et al. (2002), studies on the endogenous losses of minerals in ruminants are scarce, and the available studies have found very variable values that are different from the values used by different systems for determining beef cattle requirements. In the first edition of BR-CORTE (Valadares Filho et al., 2006), the mineral requirements for maintenance were calculated according to the recommendations of the NRC (2000) and ARC (1980), as shown in Table 1.

Table 1 - Daily endogenous total losses and absorption coefficients of calcium, phosphorus, magnesium, sodium and potassium, as presented in the first edition of the BR-CORTE

Macroelements	Endogenous losses	Absorption (%)
Ca	15.4 mg/kg BW[1]	50[1]
P	16 mg/kg BW[1]	68[1]
Mg	3.0 mg/kg BW[1]	17[2]
K	Fecal – 2.6 g/kg dry matter intake[2,3] Urinary – 37.5 mg/kg BW Salivary – 0.7 g/100 kg BW Through the skin – 1.1 g	100[2]
Na	6.8 mg/kg BW	91[2]

[1]Data from NRC (2000); [2]Data from ARC (1980); [3]Intake determined through equation presented by Valadares Filho et al. (2006) for Nellore cattle: DMI (kg/day) = -2.40011 + 0.02006 * ABW + 4.81946 × ADG – 1.51758 × ADG^2; BW = Body weight ; ADG = average daily gain; ABW = average body weight.

In this edition, we will discuss the net requirements for the maintenance of the main macrominerals studied (Ca, P, Mg, Na and K), presenting some data obtained in Brazilian conditions.

Calcium

Calcium (Ca) is the mineral found in the greatest abundance in the animal's body, representing roughly 1 to 3% of its total weight. About 99% of the Ca is present in bones and teeth and 1% in the fluids and soft tissues.The Ca that does not have a structural function usually occurs as the free ion, bound to serum proteins and complexed to organic and inorganic acids, and is essential to functions such as nerve conduction and maintenance of muscle contraction and relaxation including that of heart muscle. Ca also acts as an activator or stabilizer of some enzymes, and it is necessary for blood coagulation (Underwood, 1981).

The ruminant has a poor ability to excrete calcium that is over-absorbed relative to its needs. Urinary excretion is minimal, and the fecal endogenous losses are constant, which indicates that absorption is regulated by the intestine (Field, 1983a). The fecal Ca includes calcium with endogenous origin and dietary that was not absorbed. Factors that determine the endogenous losses of calcium are not well known, and the values obtained in studies that aimed to determine these losses are highly variable. According to CSIRO (2007), the values obtained for the excretion of Ca and P are controversial, given that there are difficulties in the distinction of losses that are really indispensable from the ones that occur because of the over-absorption of the mineral. For this purpose, there are alternative methods to determine the metabolic excretion of minerals through the utilization of radioisotopes (Hansard et al., 1954; Field, 1983a). However, the obtained values through these methods are usually differents from the ones obtained through the traditional method, from the extrapolation to zero intake (CSIRO, 2007).

Hansard et al. (1954, 1957) carried out experiments to determine the true availability,maintenance requirements and utilization of Ca by cattle using Ca radioisotopes in animals aged between 10 days and 190 months. Considering these studies, the NRC (1984) started recommending a daily net requirement of Ca for maintenance of 15.4 mg/kg of body weight and maintained this recommendation in subsequent editions (NRC, 1996; NRC, 2000), due to a lack of studies recommending a change in these values.

If the diet does not present an appropriate ratio between calcium and phosphorus, with a deficiency of one of the two elements, modifications in the requirements for the maintenance of these elements can be caused by variations in the fecal excretion of Ca. High values of Ca combined with low values of P generate a greater urinary excretion of Ca. If there is insufficient phosphorus available for bone deposition, the excess Ca, which would normally be deposited together with P, is excreted via urine (Tillman et al., 1959). Variations in the dietary levels of Ca seem not to influence the requirements for the maintenance of this mineral, as long as the levels of P remain adequate. Visek et al. (1953) observed that, in the short-term, large variations in calcium intake had little impact on the fecal excretion of endogenous Ca.

Braithwaite (1982), reevaluating the results of previous research on endogenous calcium, concluded that this value is larger in animals that are growing than in adult animals, based on body weight. It was also observed that there is a relationship between feed intake and metabolic excretion of calcium, with a daily increase of 0.64 mg/kg BW of Ca for each increase (g/kg BW) in feed intake. Furthermore, it was also noticed that there is no relationship between calcium intake and metabolic fecal calcium, which suggests that the endogenous calcium must be in non-exchangeable with the dietary calcium.

The ARC (1980) concluded that the daily endogenous losses are 16 mg/kg of body weight for Ca, with 0.8 mg/kg related to urinary losses. The AFRC (1991) uses an equation to estimate the metabolic fecal losses (MFL) as a function of the animal's dry matter intake and its body weight [MFL_{Ca} (g/day) = 0.66 × DMI (kg/day) + 0.74 × BW (kg) – 0.74]; this equation is also adopted by CSIRO (2007).

In Brazil, Ezequiel (1987) working with Nellore, Holstein and ½ Holstein-Zebu animals, observed daily endogenous losses of 33.2, 43.5 and 26.1 mg/kg BW, respectively, where these values were significantly higher than the estimates of the NRC (2000). Results obtained through the joint analysis of Ca intake and fecal excretion data from two recent experiments with Nellore and Crossbred animals (Marcondes, 2010, unpublished data; Souza, 2010, unpublished data) led to an estimate of daily metabolic fecal Ca excretion of 10.6 mg/kg EBW (r^2 = 0.67). However, it was not possible to obtain data for the urinary metabolic Ca excretion through these experiments.

Based on data from Gionbelli (2010), through a regression of retained Ca as a function of Ca intake (Figure 1), a daily Ca requirement for maintenance of 26.5 mg/kg EBW was obtained, and this value is larger than the recommendations of the NRC (2000) and AFRC (1991). In Figure 1, the slope of the regression represents the coefficient of retention, which is close to the one suggested by the NRC (2000), namely 0.50. Based on the results presented in the Figure 1, a 400-kg cattle would have a dietary Ca requirement for maintenance of 17.2 g/day. When the calculation is based on data from the NRC (2000), this requirement would be 12.3 g/day.

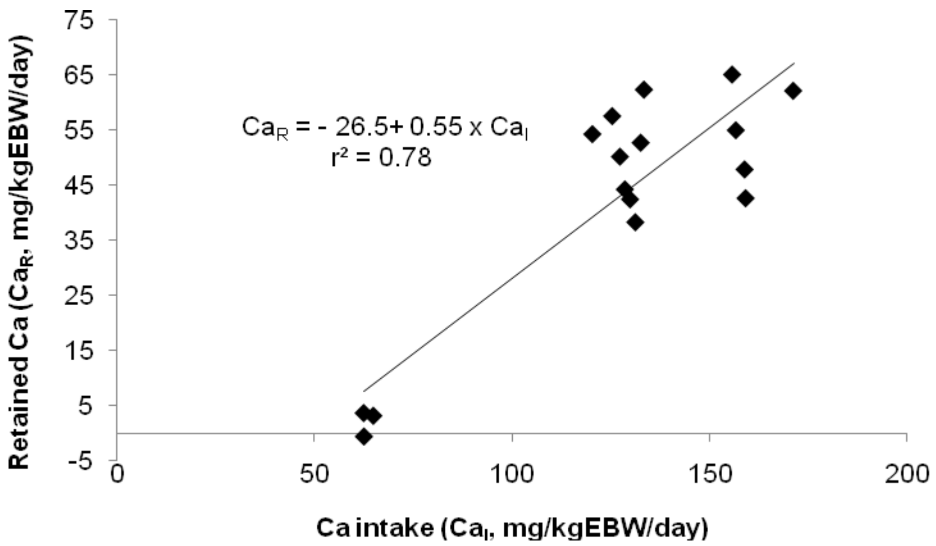


Figure 1 - Relationship between retained calcium (Ca_R) and calcium intake (Ca_I) in Nellore heifers.

Given that the studies carried out in Brazil to determine the daily maintenance Ca requirements still present inconsistent results, we suggest the adoption in this edition of BR-CORTE of the daily value of 15.4 mg/kgBW, obtained through the studies by Hansard et al. (1954, 1957) and recommended by the NRC (2000).

Phosphorus

Phosphorus (P) is the second mineral element most abundant in animals. In addition to its vital participation in the development and maintenance of the skeletal tissues, it functions also as a component of the nucleic acids which are essential in cell growth and differentiation. Jointly with other elements, P plays a role in osmotic regulation and acid-base balance. It also plays a vital role in several metabolic functions, including energy utilization and the transference of electrons, phospholipid formation and therefore fatty acids transport and amino-acid and protein synthesis (Underwood, 1981). Phosphorus is also required by the microorganisms in the rumen for cellular growth and metabolism (NRC, 2000).

Similarly to what has been done for the other macrominerals, the requirements for the maintenance of P have been calculated as the sum of the fecal and urinary metabolic excretion of this element. The NRC (2000) considers that the daily P requirement for maintenance is 16 mg/kg of the body weight. Similar to the situation with Ca, an inadequate ratio of Ca to P can alter the requirements for the maintenance of these minerals, if one of them is deficient in the diet. Hansard and Plumlee (1954) observed an increased metabolic excretion of phosphorus when the calcium intake was low and suggested that, whenever there is an insufficient quantity of calcium in the blood for bone calcification, part of the excess phosphorus that would also be used for bone deposition is excreted.

According to the ARC (1965), dietary phosphorus that exceeds the requirements of the animal is not absorbed or, if it is, is excreted in the urine. Under normal conditions, the excretion of phosphorus through urine is low, while large amounts of phosphorus are recycled via saliva. The regulation of the reabsorption of salivary phosphorus occurs in the small intestine, where losses through scurf also occur (ARC, 1980). Thus, the metabolic fecal phosphorus consists of metabolic losses from the intestine and salivary phosphorus that was not reabsorbed.

The ARC (1980) suggested a daily requirement of phosphorus for maintenance of 12 mg/kg of body weight, based on the extrapolation of the fecal and urinary metabolic excretion of phosphorus at the level zero of phosphorus intake. The AFRC (1991) reformulated the calculation for the P requirements for maintenance by using an equation developed in studies with sheep, in which the metabolic losses of P are calculated as a function of the dry matter intake, given that the greater the intake, the greater the production of saliva by the animal, and consequently, the greater the metabolic excretion of phosphorus.

The CSIRO (2007) emphasizes that the metabolic losses of P should be estimated based on the intake and physical condition of the diet. This same committee also recognizes that the metabolic excretion of P is controversial, given that it is almost entirely of salivary origin, and it is thus difficult to obtain accurate estimates to distinguish P of strictly endogenous origin from that of dietary origin. Based on this discussion, it is suggested that the fecal metabolic losses of P should be estimated in animal fed insufficient levels of phosphorus because this maximizes the absorption and the reabsorption of endogenous secretions. Based on this consideration, the CSIRO (2007) recommends the calculation of metabolic losses of P based on the work of Ternouth et al. (1996), who generated their database with animals in feedlot and on pasture system and with calcium levels below the requirements.

Moreover, metabolic losses are observed if the diet is deficient in phosphorus because the bone reserves are mobilized. Only after a minimum period of four weeks will the fecal metabolic losses be minimized (CSIRO, 2007).

In Brazil, Ezequiel (1987) obtained a daily mean value of 17.6 mg/kg BW for the phosphorus metabolic excretion in Nellore animals. Through a regression between the retained P and P intake in growing Nellore heifers, Gionbelli (2010) obtained a value for the daily endogenous loss of phosphorus of 27.1 mg/kg EBW (r^2 = 0.89). The results obtained through the joint analysis of P intake and P fecal excretion data from three recent experiments (Gionbelli, 2010; Marcondes, 2010, unpublished data; Souza, 2010, unpublished data) led to an estimate of daily fecal metabolic excretion of 25 mg/kg EBW, though with a low r^2 (0.26). Through the current database from BR-CORTE, it was not possible to estimate the metabolic losses of phosphorus via urine. As a result, the adoption of the value obtained by Ezequiel (1987) is suggested; 17.6 mg/kg BW for the daily net requirements of phosphorus for maintenance, because this value was obtained in Brazilian conditions with growing Nellore animals.

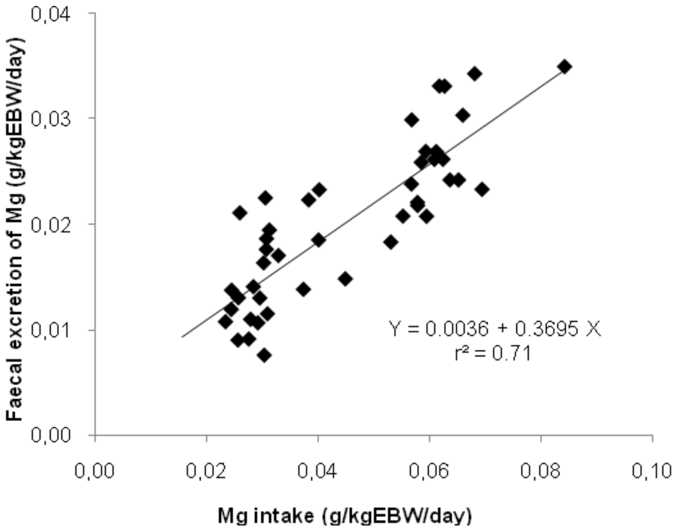
Magnesium

A large amount of the magnesium (Mg) present in the animal body is in the bones and teeth (about 70%), and it has a structural function. The magnesium present in the intracellular fluids is usually present in the mitochondria because it is used in the metabolism carried out in this organelle. In the extracellular fluids, the magnesium occurs in low concentrations in the brain-spinal fluid and blood (Underwood, 1981). Magnesium is essentially involved in the metabolism of carbohydrates and lipids as a catalyst of several types of enzymes that require this element for optimal activity (Fontenot, 1989).

According to the ARC (1980), the estimates for the endogenous fecal losses of magnesium can be obtained through three procedures: 1) extrapolation to the zero level of intake by using the relationship between the fecal loss of magnesium as a function of Mg intake from the diets regularly used; 2) measurements of fecal excretion obtained with artificial diets that are extremely deficient in Mg; or 3) the isotopic dilution method. All of these methods have their respective errors, and the ARC (1980) recommends 3.0 mg/kg of BW/day for adult cattle and sheep. This value is the same as that recommended by the NRC (2000). According to the ARC (1980), the small urinary losses are negligible. On the other hand, the NRC (2000) believes that the Mg excreted in the urine originates from over-absorbed Mg.

Allsop and Rock (1972) verified the relationship between the fecal magnesium excretion and the concentration of this element in the plasma, and they found a small but significant increase in the fecal excretion of Mg with its increase in the plasma, which can lead to an increase in the requirements for the maintenance of Mg through the increase in the absorption of this mineral. These same authors obtained estimates of 2.8 mg/kgBW as the daily endogenous fecal loss of Mg.

Ezequiel (1987) obtained very variable daily excretion values of metabolic magnesium in the feces, ranging from 0.4 mg/kgBW for Nellore animals to 6.0 mg/kgBW for Holstein animals. The results obtained through a joint analysis of Mg fecal excretion data as a function of intake from three recent experiments (Gionbelli, 2010; Marcondes, 2010, unpublished data; Souza, 2010, unpublished data) generated an estimate for the daily fecal excretion of Mg of 3.6 mg/kg EBW, with an r^2 of 0.71 (Figure 2). For the urinary metabolic losses, the data obtained from the studies of Gionbelli (2010) showed a daily value of 0.8 mg/kg EBW. Summing the urinary and fecal losses, we have a daily net requirement of Mg for maintenance of 4.4 mg/kg EBW. This value is larger than the one recommended by both the ARC (1980) and NRC (2000).



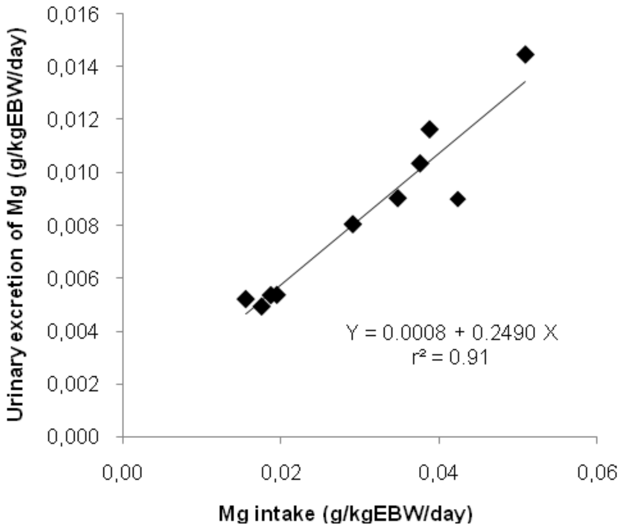


Figure 2 - Fecal and urinary excretion as a function of magnesium intake.

Based on data from Gionbelli (2010) using growing Nellore heifers, through the relationship between retained Mg as a function of Mg intake, a daily requirement of Mg for maintenance of 3.3 mg/kg EBW (Figure 3) was obtained. Using the value of the net requirement for maintenance of Mg obtained through the relationship between retained Mg as a function of the Mg intake seems more feasible than the sum of fecal and urinary metabolic losses. The former is a more direct measurement because it extrapolates to all possible losses of Mg when the intake of this element is zero. Although the value of 3.3 mg/kg EBW/day was obtained from a single experiment, the estimate seems to be adequate. Thus, the 3.3 mg/kg EBW value is suggested for the daily net requirement of Mg for the maintenance of zebu cattle.

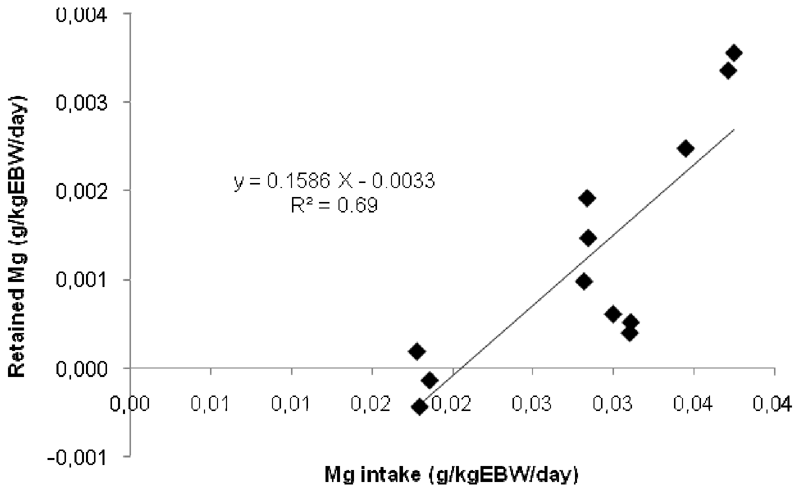


Figure 3 - Relationship between magnesium retained and magnesium intake in growing Nellore heifers.

Sodium

Sodium (Na) is the main cation present in the extracellular fluid of animals and is involved in the maintenance of osmotic pressure,regulating acid-base equilibrium and controlling water metabolism (Underwood, 1981). Sodium also plays a role in muscular contractions, the transmission of nerve impulses and the transport of glucose and amino acids.

According to the NRC (2000), ruminants have an elevated appetite for sodium, and if it is offered freely, they will intake more salt than they need. According to this same committee, sodium requirements do not exceed 0.06 to 0.08% of the diet of beef cattle in the growing stage and 0.10% of the diet of lactation cows.

Similarly to potassium, the concept of endogenous loss does not apply to sodium (ARC, 1980). However, some authors have found significant correlations between sodium excretion and intake in cattle (Lomba et al., 1969), allowing the estimation of the fecal metabolic loss of sodium through the relationship between excreted and sodium intake. Thus, the ARC (1980) considers the daily net requirements for the maintenance of sodium to be 5.8 mg/kg BW to fecal endogenous losses and 1.0 mg/kg BW to losses through the skin, not considering urinary losses. These values were adopted in the first edition of BR-CORTE (Valadares Filho et al., 2006).

The low correlation between fecal excreted sodium and sodium intake was obtained through a joint analysis of the data from three experiments in Brazil (Gionbelli, 2010; Marcondes, 2010, unpublished data; Souza, 2010, unpublished data). However, a significant relationship (r^2 = 0.73) was obtained between the Na excreted in the urine and the one intake, leading to an estimate of the daily urinary metabolic excretion of 4.6 mg/kg BW. Ezequiel (1987) found negative values for the urinary endogenous excretion of Na and 3.9 mg/kg BW for the daily fecal endogenous excretion of sodium.

A daily net requirement for maintenance of 7.0 mg/kg EBW was obtained through the data from Gionbelli (2010), using a linear regression of the retained Na as a function of the Na intake. However, the slope of the equation, which represents the coefficient of Na retention, was only 0.19, much lower than the one suggested by the ARC (1980) of 0.91, probably because the quantity of sodium in the diet was greater than the animal's needs. The value of 7.0 mg/kg EBW is very close to the suggestions of the ARC (1980) and represents all possible endogenous losses of Na, including the losses through urine, feces and skin, which, according to the ARC (1980), are larger for animals raised in tropical conditions. Thus, we recommended the utilization of this value to estimate the net requirements of Na for the maintenance of zebu cattle raised in Brazilian conditions, considering that the study of Gionbelli (2010) was conducted with growing Nellore heifers.

Potassium

Potassium (K) is the third most abundant mineral in the body and the major cation present in the intracellular fluid, found at concentrations of 100-160 mmol/L, which corresponds to roughly 25 to 30 times the concentration of K in the blood (Underwood and Suttle, 1999). The highest concentrations of potassium are found in the muscle (ARC, 1980) and through isotope ^{40}K, it is possible to estimate the corporal chemical composition of the animal (Ward, 1966). Potassium is important in acid-base balance, regulation of osmotic pressure, water balance, muscle contractions, nerve impulse transmission and certain enzymatic reactions (NRC, 2000).

According to Underwood and Suttle (1999), the main problem faced by ruminants in relation to potassium is related to its excess and not its deficiency. These authors also report that there are several metabolic mechanisms to avoid the K intake in toxic quantities, many of them related to the aldosterone hormone, which functions specifically in the kidneys to avoid excessive quantities of K.

The estimates of potassium requirements for maintenance have been made within the regular variation of dietary intake, for both fecal and urinary losses (Ezequiel, 1987). The NRC (2000) suggests that feedlot cattle need 0.6% of K in the diet for maintenance and weight gain, while animals in pasture need a maximum of 0.4%.

The ARC (1980) suggests a K requirement for maintenance based on metabolic losses through feces, urine, saliva and skin, with each one calculated in a different way, as shown in Table 1. The estimates of the ARC (1980) were adopted in the first edition of BR-CORTE (Valadares Filho et al., 2006a), and we suggest that these estimates are maintained given that data obtained at the national level for K are not very consistent, and additional research is required.

MACROMINERAL REQUIREMENTS FOR WEIGHT GAIN

Net requirement for macrominerals (NRG_Z)

The allometric model is the one most commonly used to determine the net requirements for macrominerals for weight gain (ARC, 1980), where the corporal content of the element in the animal's body is estimated through its body weight:

$$BW_Z = \beta_0 \times EBW^{\beta_1}$$

where BW_Z is the body weight content of the mineral Z (kg), and EBW is the empty body weight (kg).

When the previous equation is derived to one kg of empty body weight gain (EBG), the net requirements of minerals can be estimated to 1.0 kg of EBG, as shown below:

$$NRG_Z = \beta_0 \times \beta_1 \times EBW^{\beta_1 - 1}$$

where NRG_Z is the net requirement to one kg of empty body weight gain (kg) of a given macroelement Z, and EBW is the empty body weight (kg).

Previously, due to difficulties in estimating non-linear models, both components of the equation were log-transformed before the calculation (BW_Z and EBW), and the NRG_Z was estimated as follows (ARC, 1980):

$$\text{Log}(BW_Z) = \beta_0 + \beta_1 \times \log(EBW)$$
$$NRG_Z = 10^{\beta_0} \times \beta_1 \times EBW^{\beta_1 - 1}$$

In the Brazilian literature, there are several studies that used this methodology to estimate the NRG_Z of purebred and crossbred zebu cattle (Chizzotti et al., 2009, Marcondes, et al., 2009, Paulino, et al., 2004). The first version of the Brazilian Tables of Nutritional Requirements of Zebus, BR-CORTE, (Valadares Filho et al., 2006) also used this system to present the first proposal of macromineral requirements for zebu cattle (Table 2).

Table 2 - Net requirements for weight gain (g/day) of calcium (Ca), phosphorus (P), magnesium (Mg), potassium (K) and sodium (Na) of zebu cattle with different weights and rates of weight gain, obtained using Brazilian data

Weight gain (kg/day)	Body weight (kg)				
	250	300	350	400	450
		Calcium			
0.50	6.63	6.37	6.15	5.97	5.82
0.75	9.95	9.55	9.23	8.96	8.73
1.00	13.27	12.74	12.31	11.95	11.64
1.25	16.58	15.92	15.39	14.94	14.55
1.50	19.90	19.11	18.46	17.92	17.46
		Phosphorus			
0.50	3.52	3.37	3.25	3.15	3.06
0.75	5.29	5.06	4.88	4.72	4.59
1.00	7.05	6.75	6.50	6.30	6.12
1.25	8.81	8.43	8.13	7.87	7.65
1.50	10.57	10.12	9.75	9.45	9.18
		Potassium			
0.50	0.97	1.04	1.10	1.16	1.21
0.75	1.45	1.56	1.65	1.73	1.81
1.00	1.94	2.08	2.20	2.31	2.42
1.25	2.42	2.60	2.75	2.89	3.02
1.50	2.91	3.11	3.30	3.47	3.63
		Sodium			
0.50	0.61	0.59	0.58	0.58	0.57
0.75	0.91	0.89	0.88	0.86	0.85
1.00	1.21	1.19	1.17	1.15	1.14
1.25	1.51	1.49	1.46	1.44	1.42
1.50	1.82	1.78	1.75	1.73	1.71
		Magnesium			
0.50	0.17	0.17	0.17	0.17	0.17
0.75	0.26	0.26	0.26	0.26	0.25
1.00	0.35	0.34	0.34	0.34	0.34
1.25	0.43	0.43	0.43	0.43	0.42
1.50	0.52	0.52	0.51	0.51	0.51

Valadares Filho et al. (2006).

The use of the models so far presented is problematic because they are limited to the requirements of one kg of EBG, given that the extrapolation of non-linear models is not recommended due to considerable distortions that may occur outside of the data range.

In addition to the described problems, other considerations can be made on the deposition of macrominerals and body growth. From the five most-studied macroelements, two are mainly concentrated in the bones, as shown in Table 3.

Table 3 - Percentage of total mineral element in Nellore-Angus cattle of different sexual classes

	Bones	Soft tissue	Organs	Hide	Blood	Others
			Calcium			
Bulls	99.23	0.38	0.19	0.16	0.02	0.02
Steers	99.27	0.33	0.22	0.14	0.02	0.02
Heifers	99.15	0.38	0.28	0.16	0.02	0.01
			Phosphorus			
Bulls	90.03	7.62	1.89	0.35	0.08	0.03
Steers	90.74	6.72	2.08	0.36	0.08	0.03
Heifers	89.75	7.61	2.19	0.33	0.09	0.02
			Sodium			
Bulls	42.18	25.39	7.84	12.64	11.43	0.52
Steers	44.48	23.51	7.92	11.86	11.65	0.58
Heifers	41.99	22.77	8.53	13.26	12.85	0.61
			Potassium			
Bulls	10.33	73.01	11.24	3.73	1.56	0.13
Steers	11.07	71.49	11.47	4.18	1.63	0.15
Heifers	8.42	74.36	11.46	3.83	1.77	0.16
			Magnesium			
Bulls	71.16	20.81	3.58	3.86	0.53	0.06
Steers	73.84	18.59	3.53	3.47	0.51	0.07
Heifers	73.26	19.19	3.68	3.06	0.76	0.05

Adapted from Chizzotti et al. (2009).

As shown in Table 3 and confirmed by other authors in studies with *Bos taurus* animals (Cheeke, 2005), about 99% of calcium and 80% of phosphorus are found in the bones, with the NRG_Z of these minerals highly related to the growth of the skeleton. Once the deposition of calcium and phosphorus in the skeleton stabilizes, it is possible that the requirements for these minerals for weight gain approach zero. According to Chizzotti et al. (2009), there is a stabilization in the increase of calcium in the EBW of bulls, steers and heifers with 416, 420 and 353 kg of EBW, respectively, and a stabilization in the increase of phosphorus with 415, 420 and 345 kg of EBW, respectively. These authors, however, still suggest the use of the allometric growth model to estimate the requirements of these minerals until the suggested weights.

The AFRC (1991) also supports the theory described above because it adopts equations based on the growth of bones to estimate calcium and phosphorus requirements, emphasizing that the accumulation of minerals is highly affected by the maturity in the animals. This suggests that the use of equivalent empty body weight (EQEBW) seems to be more indicative than the EBW in estimating the net requirements for calcium and phosphorus for cattle. The AFRC (1991) uses the weight to maturity and the body weight to estimate the net requirements of calcium and phosphorus.

In relation to sodium, potassium and magnesium, there are greater proportions of these minerals in other body components. Therefore, the NRG_Z of these minerals are related to the corporal gains as a whole, with a continuous addition as the animal grows. Thus, the development of models to estimate the nutritional needs of macroelements in several EBG is necessary. Descriptive statistics of the database used to update the net requirements of macrominerals for gain are presented in Table 4.

Table 4 - Descriptive statistics of the database of Nellore and crossbred cattle used to update the net requirements for macrominerals for weight gain from the BR-CORTE

Item	Ca	P	Mg	Na	K
			Mineral retained in the EBW (kg)		
Mean	7.17	2.56	0.11	0.47	0.68
Maximum	5.26	3.49	0.17	0.76	1.20
Minimum	2.58	1.06	0.05	0.14	0.18
			Mineral retained in the EBW (% of EBW)		
Mean	1.76	0.81	0.04	0.15	0.19
Maximum	2.71	1.24	0.06	0.21	0.29
Minimum	1.15	0.55	0.02	0.10	0.11
			EBW (kg)		
Mean	310.3	324.2	309.8	318.1	338.3
Maximum	492.3	476.1	477.2	492.3	506.1
Minimum	107.7	127.3	107.7	107.7	107.7
			Number of observations		
Total	251	234	272	259	133
Nellore	162	164	207	188	108
Crossbred	89	70	65	71	25
Bulls	93	99	98	119	43
Steers	89	115	86	93	71
Heifers	69	20	88	47	19
Feedlot	219	193	251	239	109
Pasture	32	41	21	20	24
Number of studies	10	8	9	8	6

Calcium and phosphorus

Calcium represents the mineral with highest concentration in the body, with most of it found in the bones and teeth (99%) and with concentrations of 100 mg/kg in the muscle, zero in the fat and 100 g/kg in the bones (Silva, 1995). Calcium is involved with blood coagulation, maintenance of muscle contraction and relaxation including that of heart muscle (Underwood,1981), transmission of nerve impulses, hormone secretion and the activation and stabilization of enzymes (Lalman, 2005). The calcium found in the bones and teeth can be used as a reserve of this mineral, being removed when it is necessary for other functions.

Usually, there is a higher concentration of calcium in green grasses, which results in a lower deficiency of this mineral when animals are kept in pasture conditions (Valadares Filho et al., 2010).

Another factor that can affect the absorption and deposition of calcium by the animal is the phosphorus concentration in the diet. A ratio of 2:1 for calcium to phosphorus is recommended for animals that are growing. However, if this ratio is inverted, the animal will have to take calcium from the bones to utilize the excess of phosphorus in the diet. This problem can become more severe given that the animal cannot metabolize the calcium present in the bones without also metabolizing phosphorus in the process, thus making the described problem even worse (Lalman, 2005).

Another problem that can be found is tetany, caused by the deficiency of calcium or magnesium. Previously, it was thought that this problem was caused only by magnesium deficiency. However, recent studies demonstrate that calcium deficiency can also cause the disease (Lalman, 2005).

As was previously stated, phosphorus is usually discussed jointly with calcium, given that both are mainly located in the bones and teeth.Phosphorus deficiency can be aggravated in tropical conditions given that tropical grasses have a low concentration (Valadares Filho et al., 2010) due to the deficiency of phosphorus and high acidity of Brazilian soils.

To calculate the net requirements of calcium and phosphorus for weight gain (NRG_{Ca} and NRG_{P}, respectively), the relationship between calcium and phosphorus in the body and the equivalent empty body weight (EQEBW, described in chapter 5) were used. Because the existing database for macrominerals is small, it was not possible to test the effects of sexual condition or breed on the model; therefore, it was decided to use the EQEBW as a way of controlling the possible effects of breed on NRG_{Ca} and NRG_{P}.

Two models were tested to describe the relationship between calcium and phosphorus in body weight and the EQEBW. The first was an allometric model, usually used to estimate the requirements for macrominerals for weight gain in Brazil and similar to the one adopted by the AFRC (1991). The other was a quadratic model, as already used by the ARC (1965). The goal in using the quadratic model was to search for a better biological fit of the model for which few data of the mineral deposition are available (lower than 200 and over 400 kg de EQEBW, Figures 4 and 5).

The two tested models presented similar fits (r^2 = 0.67 for calcium and 0.71 for phosphorus), and through their derivatives, which represent the increase in the rate of the mineral quantity in the animal body, equations to estimate the net requirements of calcium for weight gain were constructed as follows:

Allometric	Z_{EBW} (kg)	$\hat{Y} = \beta_0 \times EQEBW^{\beta_1}$
	NRG_Z (kg/day)	$\hat{Y} = EBG \times (\beta_0 \times \beta_1 \times EQEBW^{\beta_1 - 1})$
Quadratic	Z_{EBW} (kg)	$\hat{Y} = \beta_0 + \beta_1 \times EQEBW + \beta_2 \times EQEBW^2$
	NRG_Z (kg/day)	$\hat{Y} = EBG \times (\beta_1 + 2 \times \beta_2 \times EQEBW)$

where Z_{EBW} represents the content of mineral Z in the empty body weight, NRG_Z is the net requirement of the mineral Z for weight gain, EQEBW is the equivalent empty body weight (kg) and EBG is the empty body gain (kg/day).

The equations obtained to predict the retained calcium and phosphorus and the equations to estimate the NRG_{Ca} and NRG_{P} are presented in Table 5.

Table 5 - Equations to predict the calcium and phosphorus in body weight and the net requirements for calcium and phosphorus as a function of the equivalent empty body weight (EQEBW) generated through the allometric or quadratic models

Mineral	Model	Equation
Calcium	Allometric	Ca_{EBW} (kg) = 0.17 × $EQEBW^{0,60}$ NRG_{Ca} (g) = EBG × (102 × $EQEBW^{-0,40}$)
	Quadratic	Ca_{EBW} (Kg) = 0.2 + 0.024 × EQEBW – 0.0000225 × $EQEBW^2$ NRG_{Ca} (g) = EBG × (24 – 0.045 × EQEBW)
Phosphorus	Allometric	P_{EBW} (kg) = 0.042 × $EQEBW^{0.71}$ NRG_P (g) = EBG × (29.8 × $EQEBW^{-0.29}$)
	Quadratic	P_{EBW} (Kg) = – 0.3 + 0.013 × EQEBW – 0.0000119 × $EQEBW^2$ NRG_P (g) = EBG × (13 – 0.0238 × EQEBW)

Along with the fit of the quadratic model, the point at which there is no more significant addition of the mineral in the EQEBW was determined by the linear plateau method, as suggested by Chizzotti et al. (2009). The plateaus found for calcium and phosphorus are presented in Table 6, and these represent the point at which the net requirements of these minerals for weight gain are considered equal to zero.

Table 6 - Plateau of calcium and phosphorus deposition in Nellore and crossbred cattle

Mineral	Genetic group	Plateau
Calcium	Nellore	412.8 kg of EQEBW or 469.5 kg of BW[1]
	Crossbred	412.8 kg of EQEBW or 496.8 kg of BW[1]
Phosphorus	Nellore	411.5 kg of EQEBW or 468.0 kg of BW[1]
	Crossbred	411.5 kg of EQEBW or 495.3 kg of BW[1]

[1]Considering BW = SBW / 0.96.

The utilization of a common plateau for Ca and P of 412 kg of EQEBW (469 kg of BW for Nellore and 496 kg for Crossbred) is suggested. Chizzotti et al. (2009) observed an asymptote for Ca and P deposition of 416 kg of EBW for Nellore and Crossbred animals.

Figures 4 and 5 present the fits of the allometric and quadratic models to the relationship between the quantities of Ca and P in the body weight and the EQEBW.

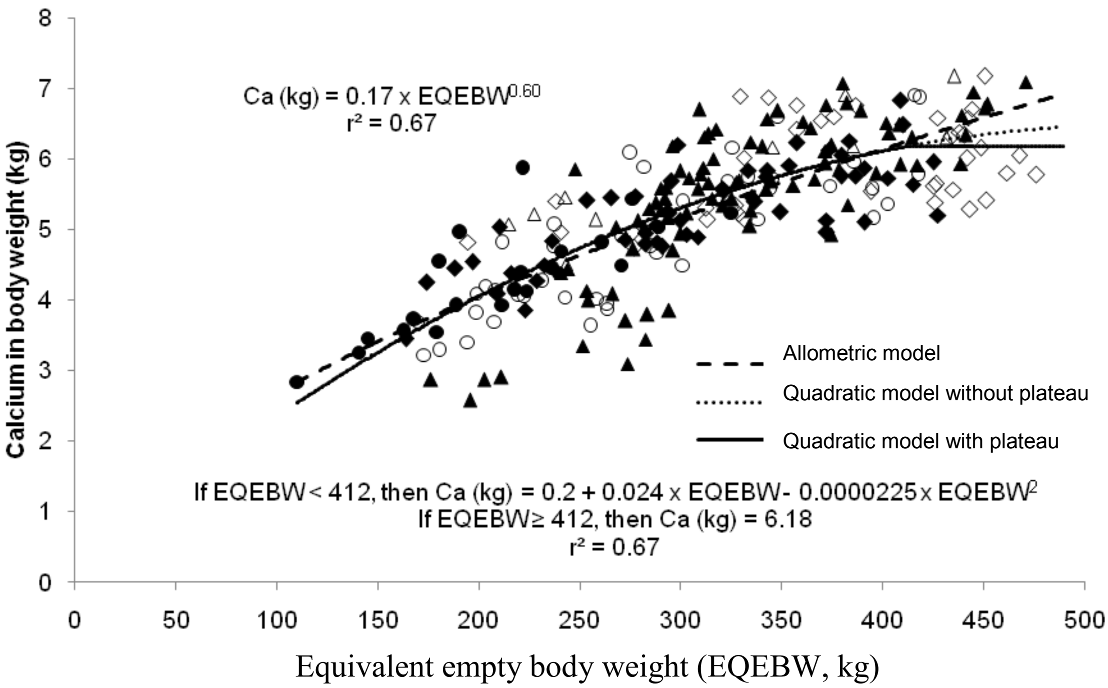


Figure 4 - Relationship between the content of calcium in the body weight and the equivalent empty body weight (EQEBW). The symbols represent data from bulls (▲, Δ), steers (◊, ♦) and heifers (○, ●). Solid points represent Nellore animals, and empty points represent Crossbred animals, *Bos indicus* with *Bos taurus*.

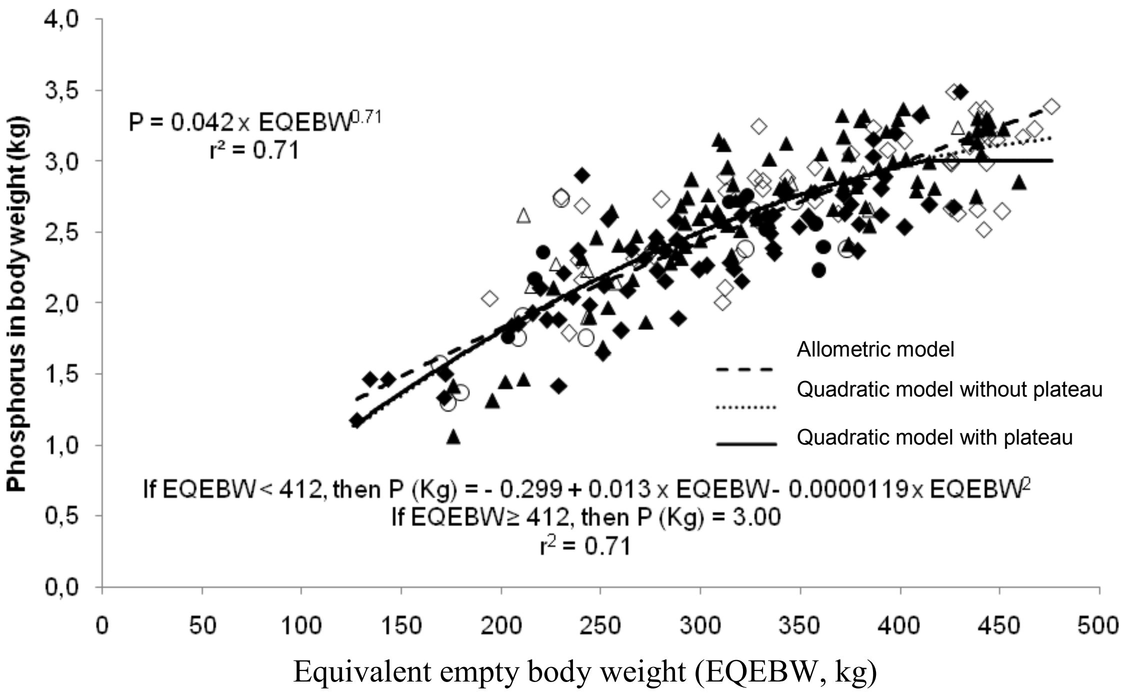


Figure 5 - Relationship between the content of phosphorus in the body weight and the equivalent empty body weight (EQEBW). The symbols represent data from bulls (▲, Δ), steers (◊, ♦) and heifers (○, ●). Solid points represent Nellore animals, and empty points represent Crossbred animals, *Bos Indicus* with *Bos taurus*.

The existing large variation of the data makes it difficult to evaluate the impact of sexual classes and genetic makeup on the net requirements for calcium and phosphorus gain. The breed impact seems to be well controlled, given that the EQEBW adjusts animals of different maturities to the same maturity; however, there is no control for the impacts of sexual condition in the model. Fontes (1995) performed an evaluation of data presented in the Brazilian literature and did not find a breed effect when the animals were divided into zebu, mixed breed with milk breeds and mixed breed with beef cattle breeds. Nevertheless, this author verified differences between bulls and steers for the net requirements, observing that the steers have a smaller net requirement for maintenance for calcium and phosphorus. On the other hand, Marcondes et al. (2009) did not find evidence of a sexual-class effect on the net requirements for calcium and phosphorus gains. The diverse systems of nutritional requirements (AFRC, 1991, CSIRO, 2007, NRC, 2000) also do not take into consideration the impacts of sexual condition or breed on calcium and phosphorus requirements.

The NRC (2000) estimated the requirements for calcium (Ca) and phosphorus (P) for weight gain as a function of the daily gain of protein, with a value for Ca of 7.1 g per 100 g of additional protein and for phosphorus of 3.9 g per 100 g of protein gain. Chizzotti et al. (2009) show that the Ca and P deposition does not follow the same pattern of protein deposition. These authors also observed an plateau of Ca and P deposition at 416 kg of EBW in Nellore×Angus animals, whereas, for the deposition of protein, this plateau was at 450 kg, leading to an overestimation of the requirements of these minerals for EBW greater than 416 kg if calculated as a function of the protein deposition. Through the current database from BR-CORTE, a small correlation was observed between the calcium or phosphorus retention and the retention of protein in the animals body (r = 0.20 and 0.26, respectively).

In recent years, mineral requirements have received considerable attention, given that the precise prediction of mineral needs can reduce the excretion of minerals and environmental pollution. Recent publications have revealed the need for reduction of the environmental impact caused by excessive excretions of phosphorus by cattle (Vasconcelos et al., 2007; O'Rourke et al., 2007; Modin-Edman et al., 2007; Pfeffer and Hristov, 2005).

Some nutritionists suggest that the requirements for phosphorus recommended by the NRC (1996) underestimate the cattle's needs (Galyean and Gleghorn, 2001) and suggest an excess supplementation of this mineral. Block et al. (2004) suggested, however, that the phosphorus requirements recommended by the NRC (2000) could be overestimated. Erickson et al. (1999, 2002) did not observe differences in the performance of steers fed 71% or 162%, nor in calves fed 76% or 190%, of the phosphorus requirements suggested by the NRC (1996), which are the same as the NRC (2000). Call et al. (1978) fed beef heifers during a period of two years with 66% or 174% of the phosphorus requirements recommended by the NRC and did not observe differences in the weight gain of these animals.

The equations generated in this edition of the BR-CORTE (Table 5) estimated net requirements for Ca and P for weight gain lower than those published in the first edition of the BR-CORTE, as can be seen in Figures 6 and 7, in which present a comparison with the equations for estimating the net requirements of Ca and P for gain recommended by other systems of nutritional requirements is also made.

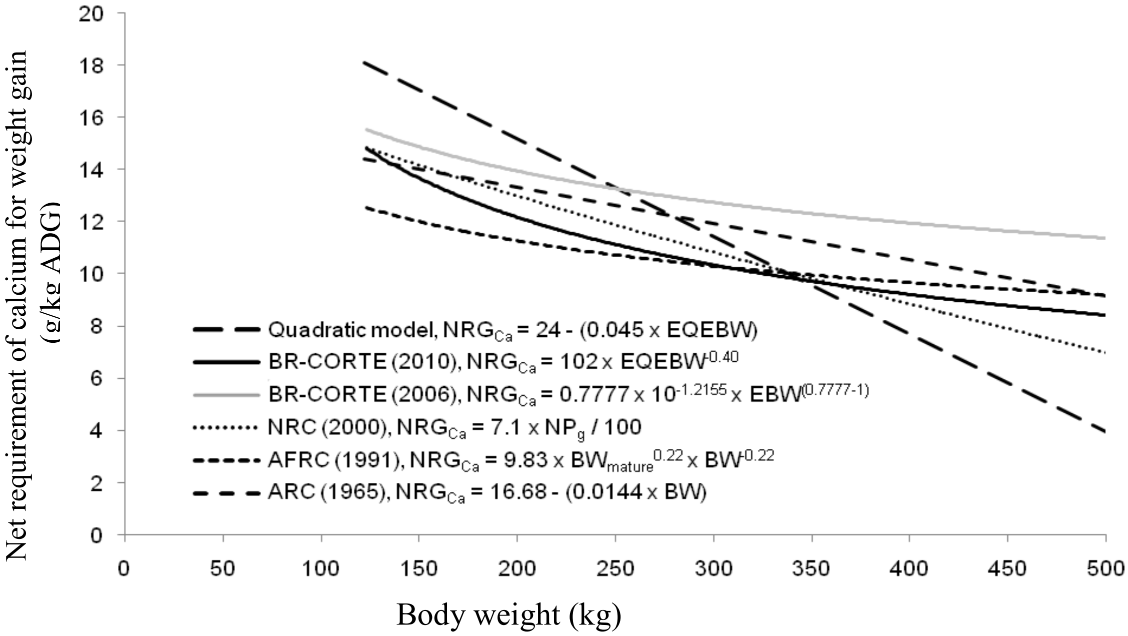


Figure 6 - Relationship between the net requirement for calcium for weight gain and the body weight, calculated with equations developed by different systems of nutritional requirements.

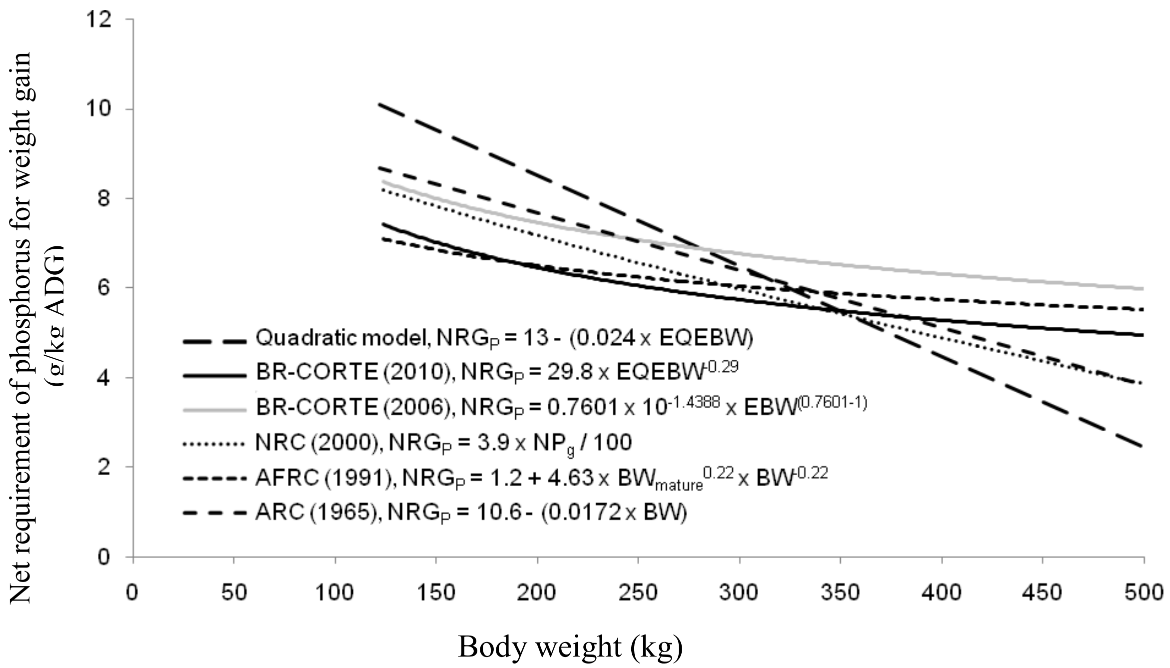


Figure 7 - Relationship between the net requirement of phosphorus for weight gain and the body weight, calculated with equations developed by different systems of nutritional requirements.

When the allometric models are used, a reduction of the estimate of the net requirements for Ca and P for weight gain was observed compared to the previous edition of BR-CORTE (Valadares Filho et al., 2006) (Figures 6 and 7). On the other hand, the quadratic models generate a larger estimate for smaller weights and a significant reduction in the net requirements for Ca and P for weight gain as a function of increases in body weight, creating smaller estimates than the ones recommended by other systems of nutritional requirements for body weights over 400 kg.

The smallest estimates of the net requirements for Ca and P for weights over 400 kg estimated through quadratic models appear to match the suggestions that the phosphorus requirements from the NRC (2000) might be overestimated (CAST, 2002; Block et al., 2004). Nevertheless, these models still need to be evaluated through experiments carried out in Brazilian conditions with different levels of Ca and P in the diet. The use of an plateau, through which the net requirements for Ca and P for weight gain are equal to zero, also need to be validated, and this is presented here as a suggestion. Chizzotti et al. (2009) already suggested the utilization of an plateau for Ca and P deposition; however, because the data from these authors are included in the database that generated the equations of this BR-CORTE edition, their study cannot be considered as a validation for this suggestion.

Thus, the allometric models used to predict the total net requirements for Ca and P (Table 5) currently used in Brazil are still recommended in this edition. The net requirements for Ca and P for weight gain of Nellore and Crossbred cattle were calculated through these equations, as presented in Tables 7 and 8.

Table 7 - Net requirements of calcium for weight gain of Purebred and Crossbred Nellore cattle with different body weights and rates of weight gain

Weight gain (kg/day)	Body weight (kg)					
	200	250	300	350	400	450
	Nellore (feedlot)					
0.50	6.04	5.52	5.13	4.83	4.57	4.36
0.75	9.06	8.28	7.70	7.24	6.86	6.55
1.00	12.07	11.04	10.27	9.65	9.15	8.73
1.25	15.09	13.80	12.83	12.07	11.44	10.91
1.50	18.11	16.56	15.40	14.48	13.72	13.09
	Crossbred (feedlot)					
0.50	6.37	5.83	5.42	5.09	4.83	4.61
0.75	9.56	8.74	8.13	7.64	7.24	6.91
1.00	12.75	11.66	10.84	10.19	9.66	9.21
1.25	15.93	14.57	13.55	12.74	12.07	11.52
1.50	19.12	17.49	16.26	15.28	14.49	13.82
	Nellore (pasture)					
0.50	6.25	5.72	5.31	5.00	4.74	4.52
0.75	9.37	8.57	7.97	7.49	7.10	6.78
1.00	12.50	11.43	10.63	9.99	9.47	9.04
1.25	15.62	14.29	13.28	12.49	11.84	11.30
1.50	18.75	17.15	15.94	14.99	14.21	13.56

Note: The differences in the requirements of Nellore and Crossbred cattle under feedlot or in pasture were originated from the differences in the EBW and EQEBW.

Table 8 - Net requirements of phosphorus for weight gain of Purebred and Crossbred Nellore cattle with different body weights and rates of weight gain

Weight gain (kg/day)	Body weight (kg)					
	200	250	300	350	400	450
	Nellore (feedlot)					
0.50	3.11	2.92	2.77	2.65	2.55	2.46
0.75	4.67	4.38	4.15	3.97	3.82	3.69
1.00	6.23	5.84	5.54	5.30	5.09	4.92
1.25	7.79	7.30	6.92	6.62	6.37	6.15
1.50	9.34	8.76	8.31	7.94	7.64	7.39
	Crossbred (feedlot)					
0.50	3.27	3.06	2.90	2.78	2.67	2.58
0.75	4.90	4.59	4.36	4.17	4.01	3.87
1.00	6.53	6.13	5.81	5.56	5.34	5.17
1.25	8.17	7.66	7.26	6.94	6.68	6.46
1.50	9.80	9.19	8.71	8.33	8.02	7.75
	Nellore (pasture)					
0.50	3.21	3.01	2.86	2.73	2.63	2.54
0.75	4.82	4.52	4.28	4.10	3.94	3.81
1.00	6.42	6.02	5.71	5.46	5.25	5.08
1.25	8.03	7.53	7.14	6.83	6.57	6.35
1.50	9.63	9.03	8.57	8.19	7.88	7.62

Note: The differences in the requirements of Nellore and Crossbred cattle under feedlot or in pasture originated from the differences in the EBW and in the EQEBW between these animals.

Magnesium

Magnesium also has a strong relationship with calcium and phosphorus given that about 73% of its total weight is found in animal bones, as presented in Table 3. However, Mg is also essential in energy metabolism, the transmission of the genetic code, membrane transport and the transmission of nerve impulses. Mg is also involved in the function of more than 300 enzymes (Lalman, 2005).

One of the possible problems related to magnesium deficiency is its relation to dietary potassium, given that excess of potassium, which is usually found in high concentration in grasses (Valadares Filho et al., 2010), can result in reduced magnesium absorption by animals, with consequent tetany and death. Because of the high concentration of potassium in grasses, magnesium supplementation is necessary when the animals are kept in pasture.

Despite the similarity and relationship between calcium, magnesium and phosphorus, the tendency of magnesium deposition to stabilize in the empty body was not observed. On the contrary, a linear tendency of magnesium deposition from 100 to 450 kg of EBW (Figure 8) was observed, and this pattern was also observed by the ARC (1965). However, the ARC (1965) found the following relationship between the corporal Mg and body weight: 0.385 × BW – 3.2.

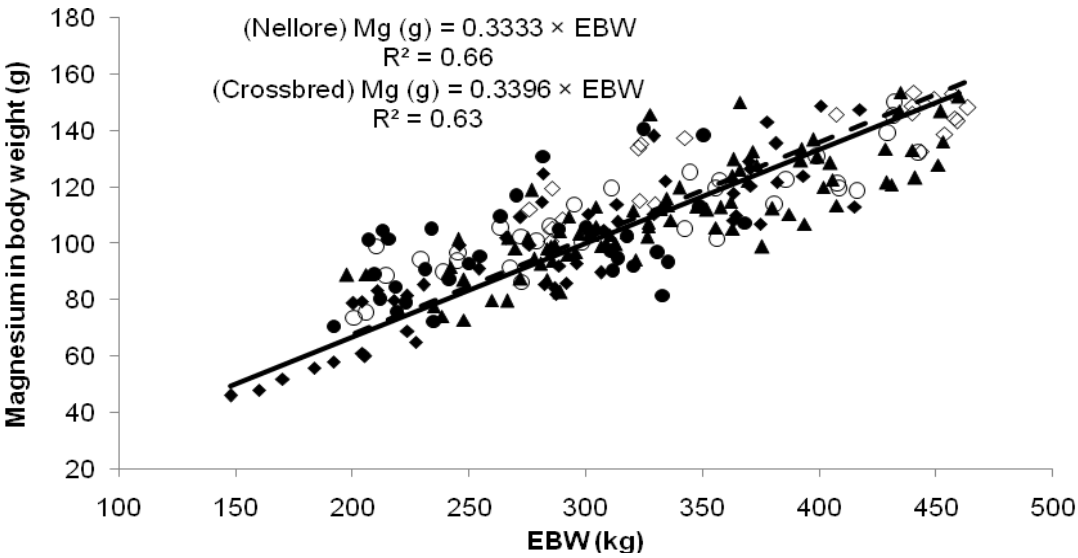


Figure 8 - Relationship between the magnesium content in the body weight and the EBW. The symbols represent data from bulls (▲, Δ), steers (◊, ♦) and heifers (○, ●). Solid points and lines represent Nellore animals, and empty points and dashed line represent Crossbred animals, *Bos Indicus* with *Bos taurus*.

The estimates of the net requirements for magnesium for gain as a function of EBG were calculated using the updated database from BR-CORTE. A group genetic impact was observed, but an effect of sexual class was not detected (Table 9). Nowadays, diverse systems (AFRC, 1993, CSIRO, 2007, NRC, 2000) use the recommendation from the ARC (1980) to estimate the net requirements for magnesium gain based on the extrapolation of the allometric equation of the magnesium content in relation to the animals' body weight. The AFRC (1993) adopted a value of 450 mg of magnesium per kg of EBG, and this value was close to the one obtained in the current study.

Thus, the use of the following equations is suggested to estimate the net requirements of magnesium for weight gain:

Nellore	Net requirements of Mg for weight gain (mg/day) = 333.3 × EBG
Crossbred	Net requirements of Mg for weight gain (mg/day) = 339.6 × EBG

where EBG is the empty body weight gain (kg/day).

Table 9 - Net requirements of magnesium and sodium for weight gain for purebred and crossbred Nellore cattle of different sexual classes and rates of weight gain

Weight gain (kg/day)	Mg (mg/day)		Na (g/day)			
			Nellore		Crossbred	
	Nellore	Crossbred	Bulls and steers	Heifers	Bulls and steers	Heifers
0.50	155.82	158.76	0.71	0.63	0.67	0.58
0.75	233.73	238.14	1.07	0.95	1.01	0.88
1.00	311.64	317.53	1.43	1.26	1.35	1.17
1.25	389.54	396.91	1.78	1.58	1.68	1.46
1.50	467.45	476.29	2.14	1.89	2.02	1.75

Sodium and Potassium

Sodium and potassium are usually discussed jointly due to their close relationship in animal metabolism. The salt (NaCl) is routinely used as a source of sodium in the ruminant diet. During several years, one of the main causes of the innate craving of ruminants for salt intake was justified as a reflex of nutritional requirements and physiological state (Cheeke, 2005). However, according to Morris (1980), ruminants have a large appetite for salt and consume much higher quantities than needed. He also affirms that the best indicator of the nutritional status of sodium is its ratio to potassium, which must be around 20:1. The diets of herbivores tend to have a high concentration of potassium due to its elevated concentration in grasses, which can result in low Na:K ratios (which can reach a maximum limit of 10:1); this factor can play a role in the greater appetite of herbivores for sodium.

Ruminants have great ability to conserve sodium because it is stored in the rumen and can be absorbed into the blood in case of sodium and potassium deficiency; in this case, the stored sodium replaces the sodium in the saliva (Cheeke, 2005).

Sodium deficiency can lead to the reduction of osmotic pressure, which can result in a corporal dehydration. The reduced growth and efficiency in the use of energy and protein are among the symptoms (McDonald et al., 2002); there is also appetite suppression (Underwood and Suttle, 1999).

The sodium requirements for weight gain (NRG_{Na}), as for magnesium, were estimated through a linear regression of the corporal content of sodium in relation to the EBW (Figure 9). Because of the greater simplicity of this model, it was possible to identify the impacts of genetic group and sexual class on the NRG_{Na}, although differences were not observed between bulls and steers (Table 9). Thus, the following equations are recommended to estimate the NRG_{Na}:

Nellore	Bulls and steers	NRG_{Na} (g/day) = 1.5243 × EBG
	Heifers	NRG_{Na} (g/day) = 1.3503 × EBG
Crossbred	Bulls and steers	NRG_{Na}(g/day) = 1.4388 × EBG
	Heifers	NRG_{Na} (g/day) = 1.2511 × EBG

where EBG is the empty body weight gain (kg/day).

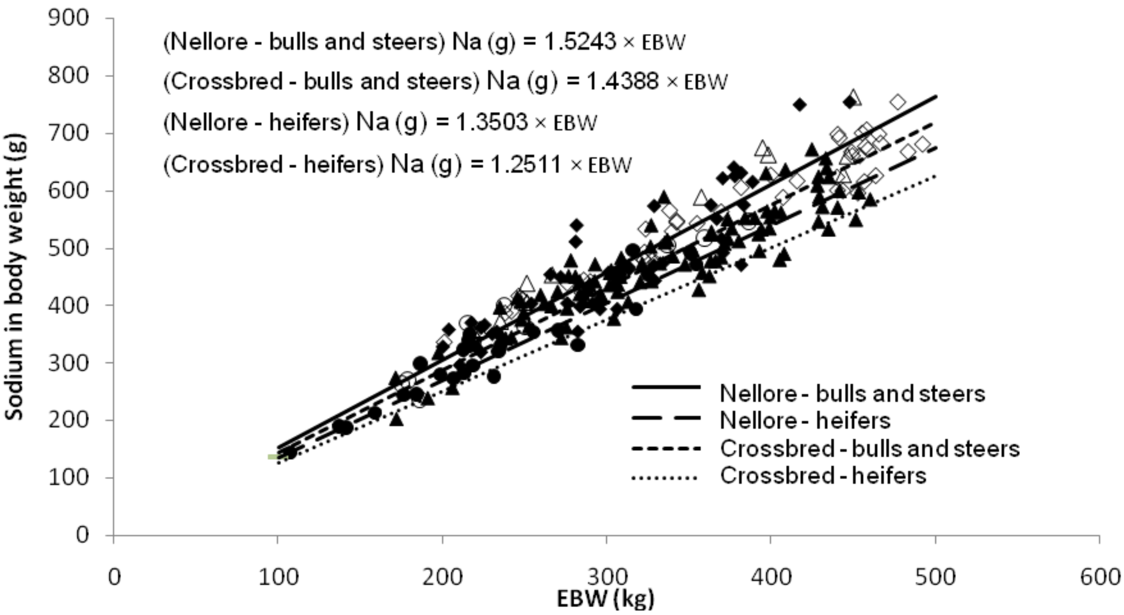


Figure 9 - Relationship between the sodium content in the body weight and the empty body weight (EBW). The symbols represent data from bulls (▲, Δ), steers (◊, ♦) and heifers (○, ●). Solid points represent Nellore animals, and empty points and dashed lines represent Crossbred animals, *Bos indicus* with *Bos taurus*.

The data presented in Table 9 for NRG_{Na} are lower than the requirements suggested by the NRC (2000) and CSIRO (2007), with values from 0.6 to 0.8 g of Na/kg DM intake,subtracting the requirements for maintenance. These values were from Morris (1980), who suggested that younger animals would have a greater need for sodium (0.8 g/kg MS) compared to older animals (0.6 g/kg MS). However, the values in Table 9 are larger to the ones presented in the last version of BR-CORTE (Table 2), with the exception of the NRG_{Na} for crossbred heifers.

Potassium is the third most abundant mineral in the body. It is important for the regulation of acid-base balance, the regulation of osmotic pressure, nerve impulses and enzymatic reactions (Lalman, 2005). Usually, potassium does not represent one of the largest deficiencies in ruminants, given that their diet includes a relatively high concentration of potassium (Table 3). However, potassium is extremely labile in plants, and its concentration in the plant can be drastically reduced during maturation and dry periods or due to inadequate handling during haymaking, decreasing by 76% (Lalman, 2005).

Cheeke (2005) suggested that potassium might play an important role in the reduction of stress effects. However, according to the author, the present results are still contradictory (Hutcheson and Cole, 1986), and more studies are necessary to completely understand the role played by potassium in stress.

The net requirements of potassium for weight gain were estimated in the same way as for sodium and magnesium, given that of the majority of this mineral is located in the muscle (Table 3). However, with increasing EQEBW, there was a tendency for increases in the potassium concentration in the body. Thus, the allometric and quadratic models were adjusted to determine the nutritional requirements of potassium for purebred and crossbred Nellore cattle (Figure 10). The two models had similar fits; however, as with calcium and phosphorus, the utilization of a quadratic model for potassium still needs to be validated. Thus, the net requirements of K for gain were estimated by the allometric model in this edition of the BR-CORTE.

Due to the low quantity of data and lack of repetitions for genetic groups and sexual classes in all classifications, it was not possible to test these effects in the model of the potassium content in the EBW. Nevertheless, because the EQEBW was used in the cited model, the NRG_K could be separately estimated for purebred and crossbred Nellore cattle (Table 10).

The equations to determine the potassium composition in the EQEBW and the NRG_K are as follows:

$$K\ (g) = 0.21 \times EQEBW^{1.38}$$
$$NRG_K\ (g/day) = EBG \times (0.29 \times EQEBW^{0.38})$$

where EQEBW is the equivalent empty body weight (kg), and EBG is the empty body weight gain (kg/day).

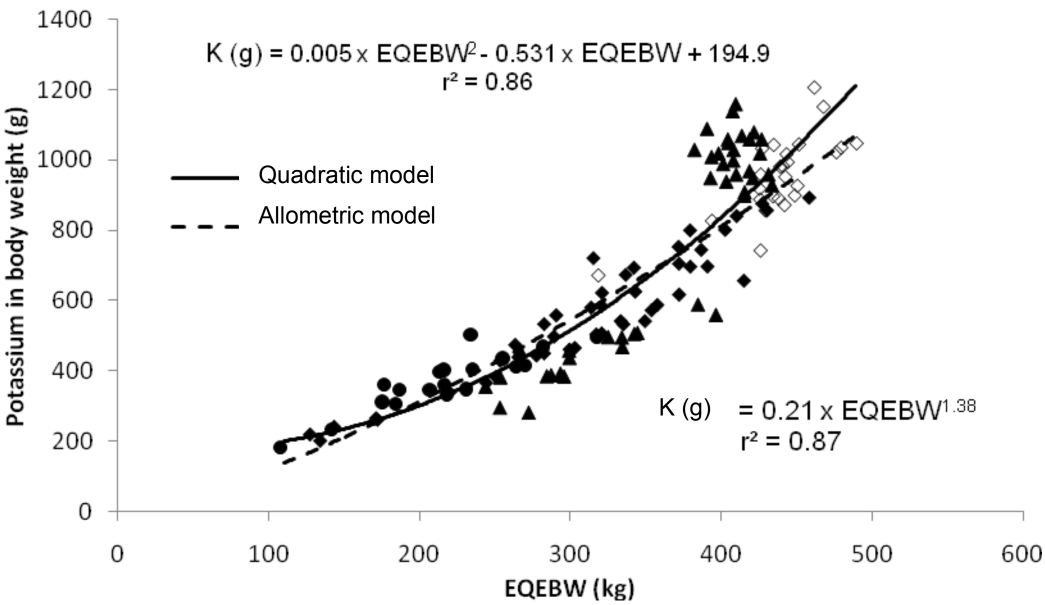


Figure 10 - Relationship between the potassium content in the body weight and the equivalent empty body weight (EQEBW). The symbols represent data from bulls (▲, Δ), steers (◊, ♦) and heifers (○, ●). Points represent Nellore cattle, and empty points and dashed lines represent Crossbred animals, *Bos indicus* with *Bos taurus*.

It is clear that there was an increase in the NRG_K compared to the last version of BR-CORTE; however, the used data still generate net requirements for gain about 70% smaller than the ones suggested by the NRC (2000), which are calculated as 0.6% of the dry matter intake. The ARC (1980) suggests a requirement of 2 g of potassium per kg of EBG, and Fontes (1995) suggested values between 1.75 and 1.82 g per kg of EBG for purebred and crossbred zebu cattle. However these authors suggest that there is an increase in the potassium concentration as the animal grows, but this fact was not observed with the present dataset (Figure 10).

Table 10 - Net requirements of potassium for weight gain for purebred and crossbred Nellore cattle with different rates of weight gain

Weight gain (kg/day)	Body weight (kg)				
	250	300	350	400	450
			Nellore (feedlot)		
0.50	1.05	1.13	1.20	1.26	1.32
0.75	1.58	1.69	1.80	1.89	1.98
1.00	2.11	2.26	2.39	2.52	2.63
1.25	2.63	2.82	2.99	3.15	3.29
1.50	3.16	3.39	3.59	3.78	3.95
			Crossbred (feedlot)		
0.50	1.06	1.14	1.21	1.27	1.33
0.75	1.60	1.71	1.81	1.91	2.00
1.00	2.13	2.28	2.42	2.54	2.66
1.25	2.66	2.85	3.02	3.18	3.33
1.50	3.19	3.42	3.63	3.82	3.99
			Nellore (pasture)		
0.50	1.06	1.14	1.20	1.27	1.33
0.75	1.59	1.70	1.81	1.90	1.99
1.00	2.12	2.27	2.41	2.53	2.65
1.25	2.65	2.84	3.01	3.17	3.31
1.50	3.18	3.41	3.61	3.80	3.98

MACROMINERAL ABSORPTION

To convert the net mineral requirements for maintenance and weight gain into dietary requirements, the true absorption coefficient for a mineral is used. This coefficient is also commonly called the bioavailability or true availability of the mineral. To calculate this efficiency factor, a regression equation is normally generated for the amount of absorbed mineral, calculated as the difference between what is ingested and what is excreted in the feces, and the mineral intake. The slope of the equation is taken as the true absorption coefficient of the mineral.

A series of studies on these coefficients can be found in the literature, and great variation can be seen in their results (Table 11). A large part of these variations arise from factors that are not yet known; others come from known factors, such as the fact that an excess amount of Ca and P in the diet leads to lower absorption, as the absorption of these minerals is regulated at the intestinal level (Field, 1983a). The following summarizes the considerations for the absorption coefficients of the major macrominerals studied (Ca, P, Mg, Na and K).

Table 11 - Absorption coefficient values for Ca, P, Mg, Na and K observed in the literature

Source	Absorption Coefficient[1]				
	Ca	P	Mg	Na	K
ARC (1980)	0.68	0.60	**0.17**	**0.91**	**1.00**
AFRC (1991)	-	0.58 a 0.70	-	-	-
NRC (1989) – Dairy cattle	0.38	0.58	-	-	0.90
NRC (1996) – Beef cattle	**0.50**	**0.68**	-	-	-
NRC (2001) – Dairy cattle (forage)	0.30	0.80	-	0.81	-
NRC (2001) – Dairy cattle (concentrate)	0.60	-	-	1.00	-
Marshal and Long (1971) – Zebu cattle, high concentrate	0.80	-	-	-	-
Blaney et al. (1982) – Tropical grasses	0.50	-	-	-	-
Field (1983b) – Maintenance	-	0.58	-	-	-
Ezequiel (1987)[2] – Nellore cattle	0.62	0.72	0.52	0.66	1.00
Coelho da Silva et al. (1991)[2]	-	-	0.16	0.76	-
Rosado (1991)[2] – Dairy cows	-	-	0.44	0.57	0.44
Valadares Filho et al. (1991)[2]	-	-	0.57	-	-
Boin (1993)[2] – Calves up to 1 year of age	-	0.78	-	-	-
Boin (1993)[2] – Cattle over 1 year of age	-	0.58	-	-	-
Coelho da Silva (1995)[2] – Dairy calves	0.72	0.63	0.38	0.54	-
Araujo et al. (2001)[2] – Calves	0.59	0.56	0.45	0.94	0.78
Souza (unpublished data)[2]	0.85	-	0.60	0.61	0.56
Marcondes (unpublished data)[2]	0.91	0.79	0.83	0.81	0.80
Gionbelli (2010)[2,3]	0.55	0.56	0.16	0.19	0.04

[1]Values in bold were used in the previous edition of BR-CORTE;[2]Experiments done in Brazil;[3]Retention coefficient.

Calcium

Calcium is mainly absorbed in the duodenum and jejunum by active transport and passive diffusion (McDowell, 1992), and its absorption is regulated by the hormone 1,25-dihydroxycholecalciferol (Vitamin D_3) (DeLuca, 1979). It has been suggested that the absorption of Ca is regulated to maintain the concentration of extracellular calcium (CSIRO, 2007).

Diets with an excess of fat can decrease the absorption of calcium because of the formation of soaps (Oltjen, 1975). The amount of calcium absorbed is affected because of several factors, such as the chemical formula and source of the mineral, the inter-relationships with other nutrients, and the demands of the animal (NRC, 1996).

Age is an important factor in the absorption coefficient for calcium in cattle. The values vary from 98% in suckling calves to negative values in old animals (Hansard et al., 1954). Calcium absorption is controlled by a homeostatic mechanism (Boin, 1993) and is therefore dependent on the relationship between the amount of dietary Ca and the demands of the animal. Excess dietary Ca in adult animals, as a result of their lower Ca requirement, may lead to lower absorption coefficients for older animals. Consequently, the use of an absorption coefficient based on the age of the animal does not appear to be necessary.

The NRC (2001) considers the use of a single Ca absorption coefficient to be inappropriate and suggests, based on the measurements obtained from several studies, that Ca obtained by forage has an absorption of 0.30 and that Ca from concentrates has an absorption of 0.60, although studies on the Ca absorption coefficient for concentrates fed to ruminants are scarce.

The retention coefficient of Ca calculated by Gionbelli (2010) and shown in Figure 1 was 0.55. The adoption of the value 0.55 as the retention coefficient of Ca is suggested in this edition of BR-CORTE, as it was obtained from growing Nellore heifers and because the results obtained in Brazil indicate a higher absorption of Ca than the values recommended by the NRC (1989, 1996 and 2001), as shown in Table 11. Furthermore, measurement of the retention coefficient seems more appropriate than measurement of the absorption coefficient, as the retention coefficient directly represents the relationship between the mineral consumed and the mineral retained and considers other possible sources of mineral loss (e.g., through the skin).

Phosphorus

The absorption of phosphorus occurs under homeostatic control at the intestinal level, and is mediated by the hormone 1,25-dihydroxycholecalciferol (Vitamin D_3). As a result, for diets poor in P, the absorption is maximized, as is the reabsorption of endogenous secretions. These factors complicate the measurements of phosphorus absorption (CSIRO, 2007). Another complicating factor is the fact that the endogenous secretion of phosphorus is primarily of salivary origin, and is therefore influenced by the amount of feed intake and the physical form of the diet (AFRC, 1991).

The absorption of P varies with the age of the animal; a reduction in absorption efficiency is observed in animals over 14 months of age (ARC, 1980; NRC, 1989). The absorption of P can be impaired by Mg, Al and Fe, which form phosphate precipitates in the gastrointestinal tract. In addition, an excess of Mo and Cu interfere directly with the absorption of P (McDowell, 1992). An excess of P intake does not increase the absorption of this mineral (AFRC, 1991).

The AFRC (1991) refers to variations in the absorption of P from forage and concentrates, as well as its content in these feeds, reporting that the highest coefficient of P absorption is found with concentrates. Therefore, this committee associated the availability with the metabolizability (q) of the diet (q = metabolizable energy / gross energy), adopting values of 58%, for $q < 0.70$, and of 70%, for $q > 0.70$.

The results reported in the literature usually indicate a coefficient of absorption of P between 0.55 and 0.80 (Table 11). The results obtained at the national level are still inconsistent; therefore, the recommended coefficient of absorption of 0.68, suggested in the previous edition of BR-CORTE, should be retained, especially because this coefficient represents an approximately average value of the results obtained in Brazil.

Magnesium

According to the NRC (2000), the rumen is the main site of Mg absorption in ruminants. However, Mg absorption is greater in young animals that are still suckling, and it decreases with advancing age (Peeler, 1972). Some authors have reported that the increased dietary levels of K in ruminants resulted in a greater Mg flux in the proximal duodenum, consequently reducing the availability of Mg in the gastrointestinal tract (Greene et al., 1988; Khorasani and Armstrong, 1990).

Fontenot et al. (1989) stated that the use of magnesium by ruminants is affected by some dietary components, mainly through changes in absorption. An increased level of K in the diet generally leads to a decreased level of Mg in blood serum, caused by a decrease in Mg absorption. According to Greene et al. (1983), this decrease in Mg absorption occurs with the K levels are higher than 2.25% of the total diet. Fontenot et al. (1989) also suggested that high concentrations of nitrogen in the diet, organic acids and long-chain fatty acids could reduce the absorption of magnesium. According to the same authors, increased levels of P can reduce the absorption of Mg, as they compete for absorption sites. Conversely, carbohydrate supplementation tends to increase the absorption of Mg, as demonstrated by the concentration of Mg in blood plasma (Madsen et al., 1976).

The ARC (1980) reported true absorption values of Mg that varied from 0.10 to 0.37 in animals that were fed hay. According to Peeler (1972), the Mg in concentrate feeds is more available than that from forage. As shown in Table 11, the coefficients of absorption of Mg found in the literature are highly variable, especially those found in studies that were developed under Brazilian conditions. Therefore, the use of the value 0.16 is suggested for the true absorption coefficient of Mg, which was obtained as the retention coefficient of Mg in a study done with growing Nellore heifers (Figure 3). This value is close to the one adopted in the previous edition of BR-CORTE, which was 0.17.

It is necessary to develop new studies in Brazil to establish this coefficient and the factors that affect it, with quantification for the variations that occur, especially between different types of diets; this data would increase the accuracy of diet formulation.

Sodium

Sodium absorption is more active in the lower intestine, and the dietary Na can be completely absorbed if it is in free form. The absorption of this mineral element is high, so little sodium is excreted in the feces; the ARC (1980) adopts the value of 0.91 for the efficiency of Na absorption. The NRC (2001) considers the coefficient of Na absorption from forage to be 0.81, whereas it is completely absorbed when in the form of NaCl.

The data from experiments conducted in Brazil show high variability in the coefficient of Na absorption observed (Table 11). Because of this variability, and of the lack of specific studies for the efficiency of absorption of this mineral under Brazilian conditions, the adoption of the value 0.91 is suggested; this value has been recommended by the ARC (1980) and was adopted in the previous edition of BR-CORTE (Valadares Filho et al., 2006).

Potassium

The absorption of potassium in ruminants is extensive, occurring from the rumen to the small intestine (Underwood and Suttle, 1999). The potassium that is present in feed is a simple ion that is normally released into the liquid matrix of the intestinal lumen of the digestive tract, becoming readily available for absorption (Emanuele and Staples, 1990; Ledoux and Martz, 1991).

As K is excreted primarily in urine, the apparent availability (apparent absorption) is a reliable criterion to estimate the efficiency of K absorption (NRC, 2001). The ARC (1980) recommends a coefficient of K absorption of 1.00. Ezequiel (1987) established a true absorption coefficient of K over 1.00 for Nellore cattle.

The average apparent absorption of potassium in eight forage-based diets for cattle and sheep was 0.85 (Miller, 1975). The potassium from inorganic sources, such as potassium chloride, potassium carbonate, potassium sulfate, potassium acetate, bicarbonate, dibasic potassium phosphate and potassium monocitrate, is readily available for absorption; it has an absorption coefficient of 1.00 (Peeler, 1972; Miller, 1975). From these observations, the NRC (2001) recommends an average coefficient of K absorption of 0.9 for every type of feed and mineral sources.

Because of the results found in the literature, and the variability seen in animals raised under Brazilian conditions (Table 11), the adoption of a coefficient of K absorption of 1.00 is suggested, just as in the previous edition of BR-CORTE (Valadares Filho et al., 2006).

CHLORINE, SULFUR AND MICROMINERALS

Chlorine

Chlorine (Cl) is the main anion present in the extracellular fluid of an animal. This mineral is necessary for the formation of hydrochloric acid in the gastric juice and for the activation of amylase. Like sodium, it is also involved in the maintenance of osmotic pressure, water balance control and regulation of the acid-base balance (Underwood, 1981).

The chlorine requirements for maintenance in beef cattle are not well defined (Underwood and Suttle, 1999), and chlorine deficiencies do not seem likely under practical conditions (NRC, 2000). Information about the endogenous loss of chlorine is not available in the literature; however, the ARC (1980) considers an unavoidable urinary loss, as is the case with sodium.

The ARC (1980) has estimated that the daily dietary requirements for beef cattle with a weight gain of 1.0 kg/day were 0.7 g per kg of dry matter intake. As there have been no studies on the determination of chlorine requirements conducted in Brazil, the use of the value proposed by the ARC (1980) is suggested.

Sulfur

The functions of sulfur (S) in the body of an animal are as diverse as the proteins of which they are a part, as they are linked to the sulfur amino acids. This mineral is present in all protein tissue in the organism, representing approximately 0.5 to 2.0% of these tissues. The most widely known sulfur amino acids are methionine, cystine, cysteine and taurine. Ruminants have unique uses of sulfur, as they possess a microbial population that is capable of incorporating inorganic sources of sulfur into microbial proteins (Underwood and Suttle, 1999).

Sulfur is also used to protect animals from the potential poisoning that can result from an excess of copper, cadmium, zinc and other metals (Underwood and Suttle, 1999).

The majority of the bacteria in the rumen are capable of synthesizing sulfur amino acids, so sulfur supplemented into the diet can be inorganic. Sulfur is found linked to proteins, leading to a higher content of sulfur in protein concentrates; however, most diets used in practice offer an adequate supply of sulfur (NRC, 2000).

The sulfur requirements for beef cattle are not well defined. The recommended concentration in beef cattle diets is 0.15% of the dry matter intake (NRC, 2000), but there is a greater need of this mineral for animals grazing in sorghum pastures. The ARC (1980) has made recommendations for sulfur based on the needs of the ruminal microbiota. If sources of non-protein nitrogen are added to the diet, a supplementation with sulfur is also needed, in the ratio of 0.067% of the supplemented N.

The adoption of a dietary requirement of 0.15% of sulfur in the dry matter basis is suggested for Brazilian conditions, where no studies were found on the determination of sulfur nutrient requirements.

Microminerals

Although they are present in the animal in very small quantities, the microminerals have important functions, acting mainly as the catalysts of enzyme and hormonal systems. Underwood and Suttle (1999) have presented a broad discussion about the dietary characteristics, nutritional requirements, metabolism, deficiencies and toxicity of each one of the essential microminerals for cattle.

As there have been no studies on the determination of micromineral requirements for cattle conducted in Brazil, it is suggested, just as in the previous edition of BR-CORTE (Valadares Filho et al., 2006), that the requirements of micromineral elements are estimated according to the NRC (2000):

Cobalt (mg/day) = dry matter intake (kg) x 0.1
Copper (mg/day) = dry matter intake (kg) x 10.0
Iodine (mg/day) = dry matter intake (kg) x 0.5
Iron (mg/day) = dry matter intake (kg) x 50.0
Manganese (mg/day) = dry matter intake (kg) x 20.0
Selenium (mg/day) = dry matter intake (kg) x 0.1
Zinc (mg/day) = dry matter intake (kg) x 30.0

TOXICITY

Some inorganic elements supplied in large quantities can cause great damage to cattle. To formulate rations, the maximum levels of the mineral elements in the diet are suggested to be set at 120% of the daily requirements, to ensure a balance of minerals in the diet, to not impair the absorption and use of the minerals and to avoid unnecessary losses. However, in practice, this balance is not always possible. Therefore, the toxic values of the mineral elements obtained from the literature are presented in Table 12.

Table 12 - Toxic levels of minerals for beef cattle

Mineral	Toxic Level
	Macrominerals
Calcium[1]	4.4% of DM
Magnesium[1]	0.4% of DM
Potassium[1]	3.0% of DM
Sodium[1]	6.5% of DM
Sulfur[1]	0.4% of DM
	Microminerals
Chromium[2]	50 mg/kg of DM
Manganese[2]	1.0 g/kg of DM
Iodine[2]	50 mg/kg of BW
Copper[3]	115 mg/kg of DM
Fluorine[3]	30 mg/kg of DM
Molybdenum[3]	6.0 mg/kg of DM
Selenium[3]	5.0 mg/kg of DM
Zinc[3]	0.5 g/kg of DM
Cobalt[2]	1.0 mg/kg of BW
Vanadium[2]	30 mg/kg of DM

[1]NRC (2000); [2]McDonald et al. (2002); [3]McDowell (1992).

CONSIDERATIONS FOR THE MINERAL REQUIREMENTS OF ANIMALS UNDER PASTURE OR TROPICAL CONDITIONS

Changes in the nutrient requirements of cattle that depend on the rearing system seem to be more closely related to the energy and protein requirements than to the mineral requirements; it is therefore suggested that there are no specific mineral requirements for physical work (Underwood, 1981).

Animals under pasture conditions perform greater physical work; that is, they have a greater demand for muscle activity because of the movement needed to search for feed, often in uneven terrain. It is known that Ca and P are necessary for muscular activity, and although there is intense metabolism of these minerals during this type of activity (Scott, 1988), there is no evidence of an increased demand for these minerals under these conditions. No changes were observed in the balance of Ca and P in animals performing light, medium or heavy work when compared to animals that did not perform this type of work (Harvey et al., 1943).

According to Aitken (1975), cited by the ARC (1980), animals reared under tropical conditions have a higher Na requirement for maintenance because losses through the skin are higher than they are for animals reared in temperate climate; an increase of 1.0 g/day is recommended for sodium requirements under tropical conditions for a 500 kg animal. The same author states that Na losses through the saliva are negligible, except for non-acclimated cattle raised under tropical conditions, for which the Na loss via saliva is 1.4 g/day for each 100 kg of body weight. Also according to the same author, cattle reared under tropical conditions have a higher chlorine requirement for maintenance because of losses through the skin and saliva; the chlorine requirement is suggested to be 1.6 g/day for a 500 kg animal reared under tropical conditions, exposed to a temperature of 40ºC for approximately 7 hours per day and 90% relative humidity, which are conditions possible to observe for animals under pasture conditions. For losses via saliva, the recommendation is 0.9 g/day for each 100 kg of body weight.

BRAZILIAN TABLES OF MINERAL REQUIREMENTS FOR BEEF CATTLE

A summary of the equations used to calculate the daily requirements of macrominerals for beef cattle under Brazilian conditions is presented in Table 13. Tables 14, 15, 16 and 17 show, respectively, the dietary requirements for calcium, phosphorus, magnesium, sodium and potassium for purebred and crossbred Nellore cattle of different weights and rates of weight gain.

Table 13 - Summary of equations used to calculate the daily requirements of macrominerals for purebred and crossbred Nellore cattle

Mineral	Net requirement for maintenance	Net requirement for weight gain (NRG)			Absorption Coefficient
Ca	15.4 mg/kg BW	NRG_{Ca} (g) = EBG × (102 × $EQEBW^{-0.40}$)			0.55
P	17.6 mg/kg BW	NRG_{P} (g) = EBG × (29.8 x $EQEBW^{-0.29}$)			0.68
Mg	3.3 mg/kg EBW	Nellore	NRG_{Mg} (mg) = 333.3 × EBG		0.16
		Crossbred	NRG_{Mg} (mg) = 339.6 × EBG		
Na	7.0 mg/kg EBW	Nellore	Bulls and steers	NRG_{Na} (g) = 1.5243 × EBG	0.91
			Heifers	NRG_{Na} (g) = 1.3503 × EBG	
		Crossbred	Bulls and steers	NRG_{Na} (g) = 1.4388 × EBG	
			Heifers	NRG_{Na} (g) = 1.2511 × EBG	
K	Fecal = 2.6 g/kg DMI Urinary = 37.5 mg/kg BW Salivary = 0.7 g/100 kg BW Skin[1] (g) = 0.7 + 0.002 x BW	NRG_{K} (g) = EBG × (0.29 x $EQEBW^{0.38}$)			1.00
Additional equations					
SBW^2 = 0.96 × BW					
EBW = 0.895 × SBW (Feedlot)					
EBW = 0.863 × SBW (Pasture)					
EQEBW = [(EBW / 430) × 440] (Nellore)					
EQEBW = [(EBW / 455) × 440] (Crossbreds)					
EBG = 0.936 × ADG (Nellore - feedlot)					
EBG = 0.966 × ADG (Crossbred - feedlot)					
EBG = 0.955 × ADG (Pasture)					

[1]Estimated based on data presented by the ARC (1980).[2]SBW = Shrunk body weight.

Therefore, taking as an example a 400 kg Nellore bull, with weight gain 1 kg/day in feedlot, the dietary requirements for Ca, P, Mg, Na and K can be calculated as follows:

Calcium:

- Maintenance = 15.4 × BW = 15.4 × 400 = 6160 mg or 6.16 g/day
- SBW = 0.96 × BW = 400 × 0.96 = 384 kg
- EBW = 0.895 × SBW = 0.895 × 384 = 343.7 kg
- EQEBW = ((EBW / 430) × 440) = ((343.7 / 430) × 440) = 351.7 kg
- EBG = 0.936 × ADG = 0.936 × 1 = 0.936 kg/day
- Weight gain = EBG × (102 × $EQEBW^{-0.40}$) = 0.936 × (102 × $351.7^{-0.40}$) = 9.15 g/day
- Total net requirement = maintenance + weight gain = 6.16 + 9.15 = 15.31 g/day
- Total dietary requirement = total net requirement / absorption = 15.31 / 0.55 = **27.84 g/day**

Phosphorus:

- Maintenance = 17.6 × BW = 17.6 × 400 = 7040 mg or 7.04 g/day
- Weight gain = EBG × (29.8 × $EQEBW^{-0.29}$) = 0.936 × (29.8 × $351.7^{-0.29}$) = 5.09 g/day
- Total net requirement = maintenance + weight gain = 7.04 + 5.09 = 12.13 g/day
- Total dietary requirement = total net requirement / absorption = 12.13 / 0.68 = **17.84 g/day**

Magnesium:

- Maintenance = 3.3 × EBW = 3.3 × 343.7 = 1134 mg or 1.134 g/day
- Weight gain = 333.3 × EBG = 333.3 × 0.936 = 312 mg or 0.312 g/day
- Total net requirement = maintenance + weight gain = 1.134 + 0.312 = 1.446 g/day
- Total dietary requirement = Total net requirement / absorption = 1.446 / 0.16 = **9.04 g/day**

Sodium:

- Maintenance = 7.0 × EBW = 7.0 × 343.7 = 2406 mg or 2.41 g/day
- Weight gain = 1.5243 × EBG = 1.5243 × 0.936 = 1.43 g/day
- Total net requirement = maintenance + weight gain = 2.41 + 1.43 = 3.84 g/day
- Total dietary requirement = Total net requirement / absorption = 3.84 / 0.91 = **4.22 g/day**

Potassium:

- Maintenance = Fecal = 2.6 g × DMI (kg) = 2.6 × 8.20 = 21.32 g/day
- Urinary = 37.5 mg × BW = 37.5 × 400 = 15000 mg or 15 g/day
- Salivary =(0.7 g / 100) × BW = (0.7 / 100) × 400 = 2.8 g/day
- Skin = 0.7 + 0.002 × BW = 0.7 + 0.002 × 400 = 1.5 g/day
- Maintenance total = 21.32 + 15 + 2.8 + 1.5 = 40.62 g/day
- Weight gain = EBG × (0.29 x $EQEBW^{0.38}$) = 0.936 × (0.29 x $351.7^{0.38}$) = 2.52 g/day
- Total net requirement = maintenance + weight gain = 40.62 + 2.52 = 43.14 g/day
- Total dietary requirement = Total net requirement / absorption = 43.14 / 1.00 = **43.14 g/day**

Where DMI is dry matter intake obtained from BR-CORTE (2006)

Table 14 - Dietary requirements, in g/day, of calcium (Ca), phosphorus (P), magnesium (Mg), sodium (Na) and potassium (K), for maintenance of Nellore and crossbred cattle of different weights and rates of weight gain

Weight gain (kg/day)	Body weight (kg)					
	200	250	300	350	400	450
			Calcium			
Any	5.60	7.00	8.40	9.80	11.20	12.60
			Phosphorus			
Any	5.18	6.47	7.76	9.06	10.35	11.65
			Magnesium			
Any	3.54	4.43	5.32	6.20	7.09	7.97
			Sodium			
Any	1.32	1.65	1.98	2.31	2.64	2.97
			Potassium (Nellore)			
0.50	20.01	24.48	28.85	33.13	37.34	41.50
0.75	21.92	26.39	30.76	35.04	39.26	43.41
1.00	23.29	27.76	32.13	36.41	40.62	44.78
1.25	24.11	28.58	32.95	37.23	41.44	45.60
1.50	24.38	28.85	33.22	37.50	41.72	45.87
			Potassium (Crossbred)			
0.50	20.00	24.49	28.86	33.16	37.39	41.55
0.75	21.80	26.29	30.67	34.96	39.19	43.35
1.00	23.16	27.64	32.02	36.32	40.55	44.71
1.25	24.08	28.56	32.94	37.24	41.46	45.63
1.50	24.55	29.04	33.42	37.71	41.94	46.11

Table 15 - Total dietary requirements (maintenance + weight gain) of calcium (g/day) for purebred and crossbred Nellore cattle with different body weights and rates of weight gain

ADG	Body weight (kg)					
(kg/day)	200	250	300	350	400	450
			Nellore (feedlot)			
0.50	16.58	17.04	17.73	18.57	19.52	20.54
0.75	22.06	22.06	22.40	22.96	23.68	24.50
1.00	27.55	27.08	27.07	27.35	27.84	28.47
1.25	33.04	32.10	31.73	31.74	32.00	32.44
1.50	38.53	37.12	36.40	36.12	36.15	36.41
			Crossbred (feedlot)			
0.50	17.19	17.60	18.25	19.06	19.98	20.98
0.75	22.98	22.90	23.18	23.69	24.37	25.17
1.00	28.77	28.19	28.10	28.33	28.76	29.35
1.25	34.57	33.49	33.03	32.96	33.15	33.54
1.50	40.36	38.79	37.96	37.59	37.54	37.73
			Nellore (pasture)			
0.50	16.96	17.39	18.06	18.88	19.81	20.82
0.75	22.64	22.59	22.89	23.43	24.12	24.92
1.00	28.33	27.79	27.72	27.97	28.42	29.03
1.25	34.01	32.98	32.55	32.51	32.73	33.14
1.50	39.69	38.18	37.39	37.05	37.03	37.25

Table 16 - Total dietary requirements (maintenance + weight gain) of phosphorus (g/day) for purebred and crossbred Nellore cattle with different body weights and rates of weight gain

ADG	Body weight (kg)					
(kg/day)	200	250	300	350	400	450
			Nellore (feedlot)			
0.50	9.76	10.76	11.84	12.95	14.10	15.27
0.75	12.05	12.91	13.87	14.90	15.97	17.08
1.00	14.34	15.06	15.91	16.85	17.84	18.89
1.25	16.63	17.20	17.94	18.79	19.72	20.70
1.50	18.92	19.35	19.98	20.74	21.59	22.51
			Crossbred (feedlot)			
0.50	9.98	10.97	12.04	13.14	14.28	15.45
0.75	12.38	13.23	14.17	15.19	16.25	17.34
1.00	14.79	15.48	16.31	17.23	18.21	19.24
1.25	17.19	17.73	18.44	19.27	20.18	21.14
1.50	19.59	19.98	20.58	21.31	22.14	23.04
			Nellore (pasture)			
0.50	9.90	10.90	11.96	13.07	14.22	15.38
0.75	12.26	13.11	14.06	15.08	16.15	17.25
1.00	14.62	15.32	16.16	17.09	18.08	19.11
1.25	16.98	17.54	18.26	19.10	20.01	20.98
1.50	19.34	19.75	20.36	21.10	21.94	22.85

Table 17 - Total dietary requirements (maintenance + weight gain) of magnesium (g/day) for purebred and crossbred Nellore cattle with different body weights and rates of weight gain

ADG (kg/day)	Body weight (kg)					
	200	250	300	350	400	450
			Nellore (feedlot)			
0.50	4.52	5.41	6.29	7.18	8.06	8.95
0.75	5.01	5.89	6.78	7.66	8.55	9.44
1.00	5.49	6.38	7.27	8.15	9.04	9.92
1.25	5.98	6.87	7.75	8.64	9.53	10.41
1.50	6.47	7.35	8.24	9.13	10.01	10.90
			Crossbred (feedlot)			
0.50	4.57	5.46	6.34	7.23	8.11	9.00
0.75	5.08	5.97	6.85	7.74	8.63	9.51
1.00	5.59	6.48	7.37	8.25	9.14	10.02
1.25	6.11	6.99	7.88	8.77	9.65	10.54
1.50	6.62	7.51	8.39	9.28	10.16	11.05
			Nellore (pasture)			
0.50	4.41	5.27	6.12	6.98	7.83	8.68
0.75	4.91	5.76	6.62	7.47	8.33	9.18
1.00	5.41	6.26	7.12	7.97	8.82	9.68
1.25	5.90	6.76	7.61	8.47	9.32	10.18
1.50	6.40	7.26	8.11	8.96	9.82	10.67

Table 18 - Total dietary requirements (maintenance + weight gain) of sodium (g/day) for purebred and crossbred Nellore cattle with different body weights and rates of weight gain

ADG (kg/day)	Body weight (kg)					
	200	250	300	350	400	450
			Nellore bulls and steers (feedlot)			
0.50	2.11	2.44	2.77	3.10	3.43	3.76
0.75	2.50	2.83	3.16	3.49	3.82	4.15
1.00	2.89	3.22	3.55	3.88	4.22	4.54
1.25	3.28	3.61	3.94	4.27	4.60	4.93
1.50	3.67	4.00	4.33	4.67	5.00	5.33
			Nellore heifers (feedlot)			
0.50	2.02	2.35	2.68	3.01	3.34	3.67
0.75	2.36	2.69	3.02	3.35	3.69	4.02
1.00	2.71	3.04	3.37	3.70	4.03	4.36
1.25	3.06	3.39	3.72	4.05	4.38	4.71
1.50	3.41	3.74	4.07	4.40	4.73	5.06
			Crossbred bulls and steers (feedlot)			
0.50	2.09	2.42	2.75	3.08	3.41	3.74
0.75	2.47	2.80	3.13	3.46	3.79	4.12
1.00	2.85	3.18	3.51	3.84	4.17	4.50
1.25	3.23	3.56	3.89	4.22	4.55	4.88
1.50	3.61	3.94	4.27	4.60	4.93	5.27
			Crossbred heifers (feedlot)			
0.50	1.97	2.30	2.63	2.96	3.29	3.62
0.75	2.29	2.62	2.95	3.28	3.61	3.94
1.00	2.61	2.94	3.27	3.60	3.93	4.26
1.25	2.93	3.26	3.59	3.92	4.25	4.58
1.50	3.25	3.58	3.91	4.24	4.57	4.90
			Nellore (pasture)			
0.50	2.07	2.39	2.71	3.03	3.35	3.67
0.75	2.47	2.79	3.11	3.43	3.75	4.07
1.00	2.87	3.19	3.51	3.83	4.15	4.47
1.25	3.27	3.59	3.91	4.23	4.55	4.87
1.50	3.67	3.99	4.31	4.63	4.95	5.27

Table 19 - Total dietary requirements (maintenance + weight gain) of potassium (g/day) for purebred and crossbred Nellore cattle with different body weights and rates of weight gain

ADG	Body weight (kg)					
(kg/day)	200	250	300	350	400	450
			Nellore (feedlot)			
0.50	20.98	25.53	29.98	34.33	38.60	42.82
0.75	23.37	27.97	32.45	36.84	41.15	45.39
1.00	25.22	29.87	34.38	38.80	43.14	47.41
1.25	26.53	31.21	35.77	40.22	44.59	48.89
1.50	27.28	32.01	36.61	41.09	45.49	49.82
			Crossbred (feedlot)			
0.50	20.98	25.55	30.01	34.37	38.66	42.88
0.75	23.27	27.88	32.38	36.77	41.09	45.35
1.00	25.11	29.77	34.31	38.74	43.09	47.37
1.25	26.52	31.22	35.79	40.26	44.64	48.96
1.50	27.49	32.23	36.84	41.34	45.76	50.10
			Nellore (pasture)			
0.50	20.98	25.54	29.98	34.33	38.61	42.82
0.75	23.38	27.98	32.46	36.85	41.16	45.40
1.00	25.24	29.88	34.40	38.82	43.16	47.43
1.25	26.54	31.23	35.79	40.24	44.61	48.91
1.50	27.30	32.03	36.63	41.12	45.52	49.85

REFERENCES

AFRC - Agricultural and Food Research Council. A reappraisal of the calcium and phosphorus requirements of sheep and cattle (Report 6). **Nutrition Abstracts and Reviews**, v.61, n.9, p.573-612, 1991.

AFRC. **Energy and Protein Requirements of Ruminants**. Wallingford, UK:Agricultural and Food Research Council. CAB International, 1993. 159p.

ALLSOP, T.F.; ROOK, J.A. Faecal magnesium output and plasma Mg concentration in sheep. **Proceedings of Nutrition Society**, v.31, n.2, p.65A-66A, 1972.

ARAÚJO, G.G.L.; COELHO DA SILVA, J.F.; VALADARES FILHO, S.C., et al. Consumo e absorção aparente de macroelementos minerais, em bezerros alimentados com dietas contendo diferentes níveis de volumoso. **Revista Brasileira de Zootecnia**, v.30, n.6, p.1824-1828, 2001.

ARC - Agricultural Research Council. **The Nutrient Requirements of Ruminant Livestock**. London: Agricultural Research Council. The Gresham Press, 1980. 351p.

ARC - Agricultural Research Council. **The Nutrient Requirements of Farm Livestock**. London, UK: Agricultural Research Council, 1965. 264p.

BLANEY, J.; GARTNER, J.W.; HEAD, T.A. The effects of oxalate in tropical grasses on calcium, phosphorus and magnesium availability to cattle. **Journal of Agricultural Science**, v.99, n.3, p.533-539, 1982.

BLOCK, H.C.; ERICKSON, G.E.; KLOPFENSTEIN, T.J. Review: re-evaluation of phosphorus requirements and phosphorus retention of feedlot cattle. **Professional Animal Scientist**, v.20, n.4, p.319-329, 2004.

BOIN, C. Exigências de minerais pelas categorias do rebanho bovino e funções desses nutrientes. In: PEIXOTO, A.M.(Ed). **Nutrição de bovinos: conceitos básicos e aplicados**. Piracicaba: FEALQ, 1993. p.407-450.

BRAITHWAITE, G.D. Endogenous faecal loss of calcium by ruminants. **Journal of Agricultural Science**, v.99, n.2, p.355-358, 1982.

CALL, J.W.; BUTCHER, J.E.; BLAKE, J.T., et al. Phosphorus influence on growth and reproduction of beef cattle. **Journal of Animal Science**, v.47, n.1, p.216-225, 1978.

CAST - Council for Agricultural Science and Technology. **Animal diet modification to decrease the potential for nitrogen and phosphorus pollution**. Council for Agricultural Science and Technology, 2002. p.16.

CHEEKE, P. R. **Applied animal nutrition: feeds and feeding.** 3.ed. Upper Saddle River, NJ: Pearson Education Inc., 2005. 604p.

CHIZZOTTI, M.L.; VALADARES FILHO, S.C.; TEDESCHI, L.O., et al. Net requirements of calcium, magnesium, sodium, phosphorus, and potassium for growth of Nellore×Red Angus bulls, steers, and heifers. **Livestock Sience**, v.124, n.1, p.242-247, 2009.

COELHO DA SILVA, J.F. Inorganic macronutrient requirements in cattle: The ARC/AFRC system and the Brazilian experience. In: Proceedings of International Symposium on the Nutritional Requirements of Ruminants, 1995, Viçosa, Brazil. **Anais.** Viçosa, Brazil: JARD, 1995. p.311-345.

COELHO DA SILVA, J.F. Exigências de macroelementos inorgânicos para bovinos: o sistema ARC/AFRC e a experiência no Brasil. In: SIMPÓSIO INTERNACIONAL SOBRE EXIGÊNCIAS NUTRICIONAIS DE RUMINANTES, 1995, Viçosa, MG. **Anais**... Viçosa, MG: Universidade Federal de Viçosa, 1995. p.467-504.

COELHO DA SILVA, J.F.; LEÃO, M.I. **Fundamentos da Nutrição dos Ruminantes**. Livroceres, 1979. 380p.

COELHO DA SILVA, J.F.; VALADARES FILHO, S.C.; LEÃO, M.I., et al. Efeito da monensina sódica e da uréia sobre o consumo, parâmetros ruminais, digestibilidade aparente e balanço nutricional em bovinos. **Revista da Sociedade Brasileira de Zootecnia**, v.20, n.5, p.454-470, 1991.

CSIRO - Commonwealth Scientific and Industrial Research Organization. **Nutrient Requirements of Domesticated Ruminants**. Collingwood, VIC: Commonwealth Scientific and Industrial Research Organization, 2007. 270p.

DeLUCA, H.F. The vitamin D system in the regulation of calcium and phosphorus metabolism. **Nutrition Reviews**, v.37, n.6, p.161-193, 1979.

EMANUELE, S.M.; STAPLES, C.R. Ruminal release of minerals from six forage species. **Journal of Animal Science**, v.68, n.7, p.2052-2060, 1990.

ERICKSON, G.E.; KLOPFENSTEIN, T.J.; MILTON, C.T., et al. Effect of dietary phosphorus on finishing steer performance, bone status, and carcass maturity. **Journal of Animal Science**, v.77, n.10, p.2832-2836, 1999.

ERICKSON, G.E.; KLOPFENSTEIN, T.J.; MILTON, C.T., et al. Phosphorus requirement of finishing feedlot calves. **Journal of Animal Science**, v.80, n.6, p.1690-1695, 2002.

EZEQUIEL, J.M.B., **Exigências de proteína e minerais de bovídeos: frações endógenas**. 1987. 131p. Tese (Doutorado em Zootecnia) - Universidade Federal de Viçosa, Viçosa, MG, 1987.

FIELD, A.C. A review of requirements of dairy and beef cattle for major elements. **Livestock Production Science**, v.10, n.4, p.327-338, 1983a.

FIELD, A.C. Maintenance requirements of phosphorus and absorbability of dietary phosphorus in sheep. **Journal of Agricultural Science**, v.100, n.1, p.231-233, 1983b.

FONTENOT, J.P.; ALLEN, V.G.; BUNCE, G.E., et al. Factors influencing magnesium absorption and metabolism in ruminants. **Journal of Animal Science**, v.67, p.3445-3455, 1989.

FONTES, C.A.A. Body composition, net requirements of protein, energy and minerals for weight gain and productive performance of Zebu and crossbred European-Zebu cattle. Experimental results.In:Proceedings of International Symposium on the Nutritional Requirements of Ruminants, 1995, Viçosa, MG, Brazil. **Anais.** Viçosa, MG, Brazil:JARD, 1995. p.265-299.

GALYEAN, M.L.; GLEGHORN, J.F. **Summary of the 2000 Texas Tech University consulting nutritionist survey**. (Disponível em: http://www.depts.ttu.edu/afs/burnett_center/progress_reports/bc12.pdf. Acesso em 30/04/2010): Texas Tech University, 2001. p.1-9.

GIONBELLI, M.P., **Desempenho produtivo e exigências nutricionais de fêmeas Nelore em crescimento**. 2010. 106p. Dissertação (Mestrado em Zootecnia) - Universidade Federal de Viçosa, Viçosa, MG, 2010.

GREENE, L.W.; MAY, B.J.; SCHELLING, G.T., et al. Site and extent of apparent magnesium and calcium absorption in steers fed monensin. **Journal of Animal Science**, v.66, n.11, p.2987-2991, 1988.

GREENE, L.W.; WEBB, K.E., JR.; FONTENOT, J.P. Effect of potassium level on site of absorption of magnesium and other macroelements in sheep. **Journal of Animal Science**, v.56, n.5, p.1214-1221, 1983.

HANSARD, S.L.; COMAR, C.L.; PLUMLEE, M.P. The effects of age upon calcium utilization and maintenance requirements in the bovine. **Journal of Animal Science**, v.13, n.1, p.25-26, 1954.

HANSARD, S.L.; CROWDER, H.M.; LYKE, W.A. The Biological Availability of Calcium in Feeds for Cattle. **Journal of Animal Science**, v.16, n.2, p.437-443, 1957.

HANSARD, S.L.; PLUMLEE, M.P. Effects of Dietary Calcium and Phosphorus Levels upon the Physiological Behavior of Calcium and Phosphorus in the Rat. **Journal of Nutrition**, v.54, n.1, p.17-31, 1954.

HARVEY, A.L.; THOMAS, B.H.; CULBERTSON, C.C., et al. Effect of work on the calcium and phosphorus retention of percheron geldings. **Journal of Animal Science**, v.2, n.1, p.103-111, 1943.

HUTCHESON, D.P.; COLE, N.A. Management of transit-stress syndrome in cattle: nutritional and environmental effects. **Journal of Animal Science**, v.62, n.2, p.555-560, 1986.

KHORASANI, G.R.; ARMSTRONG, D.G. Effect of sodium and potassium level on the absorption of magnesium and other macrominerals in sheep. **Livestock Production Science**, v.24, n.3, p.223-235, 1990.

LALMAN, D. L. Vitamin and mineral nutrition of grazing cattle. In: DOYE, D.; LALMAN, D.L. (Ed). **Beef cattle manual**. 5.ed. Stillwater, OK: Oklahoma State University, 2005. p.109-121.

LEDOUX, D.R.; MARTZ, F.A. Ruminal solubilization of selected macrominerals from forages and diets. **Journal of Dairy Science**, v.74, n.5, p.1654-1661, 1991.

LOMBA, F.; PAQUAY, R.; BIENFET, A., et al. Statistical research on the fate of dietary mineral elements in dry and lactating cows III. Phosphorus. **Journal of Agricultural Science**, v.73, n.2, p.215-222, 1969.

MADSEN, F.C.; LENTZ, D.E.; MILLER, J.K., et al. Dietary carbohydrate effects upon magnesium metabolism in sheep. **Journal of Animal Science**, v.42, n.5, p.1316-1322, 1976.

MARCONDES, M.I.; VALADARES FILHO, S.C.; PAULINO, P.V.R., et al. Exigências nutricionais de proteína, energia e macrominerais de bovinos Nelore de três classes sexuais. **Revista Brasileira de Zootecnia**, v.38, n.8, p.1587-1596, 2009.

MARSHALL, B.; LONG, M.I.E. Calcium intake and excretion of zebu cattle used for digestibility trials. **East African Agricultural and Foresty Journal**, v.37, n.1, p.46-48, 1971.

McDONALD, P.M.; EDWARDS, R.A.; GREENHALGH, J.F.D., et al. **Animal Nutrition**. Harlow, UK: Pearson, 2002. 693p.

McDOWELL, L.R. **Minerals in animal and human nutrition**. San Diego: Academic, 1992. 524p.

MILLER, W.J. New concepts and developments in metabolism and homeostasis of inorganic elements in dairy cattle. A review. **Journal of Dairy Science**, v.58, n.10, p.1549-1560, 1975.

MODIN-EDMAN, A.-K.; ÖBORN, I.; SVERDRUP, H. FARMFLOW - A dynamic model for phosphorus mass flow, simulating conventional and organic management of a Swedish dairy farm. **Agricultural Systems**, v.94, p.431-444, 2007.

MORRIS, J.G. Assessment of sodium requirements of grazing beef cattle: a review. **Journal of Animal Science**, v.50, n.1, p.145-152, 1980.

NRC – National Research Council. **Nutrient Requirements of Beef Cattle**. updated 7th.ed. Washington, DC: National Academy Press, 2000. 242p.

NRC – National Research Council. **Nutrient Requirements of Beef Cattle**. 6th.ed. Washington, DC:National Academy Press, 1984.

NRC – National Research Council. **Nutrient Requirements of Beef Cattle**. 7th.ed. Washington, DC:National Academy Press, 1996. 242p.

NRC – National Research Council. **Nutrient Requirements of Dairy Cattle**. 7th.ed. Washington, DC: National Academy Press, 2001. 362p.

NRC – National Research Council. **Nutrient Requirements of Dairy Cattle**. 6th.ed. Washington, DC: National Academy Press, 1989. 157p.

OLTJEN, R.R. Fats for ruminants-utilization and limitations, including value of protected fats In:Georgia Nutrition Conference, 1975, University of Georgia. **Anais.** University of Georgia: Athens, 1975. p.31-40.

O'ROURKE, E.M.; MICHAL, J.; KINCAID, R.L., et al. Use of fecal samples as a tool to monitor phosphorus excretion in lactating dairy cows. **Professional Animal Scientist**, v.23, n.5, p.536-540, 2007.

PAULINO, P.V.R.; COSTA, M.A.L.; VALADARES FILHO, S.D.C., et al. Exigências nutricionais de zebuínos: minerais. **Revista Brasileira de Zootecnia**, v.33, p.770-780, 2004.

PEELER, H.T. Biological availability of nutrients in feeds: availability of major mineral ions. **Journal of Animal Science**, champaign, v.35, n.3, p.695-712, 1972.

PFEFFER, E.; HRISTOV, A.N. **Nitrogen and Phosphorus Nutrition of Cattle: Reducing the Environmental Impact of Cattle Operations**. Cambridge, MA: CABI Publishing, 2005. 288p.

ROSADO, M., **Efeito do complexo ácido graxo-cálcio sobre a digestibilidade aparente, alguns parâmetros ruminais e taxa de passagem em vacas lactantes**. 1991. 96p. Dissertação (Mestrado em Zootecnia) - Universidade Federal de Viçosa, Viçosa, 1991.

SCOTT, D. Control of phosphorus balance in ruminantes. In: DOBSON, A.; DOBSON, M.J. (Ed). **Aspects of Digestive Physiology in Ruminantes**. 1.ed. Ithaca, New York: Comstock Publishing Associates, 1988. p.156-174.

SILVA, F.F.; VALADARES FILHO, S.C.; ÍTAVO, L.C.V., et al. Exigências Líquidas e Dietéticas de Energia, Proteína e Macroelementos Minerais de Bovinos de Corte no Brasil. **Revista Brasileira de Zootecnia**, v.31, n.2, p.776-792, 2002.

TERNOUTH, J.H.; BORTOLUSSI, G.; COATES, D.B., et al. The phosphorus requirements of growing cattle consuming forage diets. **Journal of Agricultural Science**, v.126, n.4, p.503-510, 1996.

TILLMAN, A.D.; BRETHOUR, J.R.; HANSARD, S.L. Comparative procedures for measuring the phosphorus requirement of cattle. **Journal of Animal Science**, v.18, p.249-255, 1959.

UNDERWOOD, E.J. **The mineral nutrition of livestock**. London: Academic press, 1981. 111p.

UNDERWOOD, E.J.; SUTTLE, N.F. **The mineral nutrition of livestock**. 3.ed. London, UK: CABI Publishing, 1999. 614p.

VALADARES FILHO, S.C.; COELHO DA SILVA, J.F.; LEÃO, M.I., et al. Absorções aparentes totais de parciais de sódio, potássio, magnésio, cobre e manganês em bovinos alimentados com ração purificada e semipurificada. In: Reunião Anual da Sociedade Brasileira de Zootecnia, 1991, João Pessoa. **Anais.** João Pessoa: SBZ, 1991.

VALADARES FILHO, S.C.; MACHADO, P.A.S.; CHIZZOTTI, M.L., et al. **Tabela brasileira de alimentos para ruminantes**. Composição química-bromatológica de alimentos - CQBAL 3.0. 3.ed. Viçosa, MG: Universidade Federal de Viçosa, 2010. Disponível em: <www.ufv.br/cqbal> Acesso em: 30/04/2010.

VALADARES FILHO, S.C.; PAULINO, P.V.R.; MAGALHÃES, K.A. **Exigências nutricionais de zebuínos e tabelas de composição de alimentos - BR CORTE**. 1.ed. Viçosa, MG: Suprema Gráfica Ltda, 2006. 142p.

VASCONCELOS, J.T.; TEDESCHI, L.O.; FOX, D.G., et al. Review: Feeding nitrogen and phosphorus in beef cattle feedlot production to mitigate environmental impacts. **Professional Animal Scientist**, v.23, n.1, p.8-17, 2007.

VISEK, W.J.; MONROE, R.A.; SWANSON, E.W., et al. Determination of Endogenous Fecal Calcium in Cattle by a Simple Isotope Dilution Method. **Journal of Nutrition**, v.50, n.1, p.23-33, 1953.

WARD, G.M. Potassium metabolism of domestic ruminants: A review. **Journal of Dairy Science**, v.49, n.3, p.268-276, 1966.