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Mineral requirements for beef cattle

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INTRODUCTION

Minerals are present in different amounts and proportions in all foods and animal tissues (Underwood, 1981). Many of them, despite being present in the body, do not play a specific role in animal metabolism. Essential minerals are elements that perform a specific function in the body (McDonald et al., 2002). Twenty-two minerals were identified as essential for animal life: calcium (Ca), phosphorus (P), potassium (K), sodium (Na), chlorine (Cl), magnesium (Mg) and sulfur (S), considered macronutrients minerals; iron (Fe), iodine (I), zinc (Zn), copper (Cu), manganese (Mn), cobalt (Co), molybdenum (Mo), selenium (Se), chromium (Cr), tin (Sn), vanadium (V), fluorine (F), silicon (Si), nickel (Ni) and argon (Ar), considered mineral micronutrients (Spears and Kegley, 2002). According to their concentration, macrominerals are expressed in g/kg of animal tissue, while trace minerals are expressed in mg/kg of animal tissue.

Although minerals are present in animals in lower proportions than other nutrients such as protein and fat, they perform vital functions in the body. Mineral deficiencies and excesses can cause severe nutritional changes that impair animal performance. Fundamentally, minerals perform five broad functions in animals (Suttle, 2010; Wilson et al., 2016):

1. **Structural:** composition of organs and body tissues, such as Ca, P, Mg, F, and Si in bones and teeth; and P and S in muscle proteins. Approximately 99% Ca, 80% P, and 70% Mg are present in the skeleton (AFRC, 1991; Coelho da Silva, 1995; NRC, 2000);
2. **Physiological:** constituents of body tissues and fluids responsible for maintaining osmotic pressure, acid-base balance, membrane permeability, and tissue irritability, such as Na, K, Cl, Ca, and Mg in the blood, brain-spinal fluid, and gastric juice (Suttle, 2010);
3. **Catalytic:** catalysts of enzymatic and hormonal systems, performed primarily by trace minerals. The regulation of lipid metabolism and synthesis by Cu and spermatogenesis by Zn are among numerous examples (Suttle, 2010);
4. **Regulatory**: replication, regulation and cell differentiation, such as the influences of Ca on signal transduction, and selenocysteine on gene transcription (Suttle, 2010); and
5. **Immune response:** in calves, Cu supplementation increases its hepatic concentration during respiratory challenges, positively impacting the immune response under stress (Wilson et al., 2016).

These functions can only be performed if adequate amounts of dietary minerals are absorbed and retained to maintain growth, development, and reproduction, as well as to replace minerals lost to milk yield, for example (Suttle, 2010). Common beef feeds typically provide cattle with their adequate nutrients (Genther and Hansen, 2014); however, the mineral concentrations are variable and/or inadequate (Smart et al., 1981), contributing to low animal performance and meat quality (Spears and Kegley, 2002). According to Arthington et al. (2014), mineral supplementation can be achieved in several ways: salt blocks fortified with minerals, injectable trace minerals, and protein-energy supplements fortified with trace minerals. Thus, the adequacy of the amount of each mineral supplied to the animals is recommended to ensure adequate animal performance and to avoid soil and watercourse contamination by minerals excreted via feces and urine.

Factorial models are the most common methods used to predict the mineral dietary requirements for cattle (ARC, 1980). The dietary requirements of each mineral correspond to the sum of the net requirements for maintenance and production and the result is divided by the absorption coefficient of the mineral in the animal's digestive tract. However, not every mineral absorbed by the animal has a function in the body, then it is excreted via urine. Thus, the use of the absorption coefficient does not seem to be the most appropriate, but the true retention coefficient, which considers mineral losses via urine.

Mineral requirements for cattle are expressed as amounts per day, per unit of product, or as a proportion of the dry matter intake (DMI). Mineral requirements can be affected by breed or genetic group, sex, age, health status, feeding, production level, and environment (Suttle, 2010). Factors inherent to feeds or diets, such as organic or inorganic fractions of the mineral, bioavailability, and chemical form of the element, along with aspects related to inter-associations (antagonism and agonism) among minerals can also influence dietary requirements.

To calculate dietary mineral requirements, it is required to know about the bioavailability, or proportion of the mineral released during digestion of the feed, enabling its absorption and use. Additionally, there are differences regarding mineral release in animals between feeds produced in tropical and temperate regions.

This chapter discusses the dietary requirements of macrominerals (Ca, P, Mg, Na, K, and S) and trace minerals (Co, Cr, Cu, Fe, Mn, Mo, Se, and Zn) for maintenance, as well as the retention coefficient of each mineral, using a database developed by research conducted in Brazil. Also, equations to estimate the net requirements for growth (NRGs) will be presented from a database of animals raised in tropical conditions. Finally, tables of dietary macromineral and trace mineral requirements will be presented for beef cattle.

MINERALS SOURCES

Currently, two categories of minerals are available for animal diets: 1) inorganic, which comprises sources such as oxides, chlorides, and sulfates; and 2) organic, comprising minerals complexed or associated with organic molecules (complexes and chelates), such as polysaccharides, amino acids or proteins (AAFCO, 1998).

Inorganic sources of minerals

There is a large number of inorganic mineral sources on the market for mineral mixtures and balanced feeds for beef cattle diets. To choose one or more sources of minerals to be used, some points must be considered, such as the cost per unit of required elements, the chemical forms in which the elements are combined, the physical forms closely related to the particle size and, above all, the guarantee of the absence of toxic substances for the animals. According to Campos (1980), the main sources of inorganic minerals used in Brazil for beef cattle diets are described in Table 10.1.

Table 10.1 - Sources of inorganic minerals for cattle

Mineral	Commercial Product	Chemical formula	% of element		Physical form
Calcium and Phosphorus	Dicalcium phosphate	$CaHPO_4.2H_2O$	23.3% Ca	18% P	White crystals
	Defluorinated rock phosphate	$Ca_3(PO_4)_2.CaX$	29.2% Ca	13.3% P	Slightly soluble powder
	Calcium carbonate	$CaCO_3$	40% Ca	-	White powder
	Calcitic limestone	$CaCO_3$	38.5% Ca	-	Insoluble powder
	Dolomitic limestone	$CaCO_3.MgCO_3$	22.3% Ca	-	Insoluble powder
	Oyster meal	$CaCO_3CaX$	38% Ca	-	Granulated
	Dibasic ammonium phosphate	$(NH_4)_2HPO_4$	-	23.5% P	White crystals
Chlorine and Sodium	Sodium chloride	NaCl	60% Cl	37% Na	White crystals
Magnesium	Magnesium oxide	MgO	60.3% Mg		White powder
	Magnesium sulfate	$MgSO_4.7H_2O$	9.9% Mg		White crystals
Sulfur	Sublimated sulfur	S	96 (99)% S		Yellow powder
Iodine	Calcium iodate	$Ca(IO_3)_2$	62% I		White crystals
	Potassium iodate	KIO_3	59% I		White crystals
Cobalt	Cobalt carbonate	$CoCO_3$	49.5% Co		White crystals
	Cobalt chloride	$CoCl_2.6H_2O$	24.7% Co		Dark red crystals
	Cobalt sulfate	$CoSO_4.7H_2O$	20.9% Co		Red crystals
Manganese	Manganese carbonate	$MnCO_3$	47.8% Mn		Red powder
	Manganese sulfate	$MnSO_4.H_2O$	32.5% Mn		Red powder
Copper	Cupric chloride	$CuCl_2.2H_2O$	37.2% Cu		Green crystals
	Cupric oxide	CuO	80% Cu		Black powder
	Cupric sulfate	$CuSO_4.5H_2O$	25.5% Cu		Blue crystals
Iron	Anhydrous ferrous sulfate	$FeSO_4$	36.7% Fe		Soluble powder
	Ferrous carbonate	$FeCO_3.H_2O$	41.7% Fe		Slightly soluble, amorphous powder
Zinc	Zinc sulfate	$ZnSO_4.7H_2O$	22.7% Zn		White crystals
	Zinc oxide	ZnO	80.3% Zn		White powder
Selenium	Sodium selenite	Na_2SeO_3	45% Se		White crystals

Adapted from Campos (1980)

Inorganic minerals, of geological or industrial origin, are still the most used sources in animal nutrition (Mottin et al., 2013). This is mainly due to the low market cost when compared to chelated minerals, which is the main advantage of using inorganic minerals (Araújo et al., 2008). On the other hand, some disadvantages are described in the literature regarding the use of inorganic minerals, such as (Araújo et al., 2008):

1) they have a greater polluting potential for the environment, mainly due to their low instability and the presence of contaminants such as arsenic, lead, and cadmium;
2) they can undergo interactions with other minerals in the gastrointestinal tract, becoming complexed and making absorption difficult or making them unavailable to animals; and
3) need to be included in diets in larger amounts than necessary due to lower bioavailability.

Organic sources of minerals

In recent years, new sources of minerals have appeared on the market and are known as organic minerals. However, due to the variety of sources available, the term “organic minerals” referring to all these products is not the most appropriate. These elements are formed by biosynthetic processes or can be combined with amino acids, proteinates, polysaccharides, and hydroxy amino acid analogues (in the form of complexes, chelates, or proteinates, depending on their nature), are characterized by having greater bioavailability and, therefore, being better utilized in the animal organism. Finally, they have a lower excretion by animals compared to inorganic minerals (Rutz and Murphy, 2009).

Currently, there is a variety of sources for organic minerals available in the market for animal nutrition. According to the Association of American Feed Control Officials (AFFCO, 2000), there are several definitions for organic minerals depending on the type and structure of the ligand, where the main compounds can be classified as follows (Table 10.2):

A complex between metal and amino acid: product resulting from the complexation between a soluble metal salt with one or more amino acids (Ex: Fe-amino acid complex);

Specific metal-amino acid complex: product resulting from the complexation of a soluble metal salt with a specific amino acid, forming coordinated covalent bonds (Ex: zinc-methionine (Zn-Met), zinc-lysine (Zn-Lis), copper-lysine (Cu -Lis));

Chelate between metal and amino acid: product resulting from the reaction between a metal ion obtained from a soluble metal salt with amino acids in the molar ratio of one mole of metal to one to three moles of amino acids (preferably two) to form coordinated covalent bonds (e.g. calcium, cobalt, copper, iron, and zinc);

A complex between metal and polysaccharides: product resulting from a complex between a soluble salt and a polysaccharide solution (Ex: zinc-polysaccharide complex);

Proteinates: product resulting from chelation between a soluble salt with amino acids and/or partially hydrolyzed proteins (e.g., manganese proteinate, zinc proteinate).

The use of organic minerals in their different forms can offer some advantages over inorganic minerals, such as (Zanetti,2014):
1) greater bioavailability;
2) the use of a lower dosage in comparison to the inorganic minerals;
3) greater retention in tissues (since they directly reach specific tissues and enzymatic systems, using the pathways of absorption and transport of molecules that are linked);
4) lower interpellation with other mineral elements or other substances in the absorption process; and
5) lower excretion into the environment.

Furthermore, Mottin et al. (2013) reported that there are some more attributions regarding the comparison between organic and inorganic minerals, mainly the type of charge of these compounds, negative or neutral, that is, they are metabolized more efficiently. In addition, the chelation process enhances passive absorption by increasing water and lipid solubility.

However, not all organic trace minerals are the same. Therefore, it is worth mentioning that the choice of the mineral source to be used must be duly based on scientific works that demonstrate the real effects of the source in improving the parameters that are being proposed in the works. Then, Table 10.2 presents the main organic minerals and their respective bioavailability.

In the current edition of BR-CORTE, all dietary requirements for minerals were estimated from studies in which only inorganic sources of minerals were used. Thus, there is a lack of information about the impact of organic minerals on dietary requirements for beef cattle.

Table 10.2 - Organic minerals and bioavailability

Classification	Type of mineral [1]	Bioavailability of the organic mineral (%) [2]
Amino acid metal chelate	Calcium	92-96
	Cobalt	85-89
	Copper	91-98
	Iron	85-94
	Zinc	87-94
Amino acid metal complex	Copper	91-98
	Iron	85-94
	Manganese	83-87
	Zinc	87-94
Specific amino acid metal complex	lysine copper	91-98
	lysine zinc	87-94
	methionine iron	85-94
	zinc methionine	87-94
Proteinates	Calcium	92-96
	Cobalt	85-89
	Copper	91-98
	Zinc	87-94
Metal polysaccharide complex	Copper	91-98
	Iron	85-94
	Zinc	87-94
	Magnesium	85-94

Adapted from AAFCO (2000)[1] and Baruselli (2000)[2] .

DIETARY MINERAL REQUIREMENTS

Mineral requirements for maintenance include those needed to maintain normal bodily functions when an animal is not growing, performing work, reproducing, or generating any product (Underwood, 1981). The body requires nutrients to maintain normal body temperature, internal metabolism for circulation, respiration, and other vital processes, and to compensate external losses and normal animal movements. These requirements are related to the needs of the animal while meeting the unavoidable losses, also called endogenous losses or secretions from the body (Fontes, 1995).

In Brazil, mineral studies evaluating endogenous losses and absorption coefficients in cattle are scarce. Moreover, the studies available present variable results, hence, it has not been possible to establish precise recommendations for cattle raised under Brazilian conditions.

The main global councils for nutrient requirements (ARC, 1980; NRC, 2000; NRC, 2001; CSIRO, 2007) consider that mineral losses via urine are negligible due to the recycling of minerals in the kidneys. However, Costa e Silva et al. (2015a) verified that mineral losses via urine can reach 35% of the mineral intake and should not be disregarded.

These values enable the true retention coefficients for all minerals to be considered rather than their apparent absorption coefficients.

Thus, in this chapter, dietary mineral requirements will be calculated from the sum of their net mineral requirements for maintenance and NRG divided by their retention coefficient.

DATABASE

Net mineral requirements for maintenance and retention coefficient of each mineral

The net mineral requirements for maintenance (intercept) and the retention coefficient (slope) of each mineral can be calculated by linear regression of the association between mineral retention and intake:

$$RM = MI - MEf - MEu$$

where RM is retained mineral, MI is the mineral intake, MEf is mineral excreted via feces, and MEu is mineral excreted via urine.

Then, to estimate the net requirement for maintenance and retention coefficient of each mineral, a database was developed from 10 experiments conducted under tropical conditions: Souza (2010), Gionbelli (2010), Marcondes (2010), Prados (2012), Zanetti (2014), Sathler (2015), Costa e Silva et al. (2015a – **2**), Prados (2016), and Zanetti et al. (2017). The minerals in the animal feed, feces, and urine are presented in Tables 10.3 (macrominerals) and 10.4 (trace minerals). This database comprised 325 animals (181 bulls, 73 steers, and 71 heifers). The animals were from the following genetic groups: Nellore (*n* = 243), Zebu × Holstein (*n* = 46), Angus × Nellore (*n* = 18), and Simmental × Nellore (*n* = 18). A meta-analysis was used in which sex (fixed effect), genetic group (fixed group), and study (random effect) were considered classificatory effects to evaluate differences for each mineral.

However, only two studies (Costa e Silva et al., 2015a; Zanetti et al., 2017) evaluated the net mineral requirement for maintenance and the retention coefficient for S and trace minerals. Therefore, only the recommendations suggested by these authors will be used in this BR-CORTE edition (Table 10.4).

Table 10.3 - Descriptive statistics of data used to estimate the net macromineral (Ca, P, Mg, Na, K, and S; g/d) requirements

Item	*n*	Mean	SD	Maximum	Minimum
Body weight (kg)	325	302	82.3	557	125
		Calcium (Ca)			
Intake	325	27.1	18.9	138	2.93
Feces	324	11.4	6.27	61.95	1.37
Urine	322	1.14	1.13	7.63	0.04
		Phosphorus (P)			
Intake	325	22.5	20.6	88.0	3.34
Feces	325	9.08	5.94	40.5	1.46
Urine	322	0.99	1.16	8.28	0.01
		Magnesium (Mg)			
Intake	325	16.6	9.42	51.2	2.49
Feces	307	8.22	5.58	41.5	0.89
Urine	304	3.98	3.43	24.4	0.03
		Sodium (Na)			
Intake	325	19.4	13.4	49.7	0.61
Feces	306	7.27	4.81	22.5	0.19
Urine	297	7.49	5.49	26.3	0.02
		Potassium (K)			
Intake	325	47.2	26.3	140	5.14
Feces	307	16.3	9.63	56.4	1.82
Urine	297	16.1	13.2	66.8	0.02
		Sulfur (S)			
Intake	149	5.75	2.08	9.29	1.20
Feces	149	2.43	1.10	4.94	0.44
Urine	143	1.65	1.24	3.96	0.04

SD = standard deviation.

Table 10.4 - Descriptive statistics of data used to estimate the net trace mineral (Cu, Fe, Mn, Se, Zn, Co, Cr, and Mo; mg/d) requirements

Item	*n*	Mean	SD	Maximum	Minimum
Body weight (kg)	149	307	92.6	557	125
		Copper (Cu)			
Intake	149	87.8	58.8	213	1.87
Feces	149	50.6	21.9	104	8.02
Urine	95	8.58	6.42	37.3	1.08
		Iron (Fe)			
Intake	149	2,103	1,173	4,780	333
Feces	149	1,608	872	3,982	316
Urine	92	98.8	73.4	410	5.40
		Manganese (Mn)			
Intake	149	212	133	493	1.87
Feces	136	193	106	425	4.71
Urine	88	2.01	1.66	6.80	0.06
		Selenium (Se)			
Intake	50	2.05	0.88	3.93	0.69
Feces	50	1.43	0.64	2.69	0.31
Urine	50	0.70	0.57	1.22	0.01
		Zinc (Zn)			
Intake	149	293	169	611	28.0
Feces	149	195	110	469	15.9
Urine	92	13.1	7.00	37.9	0.86
		Cobalt (Co)			
Intake	149	7.12	4.64	21.3	0.92
Feces	148	3.68	3.12	12.6	0.04
Urine	80	1.33	1.85	7.67	0.02
		Chromium (Cr)			
Intake	102	16.1	8.00	38.2	0.35
Feces	102	11.3	5.60	28.1	3.30
Urine	46	3.84	1.94	9.26	0.61
		Molybdenum (Mo)			
Intake	47	3.92	1.10	6.19	0.89
Feces	47	2.69	0.80	5.04	0.72
Urine	45	0.41	0.22	1.15	0.11

SD = standard deviation.

Net requirement of each mineral for growth (NRG)

The power model is commonly used to estimate the NRG (ARC, 1980), according to:

$$Mi = \beta_0 \times EBW^{\beta_1},$$

where Mi is the mineral (i) content in the body (Ca and P (kg); Mg, Na, and K (g)), β_0 and $\beta 1$ are regression parameters and EBW is the empty body weight (kg). Using the first derivation of this equation and based on the empty body gain (EBG), the NRG is estimated as follows:

$$NRGi = EBG \times (\beta 0 \times \beta 1 \times EBW^{\beta 1-1})$$

where NRGi is the net mineral requirements for mineral "i", EBG is the empty body gain (kg/d), and β_0 and $\beta 1$ are regression parameters.

Cattle reach a body weight (BW) at which there is no longer minerals deposition in the body, hence, dietary requirements refer only to animal maintenance. Thus, the point at which there is no more significant mineral addition in the EBW is determined by the plateau power method, as suggested by Chizzotti et al. (2009), for Ca and P.

For each mineral, their NRG is considered equal to zero in the EBW when the plateau is achieved.

Thus, a database was developed from 21 studies conducted under tropical conditions: Paulino (1996), Silva (2001), Veloso (2001), Paulino (2002), Backes (2003), Leonel (2003), Martins (2003), Chizzotti (2007), Véras (2006), Moraes (2006), Marcondes (2007), Paixão (2008), Sales (2008), Gionbelli (2010), Souza (2010), Marcondes (2010), Valente (2012), Rodrigues (2014), Amaral (2012), Costa e Silva et al. (2015a), and Zanetti et al. (2017). The NRG values for Ca, P, Mg, Na, and K of the animals are presented in Table 10.5.

In the BR-CORTE (2010), two methods were suggested to estimate NRGCa and NRGP: plateau quadratic and plateau power. We tested these methods and the plateau power method presented the best estimates (lower values of the mean square of error of prediction, MSEP), and was consequently chosen as the standard method to estimate NRGCa and NRGP. For NRGMg, NRGNa, and NRGK, the power method was used to estimate the plateau of deposition of these minerals, once they are more related to body fluid than deposition in bones and body tissues.

Due to the lack of literature data on NRGS and NRG for trace minerals (Co, Cr, Cu, Fe, Mn, Mo, Se, and Zn), the recommendations have been based on the studies of Costa e Silva et al. (2015a) and Zanetti et al. (2017) (Table 10.6).

Table 10.5 - Descriptive statistics of data used to estimate net macromineral (Ca, P, Mg, Na, and K) requirements for the growth of beef cattle

Genetic group/system	Sex	*n*	Item	EBW	EBG	Ca (kg)	P (kg)	Mg (g)	Na (g)	K (g)
Nellore (feedlot)	Bulls	142	Mean	342	1.04	4.64	2.95	140	492	538
			SD	83.7	0.45	1.12	0.74	50.9	134	238
			Maximum	549	1.87	7.15	4.45	311	760	990
			Minimum	172	-0.01	2.09	1.06	49.8	203	170
	Steers	148	Mean	311	0.84	5.66	2.59	103	410	605
			SD	88.6	0.49	1.13	0.76	30.7	141	219
			Maximum	460	2.30	7.97	4.20	168	640	1060
			Minimum	104	-0.21	2.66	0.60	29.7	106	154
	Heifers	84	Mean	226	0.55	4.41	1.56	81.6	323	311
			SD	64.1	0.37	1.00	0.57	28.5	153	71.0
			Maximum	368	1.25	7.15	2.76	150	708	495
			Minimum	108	-0.13	2.78	0.64	34.0	110	177
Crossbred (feedlot)	Bulls	149	Mean	394	1.39	4.20	3.00	220	511	668
			SD	94.6	0.65	1.40	1.02	106	135	261
			Maximum	600	2.74	6.95	4.43	390	764	990
			Minimum	167	0.17	1.53	0.78	45.7	284	156
	Steers	107	Mean	332	0.94	5.21	2.80	105	432	629
			SD	92.2	0.54	1.12	0.60	32.8	168	272
			Maximum	506	1.64	7.83	4.34	169	705	1046
			Minimum	161	-0.09	3.13	1.60	48.0	125	131
	Heifers	73	Mean	292	0.79	4.52	2.10	106	503	323
			SD	73.2	0.50	0.96	0.39	23.1	150	74.6
			Maximum	443	1.73	6.91	2.77	164	776	466
			Minimum	175	-0.18	2.82	1.29	62.3	237	195
Nellore (pasture)	Bulls	141	Mean	308	0.33	5.34	2.20	139	591	751
			SD	106	0.27	1.28	0.84	58.0	236	455
			Maximum	604	0.90	8.30	3.72	265	1109	1662
			Minimum	80.2	-0.41	2.70	0.39	70.0	180	170

SD = standard deviation; EBW = empty body weight (kg); EBG = empty body gain (kg); Ca = calcium; P = phosphorus; Mg = magnesium; Na = sodium; K = potassium.

This database comprised 844 animals: 432 bulls, 255 steers, and 157 heifers, from Zebu (n = 515) and crossbred cattle (n = 329). Meta-analysis was adopted and the production system (feedlot and pasture), sex (bulls, steers, and heifers), genetic group (Zebu, beef crossbred, and crossbred dairy cattle), and study were considered random effects. For the macrominerals (Ca, P, Mg, Na, and K), equations were generated separately when differences were observed for sex (bulls, steers, and heifers) or genetic group (Zebu, beef crossbred, and dairy crossbred cattle). In the crossbred cattle, there were no significant differences ($P > 0.05$) between crossbred beef and dairy cattle for any of the minerals, so their data were combined. Thereby, the equations were generated separately for Zebu and crossbred cattle when differences were observed in macromineral (Ca, P, Mg, Na, and K) data, enabling the direct effect of the genetic group to be observed.

Table 10.6 - Descriptive statistics of total contents of each mineral used to estimate net S and trace mineral (Co, Cr, Cu, Fe, Mn, Mo, Se, and Zn) requirements for the growth of beef cattle

Item	*n*	Mean	SD	Maximum	Minimum
EBW (kg)	133	288	110	549	104
EBG (kg/d)	133	0.74	0.55	1.87	-0.02
S (g)	87	610	506	2,197	86
Co (mg)	87	1,480	1,683	5,193	12
Cr (mg)	87	1,113	938	3,736	154
Cu (mg)	87	1,519	1,161	4,678	153
Mn (mg)	87	913	874	2,801	112
Mo (mg)	46	9.05	3.96	19.3	2.81
Se (mg)	50	136	92	328	21
Zn (g)	87	20.4	20.2	65.0	2.17
Fe (g)	87	31.2	22.2	78.5	7.02

EBW = empty body weight (kg); EBG = empty body gain (kg); SD = standard deviation; Co = cobalt; Cr = chromium; Cu = copper; Fe = iron; Mn = manganese; Mo = molybdenum; Se = selenium; Zn = zinc.

MACROMINERALS

In the BR-CORTE (2010), a collection of macrominerals (Ca, P, Mg, Na, and K) absorption coefficient data was based on literature studies (Table 10.7). However, due to the variability of data found, mainly in Brazil, the recommendations remained unchanged or followed the suggestions proposed by the NRC (2000) for Ca and P, and the ARC (1980) for Mg, Na, and K.

Table 10.7 - Absorption and retention coefficients of macrominerals (Ca, P, Mg, Na, and K) found in the literature

Source	Absorption coefficient (%)[1]				
	Ca	P	Mg	Na	K
Marshal and Long (1971)	80	-	-	-	-
ARC (1980)	68	60	17	**91**	**100**
Blaney et al. (1982)	50	-	-	-	-
Field (1983b)	-	58	-	-	-
Ezequiel (1987)[2]	62	72	52	66	100
AFRC (1991)	-	58 a 70	-	-	-
Coelho da Silva et al. (1991)[2]	-	-	16	76	-
Rosado (1991)[2]	-	-	44	57	44
Valadares Filho et al. (1991)[2]	-	-	57	-	-
Boin (1993) – calves[2]	-	78	-	-	-
Boin (1993) – steers[2]	-	58	-	-	-
Coelho da Silva et al. (1995)[2]	72	63	38	54	-
NRC (2000)	50	**68**	-	-	-
NRC (2001) – forages	30	80	-	81	-
NRC (2001) – concentrate	60	-	-	100	-
Araújo et al. (2001)[2]	59	56	45	94	78
Gionbelli (2010)[2,3]	**55**	56	**16**	19	4
Costa e Silva et al. (2015a)[2,3]	72	82	98	58	70
BR-CORTE (2016)[2,3]	57	68	36	37	43

[1]Values adopted from the BR-CORTE (2010) are in bold; [2]Experiments conducted in Brazil; [3]Retention coefficient. Ca = calcium; P = phosphorus; Mg = magnesium; Na = sodium; K = potassium.

However, from the database generated in this edition, some of the urinary mineral excretions were lower in relation to their intakes, for example, Ca (4.29%), P (4.33%), Cu (3.82%), Fe (3.59%), Mn (1.72%), Se (6.47%), and Zn (4.03%; Table 10.3). Nevertheless, the urinary excretion of other minerals was considered high, for example, Na (39.3%), S (34.8%), Mg (24.9%), K (30.3%), Co (14.6%), and Cr (14.6%). Therefore, we don't recommend to use the true absorption coefficient to get the dietary requirements, for all minerals. So, in this BR-CORTE edition, all the coefficients reported are the true retention coefficients, directly representing the association between mineral retention and intake.

Calcium

Ca is the most abundant mineral found in animals; approximately 99% is present in bones and teeth and 1% in soft tissues and body fluids. Ca is involved in blood coagulation, muscle contraction, nerve impulse transmission, cardiac movement regulation, hormonal secretion, and enzyme activation and stabilization (Lalman, 2005). Ruminants have a low capacity to excrete Ca absorbed in excess, represented by low urinary Ca excretions, while fecal endogenous losses are constant, which indicates that the absorption is regulated at the intestinal level (Field, 1983a). Costa e Silva et al. (2015a) verified that only 3.85% of Ca intake was excreted via urine while 47.9% was excreted via feces.

Based on Hansard et al. (1954; 1957), in which Ca radioisotopes were used to estimate its true bioavailability, requirements for maintenance, and use for cattle, the NRC (1984) recommended 15.4 mg/kg BW as the net Ca requirement for maintenance and, in the absence of further studies to verify this estimate, the same recommendation was reported in further editions (NRC, 2000; NRC, 2001; BCNR, 2016). Moreover, the ARC (1965) considered the net Ca requirement for maintenance as 16 mg/kg BW; 0.8 mg/kg BW was related to urinary losses. The

AFRC (1991) suggested an equation whereby fecal metabolic losses (FML) are estimated as a function of DMI (kg/d) and BW of the animals, which has been adopted by the CSIRO (2007):

$$FMLCa\ (g/d) = 0.66 \times DMI + 0.74 \times BW - 0.74.$$

In Brazil, few studies have estimated the net Ca requirements for maintenance. Ezequiel (1987) suggested values of 33.2, 43.5, and 26.1 mg/kg BW, using Nellore, Holstein (H), and ½ H × ½ Zebu cattle, respectively. These values are above those recommended by the main global councils (ARC, 1980; NRC, 2000). In the BR-CORTE (2010), only data from a single study (Gionbelli, 2010) were used and was the estimated net Ca requirement for maintenance was 26.5 mg/kg BW. Costa e Silva et al. (2015a), estimated the net Ca requirement for maintenance as 20 mg/kg BW for Nellore cattle. However, from the meta-analysis of seven studies in the BR-CORTE database, the net Ca requirement for maintenance and its retention coefficient were estimated as 11.7 mg/kg BW and 56.8%, respectively (Figure 10.1).

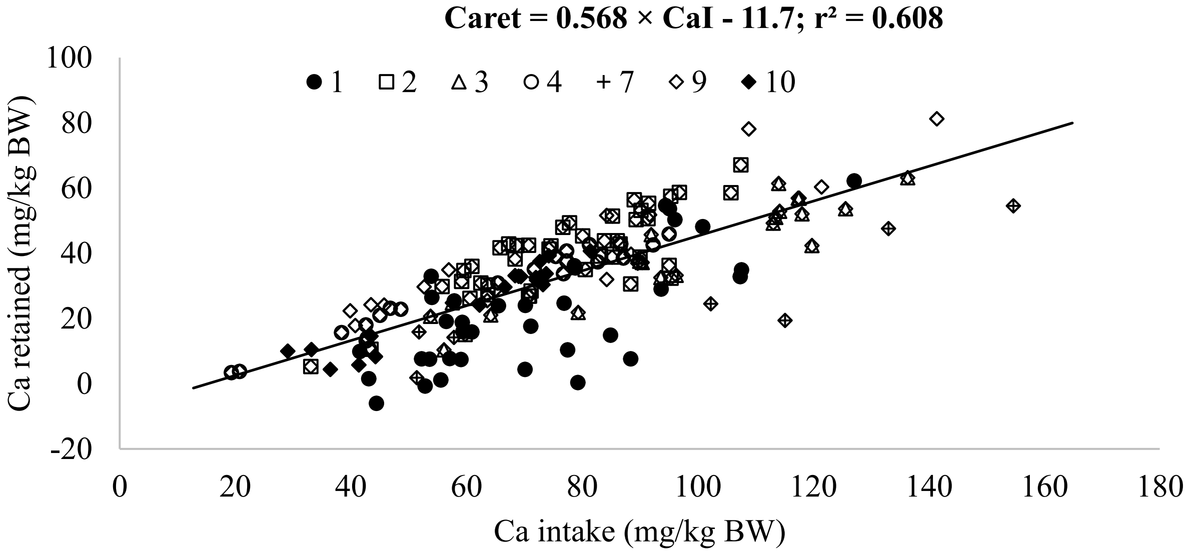

Figure 10.1 - Correlation between Ca retained (Caret) and Ca intake (CaI) in beef cattle. Costa e Silva et al. (2015a - **1** and **2**), Zanetti (2014 - **3**), Prados (2016 - **4**), Gionbelli (2010 - **7**), Prados (2012 - **9**), Zanetti et al. (2017 - **10**).

Based on the estimates in this BR-CORTE edition and the NRC (2000) recommendation, a 300-kg animal would require 3.51 and 4.62 g/d net Ca requirement for maintenance. Thus, the Ca required to compensate for the endogenous losses can be overestimated. Hence, a decreased supply of this mineral to the animals should decrease fecal Ca excretions to the environment.

The nutrient councils (ARC, 1980; AFRC, 1991; NRC, 2000; NRC, 2001) consider that mineral losses via urine are negligible, suggesting the absorption coefficient to be used to estimate mineral requirements. The AFRC (1991), NRC (2000), and NRC (2001) reported that the absorption coefficient might be 68, 70, and 50%, respectively, providing an average of 62.7%, which is close to the retention coefficient found in this BR-CORTE edition. Therefore, we recommend 56.8% to be used as the true retention coefficient of Ca for beef cattle.

Sathler (2015) evaluated Ca absorption at different sites along the gastrointestinal tract. Ca absorption in the rumen depended on the supply of a supplementary Ca source in the diet, which was approximately 25% with supplementation and 5.86% without. In contrast, when Ca absorption was evaluated in the small and large intestines, the absorption of Ca in the small intestine was 3.02 and 10.5% for diets with and without supplementation, respectively. In the large intestine, these values were 15.2 and 27.7%, respectively. Thereby, dietary inorganic Ca supplementation leads to a greater Ca absorption in the rumen, while the absorption of Ca occurs mostly in the small and large intestines in the absence of an inorganic source.

Fontes (1995) evaluated NRGCa data published in the Brazilian literature and found no effect of the genetic group when animals were divided into Zebu, dairy crossbred, and beef crossbred but verified differences between bulls and steers, with steers presenting lower NRGCa values. In contrast, Marcondes et al. (2009) did not find sex effect on NRGCa. Similarly, several nutrient requirements councils (AFRC, 1991; NRC, 2000; CSIRO, 2007) did not find the effects of sex or genetic group on Ca dietary requirements. In this BR-CORTE edition, differences among genetic groups were observed for NRGCa with Zebu cattle presenting lower NRGCa compared with crossbred cattle ($P < 0.0001$), resulting in distinct estimates of NRGCa (Table 10.8). Moreover, for all equations, a plateau was calculated at which the mineral deposited in the body becomes constant and the NRGCa value is equal to zero (Table 10.8).

Table 10.8 - Net requirements of Ca for growth and plateau of Ca deposition as a function of genetic group (Zebu and crossbred cattle)

GG[1]	Plateau	Body content (kg)	NRGCa[2]
Zebu cattle	EBW < 462 kg	$0.294 \times EBW^{0.50}$	$EBG \times (147 \times EBW^{-0.50})$
	EBW ≥ 462 kg	6.32	0
Crossbred cattle	EBW < 453 kg	$0.096 \times EBW^{0.68}$	$EBG \times (66.0 \times EBW^{-0.32)}$
	EBW ≥ 453 kg	6.17	0

[1]GG = genetic group; [2]NRGCa = net Ca requirement for growth; EBW = empty body weight (kg); EBG = empty body gain (kg).

The NRC (2000) estimated Ca growth requirements as 7.1 g per 100 g/d of protein gain in animals. However, Chizzotti et al. (2009) reported that Ca deposition was poorly associated with protein deposition. Moreover, these authors estimated that the plateau for protein, Ca and P deposition occurred at 450, 416, and 416 kg EBW for Nellore × Angus cattle. When the mineral requirements were calculated as a function of protein deposition, they were overestimated for EBWs between 416 and 450 kg. In the BR-CORTE (2010), a common plateau was suggested for Ca and P of 412 kg equivalent EBW (469 kg BW for Nellore, and 496 kg BW for crossbred beef cattle). In this BR-CORTE edition, the inclusion of data for heavier animals resulted in better adjustment, and differences among genetic groups were verified, and a plateau for Ca deposition could be estimated for each genetic group (Table 10.8). Therefore, we suggest that the EBW at which there is no more Ca deposition to be 462 and 453 kg EBW for Zebu and crossbred cattle, respectively.

In the last few years, dietary mineral requirements have received considerable attention, mainly due to the association between mineral excretion and environment pollution. Costa e Silva et al. (2015b) decreased the dietary Ca requirements recommended in the BR-CORTE (2010) by 43% in Nellore steers and heifers and verified that this decrease did not influence animal performance, intake, or nutrient digestibility. Similarly, Prados et al. (2015) found that decreasing the recommended dietary Ca requirements in the BR-CORTE (2010) by 38% in Holstein × Zebu bulls did not affect animal performance or mineral concentrations in the bones. These authors concluded that lowering Ca supply could decrease costs in feedlot operations and Ca excretion to the environment. Therefore, more studies that evaluate reduced amounts of Ca in cattle diets to reduce the excretion of this mineral should be conducted.

Phosphorus

Phosphorus (P) is the second most abundant mineral in animals, with 80% found in bones and teeth. The remaining 20% is distributed in fluids and tissues (Suttle, 2010). Phosphorus is required for bone formation and mineralization, and is important for the growth and differentiation of ribonucleic acids. Additionally, P is fundamental for osmotic regulation and acid-base balance, energy use, electron transfer, phospholipid production, fatty acid transport, and amino acid and protein production (Suttle, 2010). Phosphorus is also required by rumen microorganisms for growth and cell metabolism (NRC, 2000).

Dietary P that exceeds animal requirements is not absorbed or, if so, is excreted in the urine. Urinary P excretion is low in normal conditions as large amounts of P are recycled by the saliva (ARC, 1965). Thereby, the net requirements of P for maintenance were calculated by the sum of fecal and urinary metabolic P excretions. The ARC (1980) suggests that this value is 12 mg/kg BW. The AFRC (1991) calculated the net requirements of P for maintenance from an equation based on studies in sheep, whereby metabolic losses of P were calculated as a function of DMI. Furthermore, the NRC (2000) considers the net requirement of P for maintenance to be 16 mg/kg BW. From the BR-CORTE database, the net mineral requirement for maintenance and the true retention coefficient of P were 13.5 mg/kg BW and 67.8%, respectively (Figure 10.2).

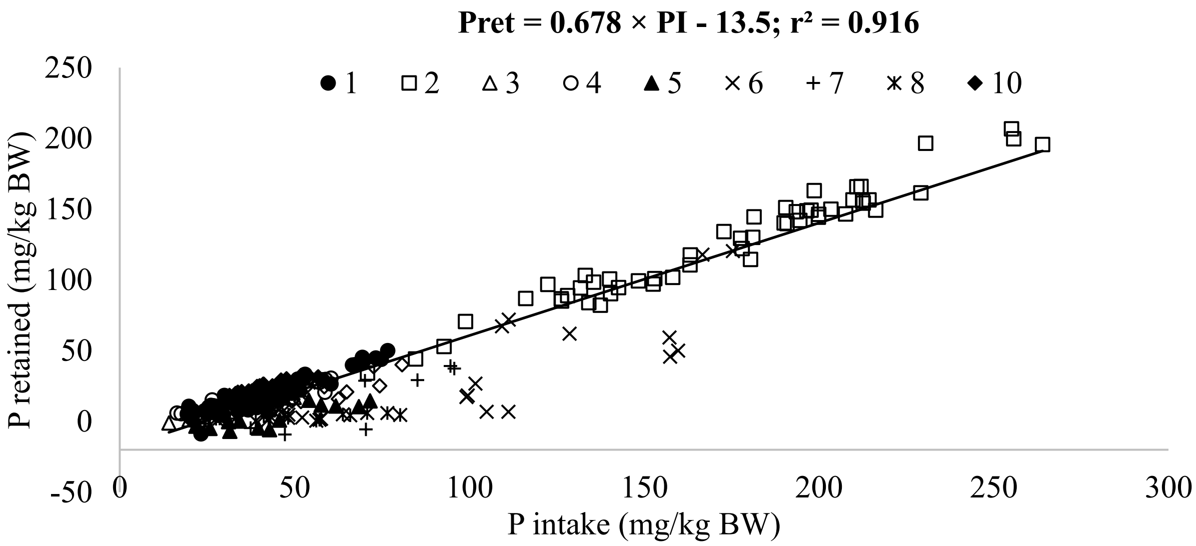

Figure 10.2 - Correlation between P retained (Pret) and P intake (PI) in beef cattle. Costa e Silva et al. (2015a - **1** and **2**), Zanetti (2014 - **3**), Prados (2016 - **4**), Souza (2010 - **5**), Marcondes (2010 - **6**), Gionbelli (2010 - **7**), Sathler (2015 - **8**), Zanetti et al. (2017 - **10**).

Sathler (2015) evaluated P absorption in diets with and without a supplementary inorganic source of P (dicalcium phosphate) and observed that regardless of the P supply, ruminal absorption of P is negative due to P recycling via saliva that arrives in the rumen and is not considered as input to the system. Thus, it is necessary to evaluate the amount of P that is recycled by the saliva as a function of the dietary P content. Furthermore, this author verified that 67.3 and 25.5% of P intake is absorbed in the small and large intestines, respectively, being the main sites of P absorption. According to the NRC (2000), supplementary sources of P can be ranked according to thr bioavailability as dicalcium phosphate > fluorinated phosphate > bone meal (Peeler, 1972). The global councils (AFRC, 1991; NRC, 2000; NRC, 2001; CSIRO, 2007) report absorption coefficients of P between 58 to 75%. Considering that the studies providing data for the estimates used in this BR-CORTE edition were based on dicalcium phosphate as the supplementary source of P, 67.8% is recommended as the true retention coefficient of P. Also, in contrast to the global councils, this BR-CORTE edition considers the retention coefficient instead of the absorption one.

The NRGP is presented in Table 10.9. The EBW at which there is no significant increase of P was also estimated. As observed with Ca, studies of nutrient requirements did not consider the effects of sex or genetic group on the dietary P requirements and this was documented in the previous BR-CORTE editions. However, with the inclusion of new studies developed with animals having a BW greater than 500 kg, NRGP differences were detected among genetic groups (Zebu and crossbred cattle; Table 10.9). The NRC (2000) estimated NRGP as 3.9 g per 100 g/d of protein gain. In this BR-CORTE edition, Zebu cattle presented a higher NRGP than crossbred cattle. Regarding the EBW for stabilization of P deposition, Zebu, and crossbred cattle reached values of 445 and 479 kg, respectively.

Table 10.9 - Net requirements of P for growth and plateau of P deposition as a function of genetic group (Zebu and crossbred cattle)

GG	Plateau	Body content (kg)	NRGP[2]
Zebu cattle	EBW < 445 kg	$0.05995 \times EBW^{0.6446}$	$EBG \times (38.6 \times EBW^{-0.36})$
	EBW ≥ 445 kg	3.05	0
Crossbred cattle	EBW < 479 kg	$0.0339 \times EBW^{0.7496}$	$EBG \times (25.4 \times EBW^{-0.25})$
	EBW ≥ 479 kg	3.46	0

[1]GG = genetic group; [2]NRGP = net requirement of P for growth; EBW = empty body weight (kg); EBG = empty body gain (kg).

Current publications have addressed the need to decrease environment impacts caused by P excretions by cattle (Vasconcelos et al., 2007; Costa e Silva et al., 2015b; Prados et al., 2015). Costa e Silva et al. (2015b) verified that a decrease of 20% of P in the diet of Nellore steers and heifers did not impact intake, nutrient digestibility, or animal performance. Similarly, Prados et al. (2015) found that decreasing the BR-CORTE (2010) recommended dietary requirements of P of crossbred cattle by 14% did not affect animal performance or P bone concentrations. Also, Erickson et al. (1999; 2002) did not observe differences in either steers or calves performance when fed diets with 71 or 162% (steer) and 76 or 190% (calves) of P requirements recommended by the NRC (2000). Call et al. (1978) fed beef heifers for two years with 66 and 174% of the P requirements recommended by the NRC (2000) and did not observe differences in weight gain. This shows that dietary P requirements can be decreased without affecting animal performance and that the excess of dietary P is excreted in the feces. Furthermore, the mineral nutrition of cattle is not fully understood, and we recommend further studies in this area to have a better understanding of the mineral metabolism in cattle.

The ARC (1980) reports that the association between dietary Ca and P in ruminants is important because both minerals participate in bone production, and recommends a Ca:P ratio between 1:1 and 2:1. An inadequate Ca:P ratio can alter these maintenance requirements if either mineral is deficient in the diet. Hansard and Plumlee (1954) observed an increase in metabolic excretion of P when Ca intake was low and suggested that a portion of the excess P that would typically be used for bone deposition is excreted when there is insufficient Ca in the blood for bone calcification. Costa e Silva et al. (2015a) found an average Ca:P ratio of 2.15:1 for Nellore cattle with three different sexes raised in a feedlot. Zanetti et al. (2017) found the feeding behavior, nutrient intake, and performance of Nellore bulls during the growing and finishing phases were not affected by a Ca:P ratio between 0.63 to 1.82. Furthermore, this author observed that this low Ca:P ratio decreased their fecal excretion, resulting in less environment impact.

In this BR-CORTE edition, the ratio between Ca and P was 1.46:1, which is close to the inferior limit recommended by the NRC (2000). However, the NRC (2000) emphasized that a Ca:P ratio between 1:1 to 7:1 resulted in similar ruminant performance (Dowe et al., 1957; Wise et al., 1963).

Magnesium

Approximately 70% of the Mg in the body is located in the bones, while the remaining 30% acts in the muscle and other soft tissues. Only 1% of Mg is found in extracellular fluids. In the soft tissues, Mg is involved in the energy metabolism, mainly through Mg-ATP complex, maintenance of electric potential that affects intra- and extracellular ionic gradients, and enzyme activation. The maintenance of the ideal concentrations of is essential for its functions. According to the ARC (1980), endogenous Mg losses via urine are disregarded. However, from datasets used in this BR-CORTE edition, 49.5% of the Mg intake (Table 10.3) is excreted in feces, while 24% is excreted via urine. Therefore, urinary excretion of Mg should be considered to accurately estimate its retention coefficient, which is 35.5 % (Figure 10.3). In comparison, the ARC (1980) and NRC (2000, 2001) considered absorption coefficients with mean values of 29.4% and 17%. The ARC (1980) and NRC (2001) suggested 3 mg/kg BW as the net requirement of Mg for maintenance. However, this BR-CORTE edition shows that the estimated net requirement of Mg for maintenance is 5.9 mg/kg BW (Figure 10.3).

In the BR-CORTE (2010), the NRGMg values were estimated from the EBG. This BR-CORTE edition adopted the power model intending to standardize mineral requirements. Thus, the NRGMg was estimated and the effect of the genetic group was observed (Table 10.10).

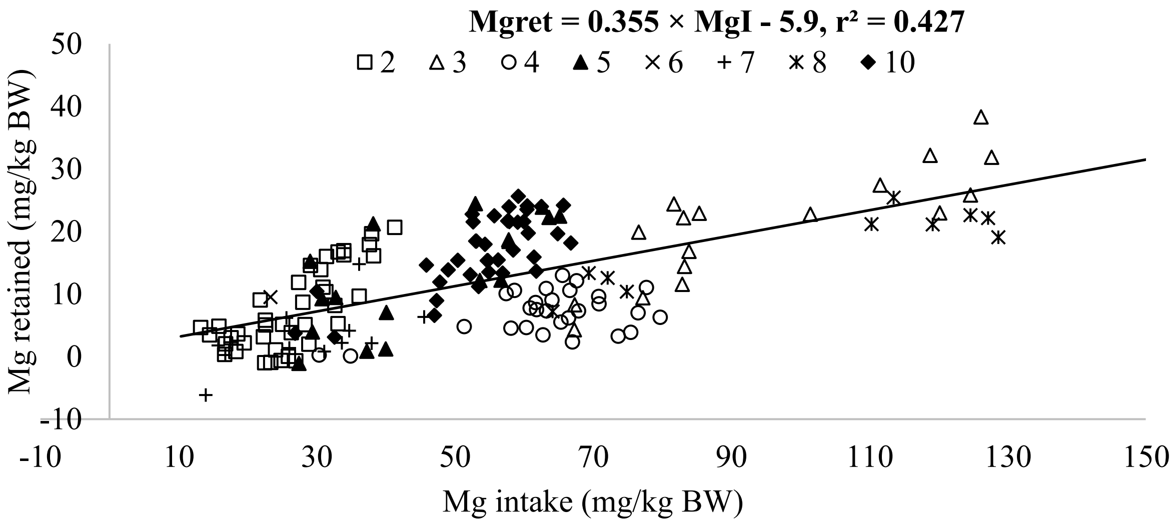

Figure 10.3 - Correlation between Mg retained (Mgret) and Mg intake (MgI) in beef cattle. Costa e Silva et al. (2015a - **2**), Zanetti (2014 - **3**), Prados (2016 - **4**), Souza (2010 - **5**), Marcondes (2010 - **6**), Gionbelli (2010 - **7**), Sathler (2015 - **8**), Zanetti et al. (2017 - **10**).

Table 10.10 - Net requirements of Mg for growth as a function of the genetic group (Zebu and crossbred cattle)

GG	Body content (g)	NRGMg[2]
Zebu cattle	$0.3427 \times EBW^{1,0113}$	$EBG \times (0.3466 \times EBW^{0,0113})$
Crossbred cattle	$1.3918 \times EBW^{0,7614}$	$EBG \times (1.0597 \times EBW^{-0,2386})$

[1]GG = genetic group; [2]NRGMg = net requirement of Mg for growth; EBW = empty body weight (kg); EBG = empty body gain (kg).

Sodium

Na presents the greatest concentration among the ions that contribute to the osmotic balance. Moreover, Na contributes to muscle contraction, nerve impulse transmission, and nutrient (e.g. glucose) transport. The ARC (1980) suggests that dietary Na is not complexed and, therefore, is completely absorbed. This infers that fecal endogenous losses do not apply to Na. However, the amount of Na in feces and urine is 37.5 and 38.6% of Na intake, respectively (Table 10.3). Based on this data, the net requirements of Na for maintenance and the true retention coefficient of Na were estimated as 6.3 mg/kg BW and 37.1%, respectively (Figure 10.4). This net requirement of Na for maintenance is lower than that suggested by the ARC (1980) and the NRC (2001) of 6.8 and 15 mg/kg BW, respectively. According to Aitken (1976), Na losses via saliva are negligible, except for non-acclimated cattle in tropical conditions, where the Na loss through saliva is 1.4 g/d for each 100 kg BW. However, there is no data from animals raised in tropical conditions that evaluate endogenous losses through the skin and the saliva.

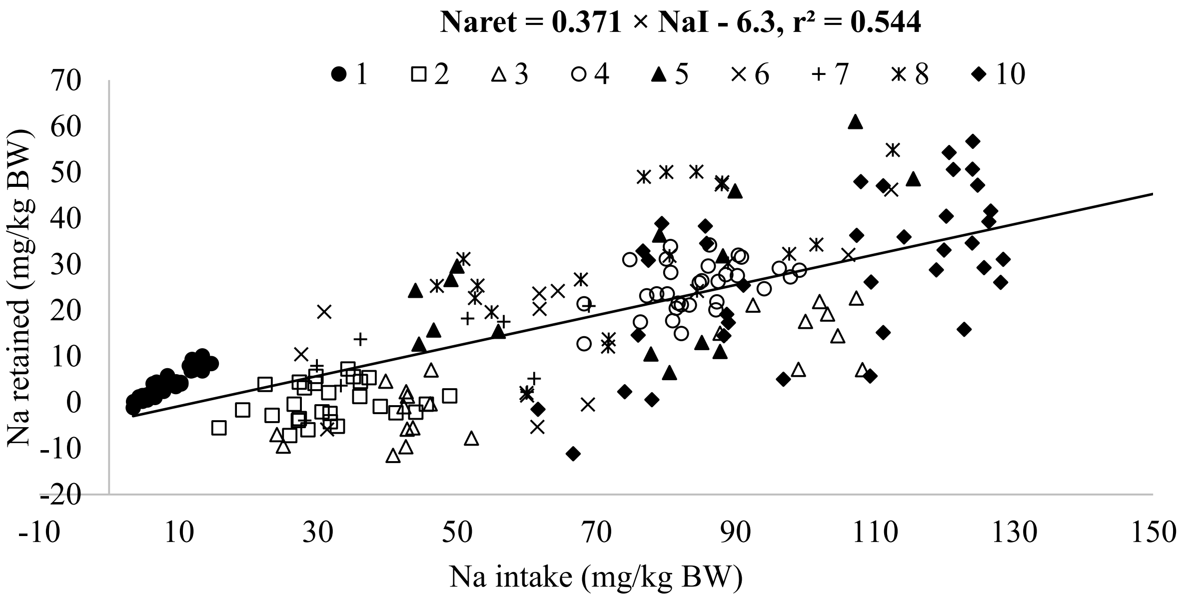

Figure 10.4 - Correlation between Na retained (Naret) and Na intake (NaI) in beef cattle. Costa e Silva et al. (2015a - **1** and **2**), Zanetti (2014 - **3**), Prados (2016 - **4**), Souza (2010 **- 5**), Marcondes (2010 **- 6**), Gionbelli (2010 - **7**), Sathler (2015 - **8**), Zanetti et al. (2017 - **10**).

The NRC (2000 , 2001) recommended 91 and 90% as the absorption coefficient of Na, respectively. However, from the BR-CORTE database, the retention coefficient was estimated as 37.1% (Figure 10.4). This difference may be due to the excretion of Na in the urine, which is not accounted for by global councils (NRC, 2000; NRC, 2001), even with the urinary Na reaching approximately 38.6% (Table 10.3). However, we highlight that some estimated dietary requirements in this BR-CORTE edition used data from diets formulated with sodium bicarbonate and magnesium oxide, as buffering and alkalizing agents, respectively, which could have contributed to the increased urinary excretion of these minerals.

In the BR-CORTE (2010), the effects of sex and the genetic group were identified based on the NRGNa, acquired using the same model as the one used for Mg. Thus, in this BR-CORTE edition, the effect of the genetic group was observed for the NRGNa using the power model (Table 10.11).

Table 10.11 - Net requirements of Na for growth as a function of genetic group (Zebu and crossbred cattle)

GG[1]	Body content (g)	NRGNa[2]
Zebu cattle	$7.9897 \times EBW^{0.7002}$	$EBG \times (5.594 \times EBW^{-0.2998})$
Crossbred cattle	$2.0985 \times EBW^{0.942}$	$EBG \times (1.977 \times EBW^{-0.058})$

[1]GG = genetic group; [2]NRGNa = net Na requirement for growth; EBW = empty body weight (kg); EBG = empty body gain (kg).

Common salt (NaCl) is routinely used in ruminant feeding as Na source. One of the main reasons for the innate desire of ruminants to consume salt was justified as a reflex response to dietary requirements and physiological status (Cheeke, 2005). However, ruminants have a considerable appetite for salt, consuming amounts greater than required (Morris, 1980). Thereby, the best indicator of Na nutrient status is its ratio with K, which should be approximately 20:1. Generally, diets of herbivores present a high K content due to its high concentrations in forages, which can cause low Na:K ratios (reaching a minimum limit of 10:1), contributing to an enhanced appetite for Na in herbivores.

Ruminants have a high capacity to retain Na in the rumen because Na can be absorbed into the blood in cases of Na deficiency, and under these conditions, K replaces Na in saliva (Cheeke, 2005). Na deficiency can decrease osmotic pressure, causing body dehydration. Decreased growth and protein efficiency and energy use are among the symptoms of Na deficiency (McDonald et al., 2002). More severe deficiency causes depraved appetite (Underwood and Suttle, 1999).

Potassium

Potassium (K) is the third most abundant ion in the body and the major cation in intracellular fluid. Along with Na, K has important functions in osmotic balance, muscle contraction, nerve impulse transmission, and several enzymatic systems. According to the ARC (1980), endogenous losses of K can be divided into estimated fecal (2.6 g/kg DM), urinary (37.5 mg/kg BW), salivary (0.7g/100 kg BW), and skin (1.1 g/d) losses, with the net requirements of K for maintenance calculated as the sum of these losses. These estimates were adopted by the BR-CORTE (2010). Notwithstanding, the data used by the ARC (1980) were only based on one study (St. Omer and Roberts, 1967), in which nine heifers were studied using a 3 × 3 Latin square experimental design to evaluate mineral balance. To standardize the net mineral requirements for maintenance, the BR-CORTE dataset estimates the net requirements of K for maintenance as 23.5 mg/kg BW (Figure 10.5). This value is lower than 38 mg/kg BW, which is recommended by the NRC (2001).

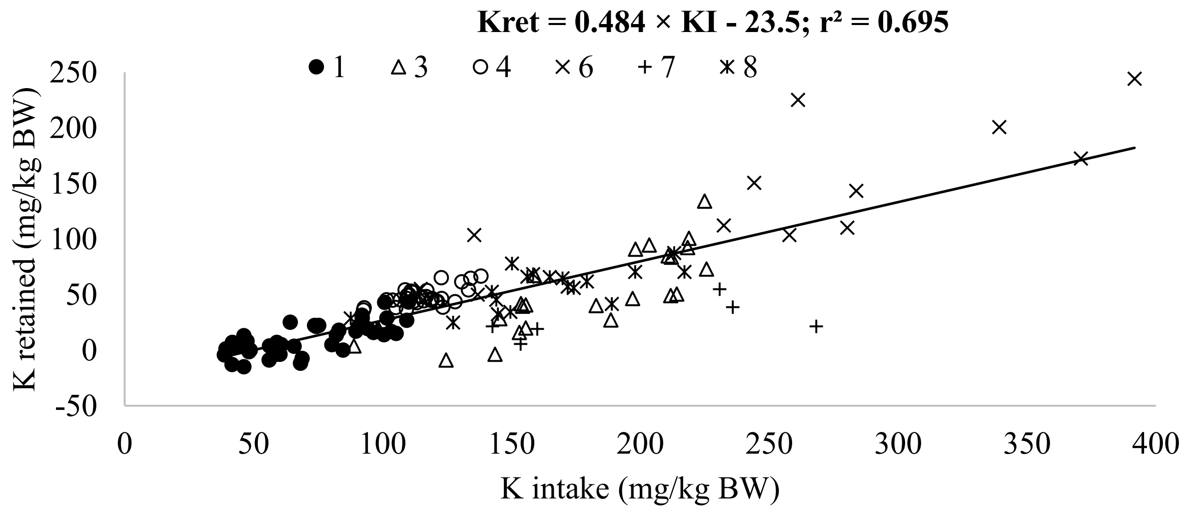

Figure 10.5 - Correlation between K retained (Kret) and K intake (KI) in beef cattle. Costa e Silva et al. (2015a - **1**), Zanetti (2014 - **3**), Prados (2016 - **4**), Marcondes (2010 - **6**), Gionbelli (2010 - **7**), Sathler (2015 - **8**).

Ward (1966) reported that K is absorbed in the rumen, abomasum, and small and large intestines. Sathler (2015) evaluated the absorption of K from several sites within the gastrointestinal tract and observed a negative absorption of K in the rumen and colon, suggesting that the secretion of K into the gastrointestinal tract is greater than its absorption. The substantial amount of ruminal K was due to salivary K secretions that were not quantified as part of K intake. The substantial colonic K secretion that occurs when Na absorption is high may be due to the contribution of K, Na, and Cl ion channels to transepithelial flow by coupling electrochemical gradients (Sathler, 2015).

The ARC (1980) and the NRC (2001) considered the absorption coefficient of K as 100 and 90%, respectively. These high values can be justified by Ward (1966), who indicated that urine is the main route of K excretion, which minimizes K reserves. Based on the dataset developed for this BR-CORTE edition, the fecal excretion of K cannot be neglected and the urinary excretion of K does not represent the total daily K excretion. Indeed, fecal and urinary excretions of K were 35.3 and 30.3% of the K intake, respectively, which provided a true retention coefficient of 48.4% (Figure 10.5), that is the value recommended in this BR-CORTE edition. This shows that there is no main route for K excretion. Therefore, the relatively lower nutrient requirement values currently recommended by several global councils should be re-assessed.

Regarding the effect of genetic group, the NRGK resulted in distinct equations for Zebu and crossbred cattle (Table 10.12). This NRGK is approximately 17% lower than the one previously reported in the BR-CORTE (2010).

Table 10.12 - Net requirements of K for growth as a function of genetic group (Zebu and crossbred cattle)

GG[1]	Body content (g)	NRGK[2]
Zebu cattle	$0.8437 \times EBW^{1.1216}$	$EBG \times (0.9463 \times EBW^{0.1216})$
Crossbred cattle	$0.2589 \times EBW^{1.3200}$	$EBG \times (0.3418 \times EBW^{0.3200})$

[1]GG = genetic group; [2]NRGK = net requirements of K for growth; EBW = empty body weight (kg); EBG = empty body gain (kg).

Sulfur

Several biomolecules are composed of S, such as amino acids (methionine, cystine, and cysteine), hormones (insulin and oxytocin), and metalloproteins, which are important to safeguard animals against Cu, Cd, and Zn excesses (Suttle, 2010).

Despite affirming that the dietary S requirements for beef and dairy cattle are not well-defined (NRC, 2000; NRC, 2001), the NRC recommended values between 1.5 and 2.0 g/kg DM. However, no net requirement of S for maintenance or retention coefficient were provided. From the database of this BR-CORTE edition, the net requirements of S for maintenance and the retention coefficient for Nellore cattle were 10.4 mg/kg BW and 77.3%, respectively (Figure 10.6).

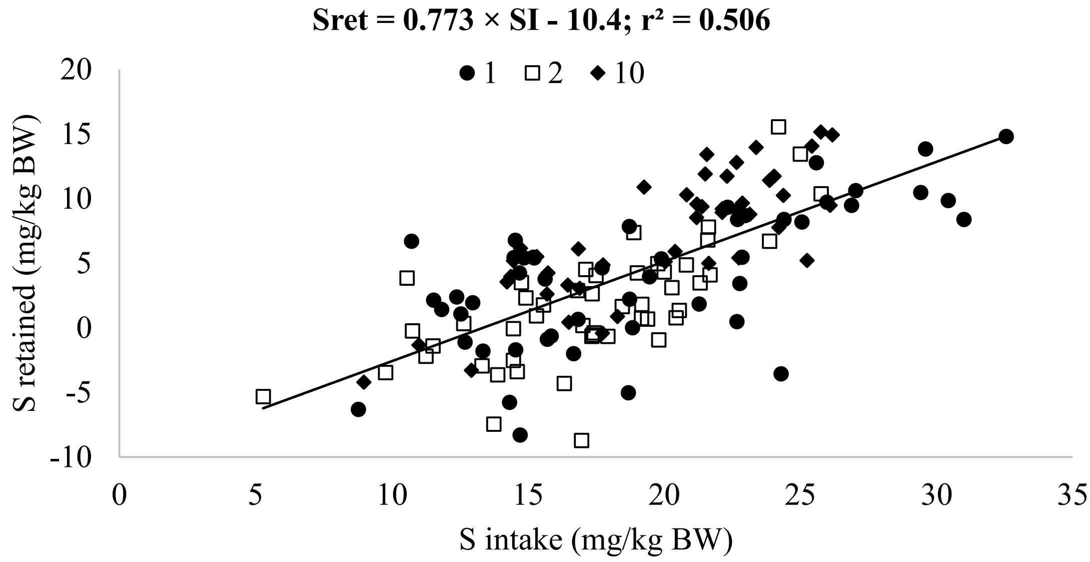

Figure 10.6 - Correlation between S retained (Sret) and S intake (SI) in beef cattle. Data from Costa e Silva et al. (2015a - **1 and 2**) and Zanetti et al. (2017 – **10**).

The NRGS is based on the data available, which is a single study developed by Costa e Silva et al. (2015a) and estimated based on the following equation:

$$NRGS = EBG \times (0.03 \times EBW^{0.89})$$

where EBG is the empty body gain (kg/d) and EBW is the empty body weight (kg).

In contrast to the other macrominerals, the exponent of the equation was positive, which infers that as the animal grows (increases its EBW), the NRGS increases. When expressed as DMI (g/kg), the estimated average dietary requirement of S is 1.36 g/kg DM, which approximates to that recommended by the NRC (2000), but is lower than that recommended by the NRC (2001). Costa e Silva et al. (2015a) reported that these differences could be due to the NRC (2001) data that was based on a single study (Bouchard and Conrad, 1973) of mid-term lactation Holstein cows producing 30 to 37 kg milk/d. However, we highlight the need for more studies to evaluate dietary requirements of S to improve the accuracy of these estimates.

Chlorine

In nature and in the body, Cl exists primarily as the chloride anion, Cl^-, which is the major anion present in extracellular fluid. This mineral is needed for the production of HCl in the gastric juice and amylase activation. Both Na and Cl^- are involved in the osmotic pressure maintenance, hydric balance control, and acid-base balance regulation (Underwood, 1981). To date, studies on dietary Cl^- are primarily concerned about microorganism control, such as *Escherichia coli* in the gastrointestinal tract (Callaway et al., 2002; Anderson et al., 2005), rather than evaluating the dietary requirements of this mineral.

Thus, the net requirements of Cl for maintenance and its retention coefficient in beef cattle are not well defined (Underwood and Suttle, 1999). Chloride deficiency does not seem probable in practical conditions (NRC, 2000). Information about endogenous Cl^- losses are not found in the literature; nevertheless, the ARC (1980) considers that there is an inevitable urinary loss, as occurs for Na. According to Aitken (1976), cattle raised under tropical conditions have a high maintenance requirement of Cl^- due to losses via skin and saliva, suggesting 1.6 g/d for a 500-kg animal raised under tropical conditions, *i.e.* exposed to approximately 40ºC for 7 h/d and air humidity of 90%. Such conditions are particularly probable in grazing animals raised under these conditions. For salivary losses, the recommendation of Cl^- is 0.9 g/d for each 100 kg BW. Smith et al. (2012) reported an average absorption of Cl^- (as $NaClO_3$) in cattle of 12.6% based on a compilation of studies that evaluated several chlorides using $^{36}Cl^-$ as isotopic marker.

The ARC (1980) estimated dietary requirements of 0.7 g/kg DM in beef cattle gaining 1.0 kg/d and due to the absence of studies on this subject in Brazil, we suggest that this value is adopted.

TRACE MINERALS

Due to the lack of studies on the dietary requirements of trace minerals in the literature, the recommendations in this BR-CORTE edition are only based on two studies (Costa e Silva et al, 2015a; Zanetti et al., 2017) and their descriptive statistics are shown in Table 10.4.

Copper

The functions of Cu in the body are related to lipid metabolism and the activation of several enzymes, such as cytochrome oxidase, ceruloplasmin, and superoxide dismutase. The main reserve organ of Cu is the liver, where Cu concentrations are influenced by dietary concentrations. Costa e Silva et al (2015a) reported an average intake of Cu of 83.5 mg/d, and Cu retention of 25.4 mg/d, which suggests that only 30.4% of the Cu intake is retained in animals. Nevertheless, 65.7 and 3.8% of the Cu intake was excreted via feces and urine, respectively. Sathler (2015) reported that fecal excretion of Cu in Nellore bulls varied from 38.6 to 62.0% of Cu intake, depending on whether macrominerals and/or trace elements were included in the diet. However, the urinary excretion of Cu was not measured.

In this BR-CORTE edition, the net requirements of Cu for maintenance was 95.6 μg/kg BW (Figure 10.7). This is higher than the value of 7.1 μg/kg BW recommended by the ARC (1980); however, to reach this value, the ARC (1980) assumed an equation that uses Cu intake, hepatic Cu loss, and BW changes. Meanwhile, the Australian system (CSIRO, 2007) adopted 4 μg/kg BW as the Cu requirement for maintenance, based on the results of a single study (Suttle, 1974) that evaluated Cu bioavailability in sheep.

Cu absorption in ruminants is considered low (<1 to 10%) compared to that reported for non-ruminants (Underwood and Suttle, 1999). Calves absorb approximately 70% of their dietary Cu, while adult cattle absorb 1 to 5% (NRC, 2001). This is primarily due to the complex interactions that occur in the rumen (Sathler, 2015). However, Sathler (2015) found that the absorption coefficient of Cu varied from 38.2 to 61.2%, depending on whether macrominerals and/or trace elements were included in the diet. The lowest absorption occurred when macrominerals but no trace elements were supplied.

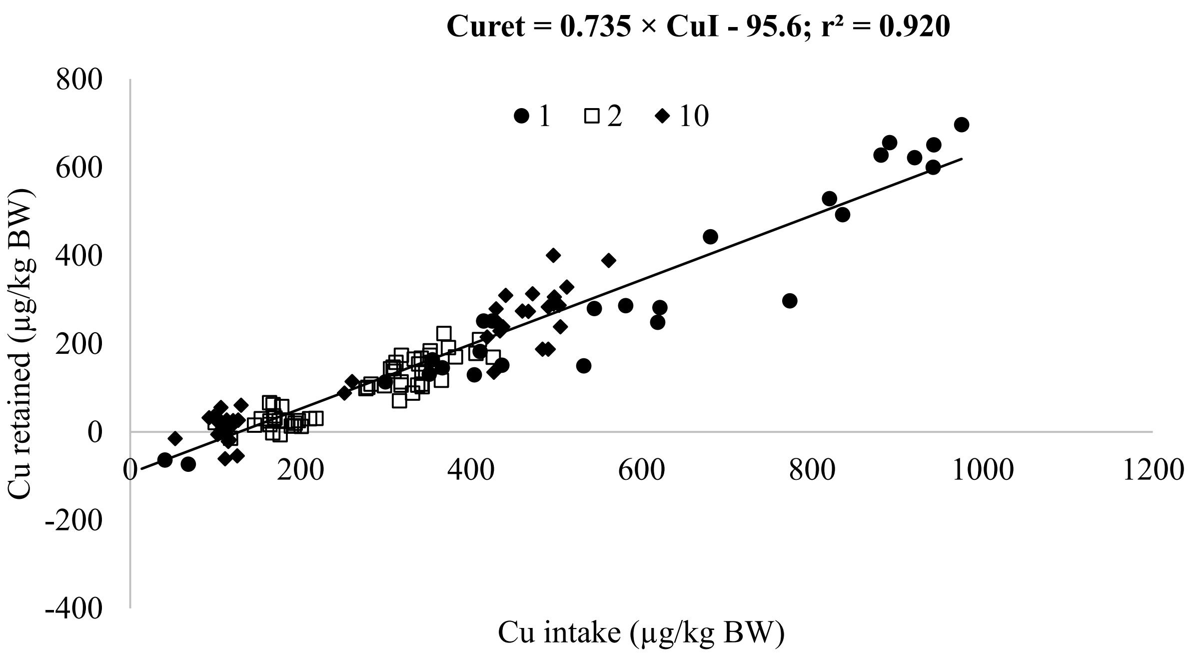

Figure 10.7 - Correlation between Cu retained (Curet) and Cu intake (CuI) in beef cattle. Data from Costa e Silva et al. (2015a - **1 and 2**) and Zanetti et al. (2017 – **10**).

Several factors can affect Cu absorption in ruminants, such as high dietary concentrations of Mo and S. These minerals interact with Cu, producing thiomolybdates, an insoluble complex, rendering Cu unavailable for absorption (Suttle, 1991). According to the NRC (2001), dietary requirements of Cu varied from 4 to 15 mg/kg DM depending on the dietary concentration of Mo and S. Thus, further studies that evaluate the interference of Mo and S in Cu absorption should be conducted to investigate the amount of Cu required to prevent its deficiency in animals. Furthermore, some studies have shown a decrease in ruminal absorption of Cu when Ca is added to the diet (Dick, 1954; Kirchgessner and Weser, 1965). Sathler (2015) reported that Cu absorption in the rumen, small intestine, and large intestine varied depending on the macromineral and/or trace element supplementation.

Costa e Silva et al. (2015a) suggested that the retention coefficient provides the most accurate estimate of dietary requirements and that the urinary excretion of mineral cannot be discarded. A total of 3.8% of Cu intake is excreted via urine (Costa e Silva et al., 2015a). Thus, the retention coefficient is 73.5% (Figure 10.7). This value is higher than 6% that is reported by the ARC (1980), which was recommended as the liver absorption coefficient, and found on studies with sheep.

The NRGCu was estimated as follows:

$$NRGCu = EBG \times (1.25 \times EBW^{0.33})$$

where EBG is the empty body gain (kg/d) and EBW is the empty body weight (kg, Costa e Silva et al., 2015a).

The exponent of the equation is positive, so, as S, we concluded that as the animal grows (increases EBW), the NRGCu increases.

Mullis et al. (2003) estimated dietary Cu requirements for Angus and Simmental heifers as 7 mg/kg DMI. The NRC (2000) recommends 10 mg/kg DMI dietary Cu for beef cattle. However, these recommendations do not consider the amount of Cu supplied in the basal diet but only the one used for supplementation. Costa e Silva et al. (2015a) evaluated the composition of the basal diet and found that the average dietary requirements of Cu for Nellore cattle were 9.53 mg/kg DMI and this BR-CORTE edition supports this recommendation. Nevertheless, Prados (2016) compared diets with (5.85 mg/kg DMI) and without Cu supplementation and found no difference in animal performance.

Iron

Iron (Fe) is an important component of various proteins that participate in the oxygen use and transport, such as hemoglobin, which contains 50% of all the Fe present in animals, myoglobin, cytochromes, and iron-sulfur proteins involved in the electron transport chain (NRC, 2000). In addition, an insufficient supply of Fe can decrease body reserves and Fe concentrations in the serum and blood hemoglobin (Thomas, 1970).

The NRC (2000) adopted results from two experiments (Bremmer and Dalgarno, 1973; Bernier et al., 1984), which evaluated Fe supplementation in calves fed milk to prevent anemia and concluded that 40 to 50 mg/kg DMI was adequate for animal growth and anemia prevention. Based on the data from Costa e Silva et al. (2015a) and Zanetti et al. (2017), the net requirements of Fe for maintenance and the retention coefficient in beef cattle are 2.9 mg/kg BW and 73.4%, respectively (Figure 10.8).

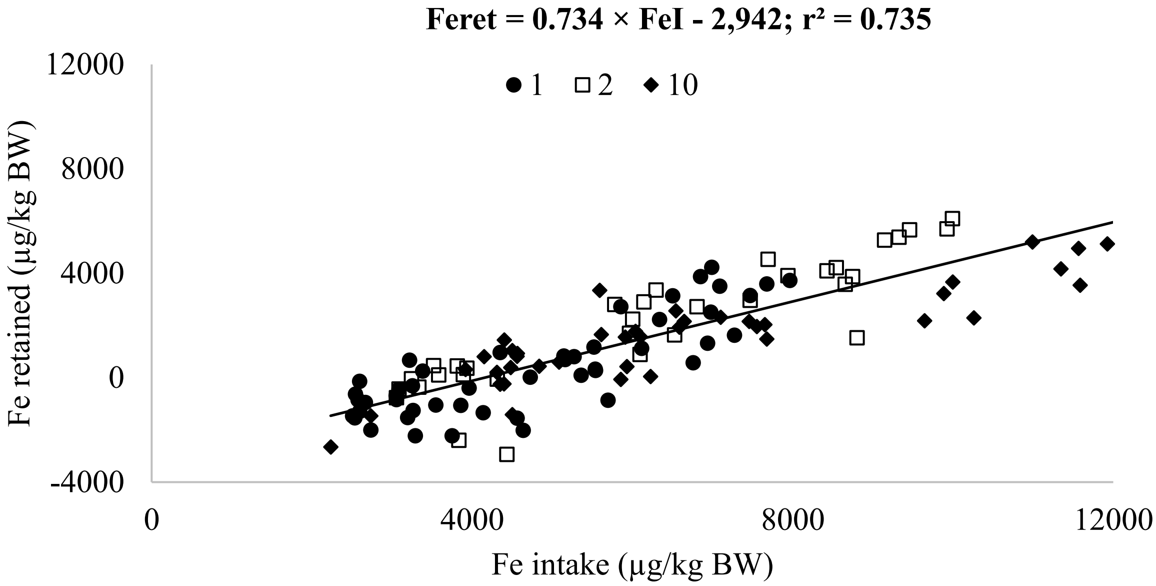

Figure 10.8 - Correlation between Fe retained (Feret) and Fe intake (FeI) in beef cattle. Data from Costa e Silva et al. (2015a - **1 and 2**) and Zanetti et al. (2017 – **10**).

For NRGFe, we used the equation suggested by Zanetti et al. (2017) :

$$NRGFe = EBG \times (10.4 \times EBW^{0.24})$$

where EBG is the empty body gain (kg/d) and EBW is the empty body weight (kg).

Thereby, the NRGFe increases as the animal grows, although at a slower rate. Similarly, the NRC (2000) suggests that as the animal grows, the relative requirements decrease because blood volume does not increase proportionally to BW.

The NRC (2000) recommended 50 mg/kg DMI as the dietary requirement of Fe. We suggest a higher average of 166 mg/kg DMI. However, we highlight that Fe concentration in the basal diet was considered in this BR-CORTE edition, while the NRC (2000) only evaluated Fe supplementation, discarding the amount of Fe provided by milk to the animals.

Manganese

Manganese (Mn) is widely distributed in the body tissues and fluids and its amount can vary according to species, age, organ, and the presence of other trace minerals in the diet. Some studies (Bentley and Phillips, 1951; Rojas et al, 1965; DiCostanzo et al, 1986) reported that Mn levels were associated with reproductive aspects but did not affect animal performance. Schroeder et al. (1966) recommended 20 to 25 mg/kg DMI of Mn for a good skeletal development.

The net requirements of Mn for maintenance and the retention coefficient were 184.9 µg/kg BW and 43.9%, respectively (Figure 10.9). The NRC (2001) suggests 2 µg/kg BW and 75% as the net requirements of Mn for maintenance and the absorption coefficient, respectively. However, some authors (Sansom et al, 1978; Sullivan et al, 1979; Van Bruwaene et al, 1984) suggest that only 1 to 4% Mn is absorbed regardless of its dietary concentration and that it is primarily absorbed in the small intestine. Sathler (2015) evaluated the partial absorption coefficients in the rumen, abomasum, and omasum and found that the main site of absorption was the rumen, where 35.1% of the Mn intake was absorbed. Furthermore, Hurley and Keen (1987) reported that high dietary concentrations of other minerals, such as Ca, P, and Fe, decrease Mn absorption. Sathler (2015) also reported that diets with high concentrations of macrominerals and trace minerals resulted in an absorption coefficient 15% lower than diets containing trace minerals without macrominerals. However, this author verified that the Mn absorption in the small intestine using the treatment with all minerals was greater compared to the treatment without macrominerals, with no differences in the coefficient of total apparent absorption.

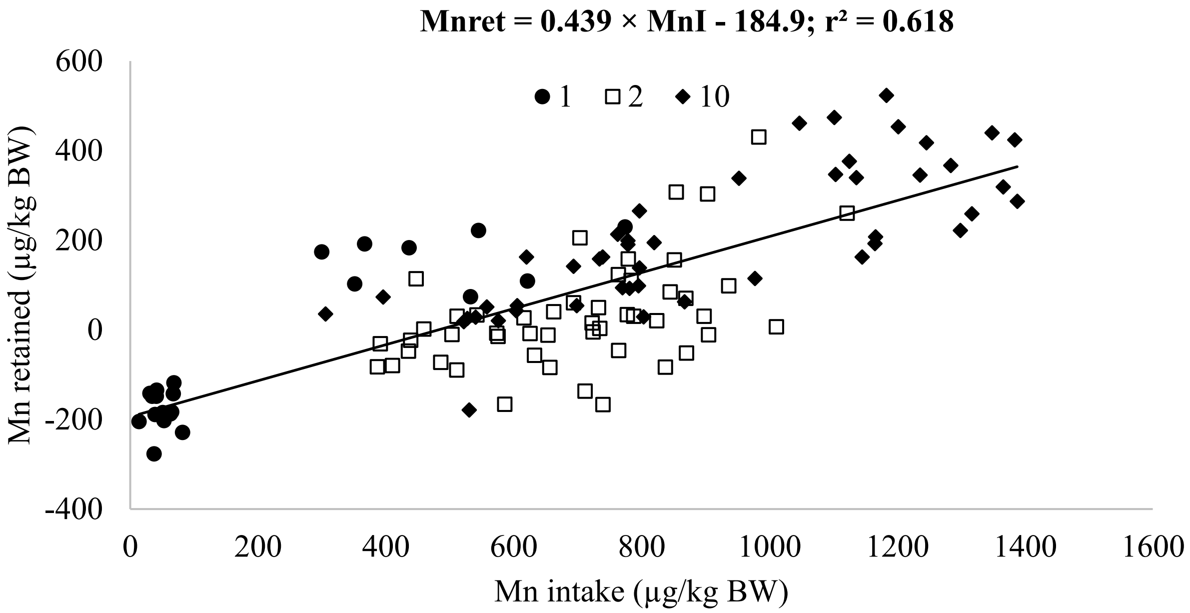

Figure 10.9 - Correlation between Mn retained (Mnret) and Mn intake (MnI) in beef cattle. Data from Costa e Silva et al. (2015a - **1 and 2**) and Zanetti et al. (2017 – **10**).

For NRGMn, Costa e Silva et al. (2015a) suggested the following equation:

$$NRGMn = EBG \times (0.07 \times EBW^{0.80})$$

where EBG is the empty body gain (kg/d) and EBW is the empty body weight (kg).

The NRC (2000) recommended 20 mg/kg DMI of dietary requirements of Mn and this was adopted by the BR-CORTE (2010). Hartmans (1974) fed cows with 2.5 to 3.5 years of age with diets containing 16 to 21 mg/kg DMI and did not observe symptons of Mn deficiency or improved animal performance. Possibly, the supply of Mn was above the requirements for optimal performance. Costa e Silva et al. (2015a) estimated dietary requirements of Mn as 9.59 mg/kg DMI and showed that similar animal performance was achieved when 10 mg/kg DMI was supplied.

Selenium

Se concentration in animals depends on the dietary amount of Se, its chemical form, and the tissue where the Se concentration is measured. According to Behne and Wolters (1983), high Se concentrations can occur in the liver and kidneys whereas the highest Se contents are captured by the muscles. In these tissues, Se activates enzymes involved in the production of thyroid hormones (T3 and T4), and as an antioxidant, decreasing hydrogen peroxide concentrations.

For the net requirements of Se for maintenance and the retention coefficient, we used the recommendations by Costa e Silva et al. (2015a) of 3.72 g/kg BW and 48.7%, respectively (Figure 10.10). This retention coefficient is higher than that by Wright and Bell (1966) who used a Se isotope in sheep and found an absorption coefficient of 35%. A similar value (30%) was suggested by the CSIRO (2007). However, the value found by Costa e Silva et al. (2015a) is within 40 to 50%, which is the range established by the NRC (2001).

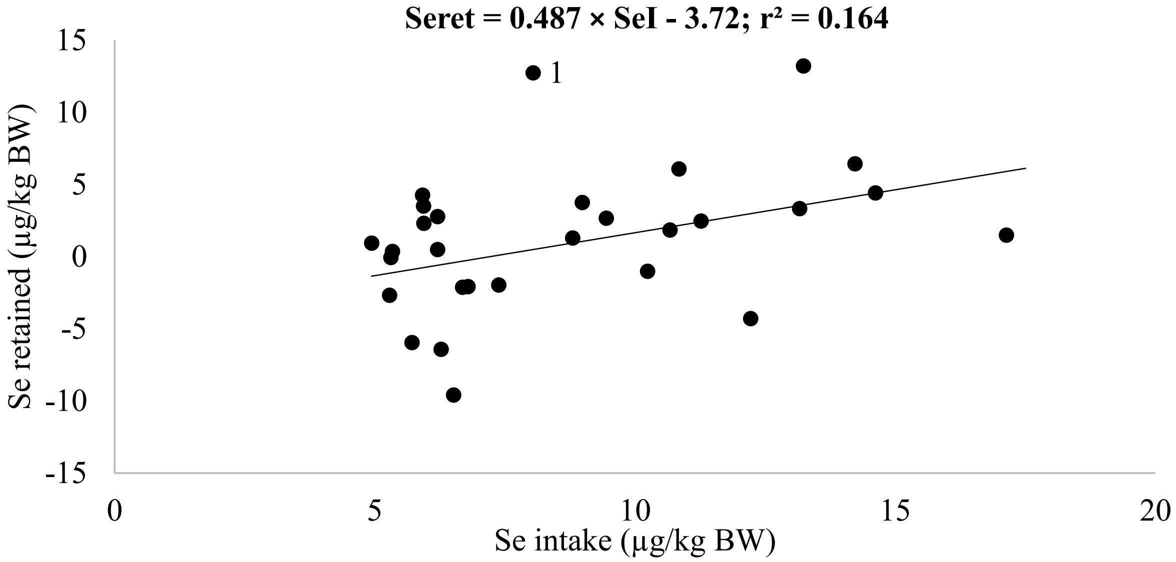

Figure 10.10 - Correlation between Se retained (Seret) and Se intake (SeI) in beef cattle. Data from Costa e Silva et al. (2015a - **1**).

For NRGSe, Costa e Silva et al. (2015a) suggested the following equation:

$$NRGSe = EBG \times (1.07 \times EBW^{-0.07})$$

where EBG is the empty body gain (kg/d) and EBW is the empty body weight (kg).

Thus, we conclude that NRGSe does not vary as the animal grows because the exponent of the equation is close to zero. Subclinical signs of Se deficiency have been reported in beef cows and calves fed forage containing 0.02 to 0.05 mg Se/kg DMI (Morris et al, 1984; Hidiroglou et al, 1985; Spears et al., 1986). In reference to these studies, the NRC (2000) recommended 0.1 mg/kg DMI as the dietary requirement of Se. However, Costa e Silva et al. (2015a) estimated 0.57 mg/kg DMI as the dietary requirements of Se. Moreover, this value is higher than that recommended by the CSIRO (2007) and the NRC (2001) of 0.05 and 0.30 mg/kg DMI, respectively. However, we emphasize that the values suggested by Costa e Silva et al. (2015a) were derived from only one experiment, containing 50 Nellore cattle, with BW varying between 121 and 300 kg. Therefore, we recommend further studies before the dietary requirements are conclusively defined.

Zinc

The functions of Zn in the body are mainly related to enzymatic action, either as a cofactor or by enzyme activation. Additionally, the development and functionality of the immune system are Zn-dependent. Some researchers (Delezenne, 1919; Bodansky, 1920; Weitzel et al, 1954) reported that the Zn concentrations in plants and animals are often comparable to Fe contents and are generally greater than other trace elements (Hambidge et al., 1986). The NRC (2000) used the average of three studies (Miller et al 1966; Hansard et al, 1968; Schwarz and Kirchgessner, 1975) to estimate Zn endogenous losses and estimated 12 µg/kg BW as the net requirements of Zn for maintenance. Weigand and Kirchgessner (1982) estimated the net requirements of Zn for maintenance in lactating cows as 53 µg/kg BW. Furthermore, the ARC (1980) and the NRC (2001) estimated the net requirements of Zn for maintenance as 55 µg/kg BW, while the CSIRO (2007) recommended 45 µg/kg BW. However, experiments conducted under tropical conditions and, adopted in the dataset of this BR-CORTE edition, suggest that the net requirements of Zn for maintenance is 334.4 µg/kg BW (Figure 10.11), which is higher than the above mentioned recommendations.

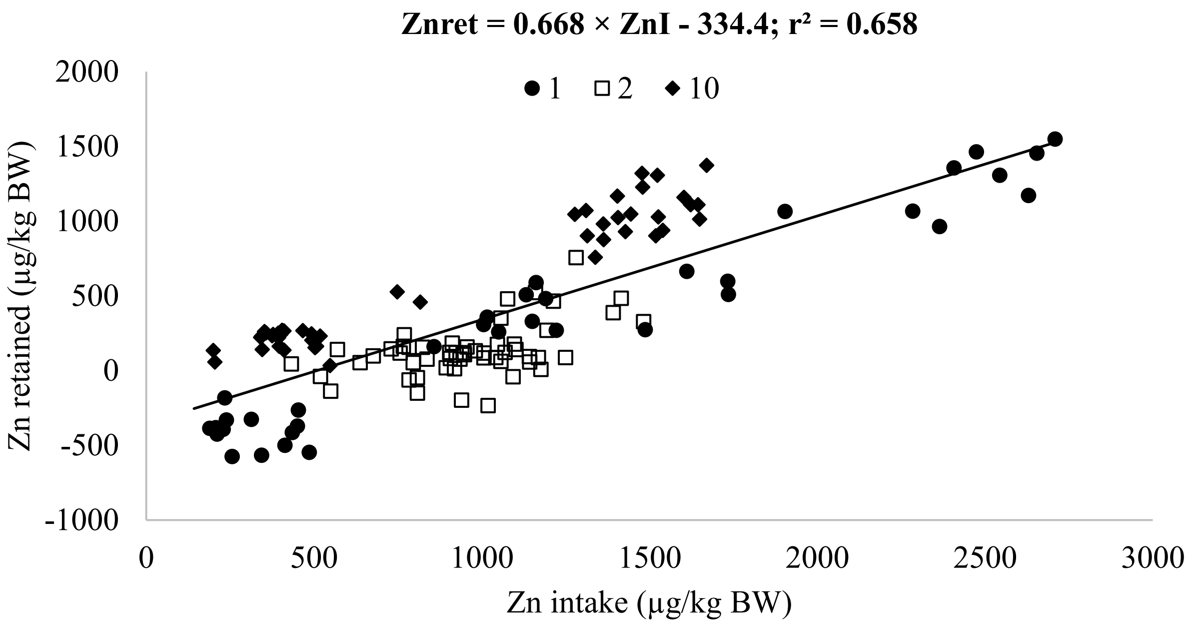

Figure 10.11 - Correlation between Zn retained (Znret) and Zn intake (ZnI) in beef cattle. Data from Costa e Silva et al. (2015a - **1 and 2**) and Zanetti et al. (2017 – **10**).

The ARC (1980) suggested two absorption coefficients for Zn, 30% for young ruminants and 20% for mature animals. The CSIRO (2007) adopted the true absorption coefficient of 60% for pre-ruminant calves and 40% for older animals with a functional rumen (SCA, 1990). However, from the BR-CORTE database, we observed a retention coefficient of 66.8% (Figure 10.11). Cragle and Miller (1965) suggested that Zn absorption occurs mainly in the abomasum and small intestine. However, Sathler (2015) verified that in diets with and without supplementation of trace elements, Zn was primarily absorbed in the rumen (approximately 43.7% of the Zn intake) and large intestine (an average of 27% of the Zn intake), respectively. Moreover, some studies (Mills et al, 1967; Perry et al, 1968) showed that Zn absorption is decreased when Ca is included in the diet. However, Sathler (2015) reported no differences in Zn absorption regardless of the dietary Ca. Nevertheless, Prados (2016) verified lower concentration of Zn in the liver when there was Ca supplementation in the diet, due to the interaction between Ca and Zn, lowering Zn absorption.

For NRGZn, Costa e Silva et al. (2015a) recommended the following equation:

$$NRGZn = EBG \times (1.16 \times EBW^{0.86})$$

where EBG is the empty body gain (kg/d) and EBW is the empty body weight (kg).

The ARC (1980) suggested that 16 to 31 mg Zn/kg BW can be incorporated into the body tissue for each kilogram of BW gain. The NRC (2000) considered the dietary requirements of Zn as 30 mg/kg DMI, while the CSIRO (2007) recommended 11.6 mg/kg DMI. However, the NRC (2000) recommendations were based on two studies (Perry et al, 1968; Pond and Otjen, 1988) that evaluated growth response to Zn supplementation when Zn concentration in the basal diet was unknown. However, Costa e Silva et al. (2015a) considered the Zn composition in the basal diet and reported 61 mg/kg DMI as the dietary requirement of Zn for Nellore cattle.

Cobalt

Co is the precursor of vitamin B_{12}, which is associated with energy metabolism. However, the amount of dietary Co that is converted to vitamin B_{12} varies from 3 to 13% of the Co intake (Smith, 1987). Furthermore, some studies (Monroe et al, 1952; Looney et al, 1976) found that 84 to 98% of the Co supplied in the diet is found in the feces approximately 5 to 14 days after intake. In this

BR-CORTE edition, the true retention coefficient was estimated as 86.8% (Figure 10.12) showing that only 13.2% of the Co intake was excreted via feces and urine. Additionally, the net Co requirements for maintenance in Nellore cattle was 13.5 µg/kg BW (Figure 10.12).

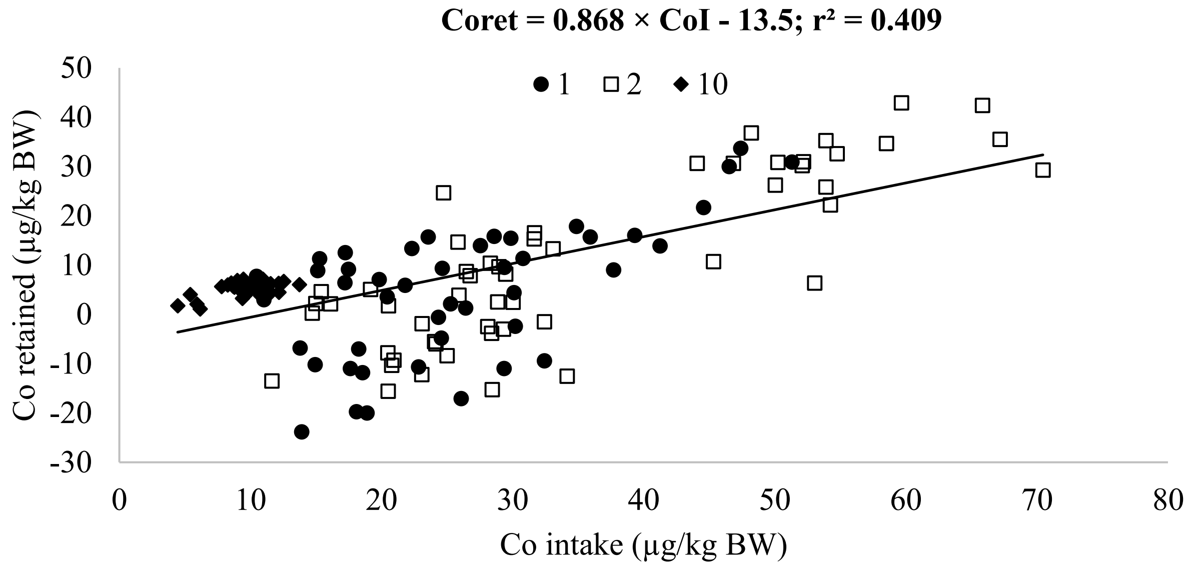

Figure 10.12 - Correlation between Co retained (Coret) and Co intake (CoI) in beef cattle. Data from Costa e Silva et al. (2015a - **1 and 2**) and Zanetti et al. (2017 - **10**).

The NRGCo was based on the equation suggested by Zanetti et al. (2017):

$$NRGCo = EBG \times (0.045 \times EBW^{-0.023})$$

where EBG is the empty body gain (kg/d) and EBW is the empty body weight (kg).

Thus, the NRGCo decreases as the EBW increases at an almost constant rate. Smith (1987) suggested 0.11 mg/kg DMI as the dietary requirement of Co, and this was adopted by the NRC (2000 and 2001). However, Smith (1987) did not consider the absorption coefficient or the Co content of the feeds. Thus, in this BR-CORTE edition, the dietary Co requirement was 0.63 mg/kg DMI, considering the retention coefficient and the contents of Co of the feeds.

Chromium

In the previous editions of BR-CORTE, the recommendations for the NRGCr and the retention coefficient were not suggested. However, Costa e Silva et al. (2015a) estimated the net Cr required for maintenance and the retention coefficient and the retention coefficient as 22.9 µg/kg BW and 78.4%, respectively (Figure 10.13).

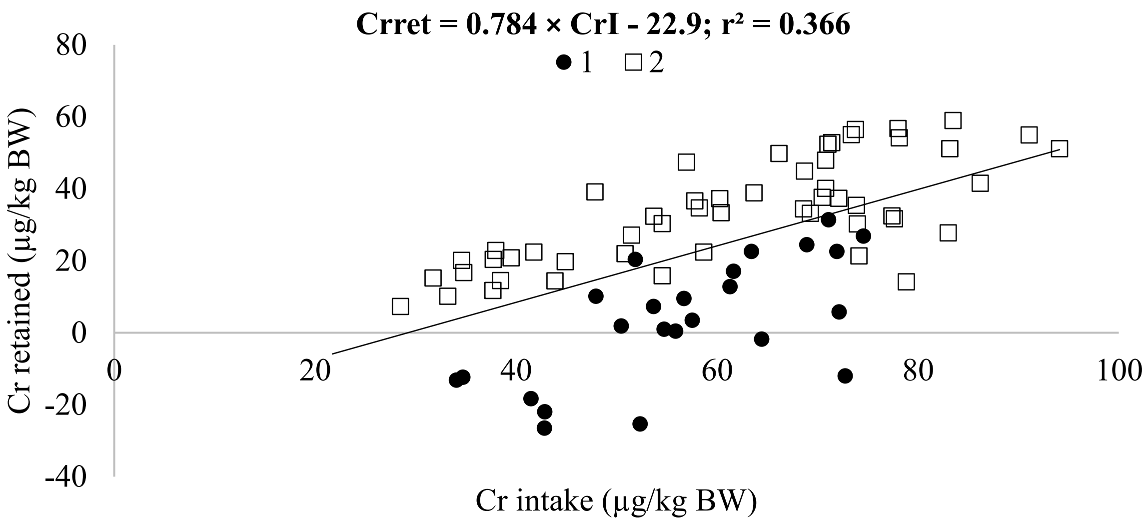

Figure 10.13 - Correlation between Cr retained (Crret) and Cr intake (CrI) in beef cattle. Data from Costa e Silva et al. (2015a - **1 and 2**).

Moreover, Costa e Silva et al. (2015a) estimated the NRGCr and suggested the following equation:

$$NRGCr = EBG \times (0.23 \times EBW^{0.61})$$

where EBG is empty body gain (kg/d) and EBW is the empty body weight (kg).

Bernhard et al. (2012) evaluated the effects of Cr supplementation on steer performance and observed a difference in the average daily gain (ADG) of non-supplemented steers compared to those receiving 0.3 mg/kg DMI. Additionally, some studies (Butting et al., 1994; Kegley and Spears, 1995) evaluated Cr supplementation in calves and suggested that 0.4 mg Cr/kg DMI inclusion increases glucose clearance rate. The NRC (2000) adopted this recommendation of 0.4 mg/kg DMI as the dietary requirement of Cr for beef cattle, despite being based on Cr supplementation and disregarding the Cr provided by the basal diet. However, Costa e Silva et al. (2015a) estimated 2.53 mg/kg DMI.

Molybdenum

Molybdenum (Mo) is an essential component of xanthine oxidase, aldehyde oxidase, and sulfite oxidase (Mills and Davis, 1987). Some authors have correlated Mo supplementation with improved microbial activity, increased cellulose digestion (Ellis et al., 1958), or increased disappearance rate of DM in the rumen (Sharif et al., 1990). Mo is related to the intra-ruminal synthesis of thio- or oxi-thiomolybdate, which can further react with Cu to inhibit the effects of dietary Mo and S sources by ruminants. However, studies evaluating the evidence of the direct and indirect production of thiomolybdates in ruminal contents of cattle remain inconclusive. Thus, it is necessary to verify the influence of changes in the dietary supply of Cu on the presence of soluble thiomolybdates in the rumen fluid and the Cu and Mo concentrations and distributions in the blood plasma. The NRC does not provide the dietary requirements of Mo, because its deficiencies are rarely observed. Zanetti et al. (2017) established the values of 3.27 µg/kg BW and 49.7% as the endogenous losses and the retention coefficient for Mo, respectively (Figure 10.14).

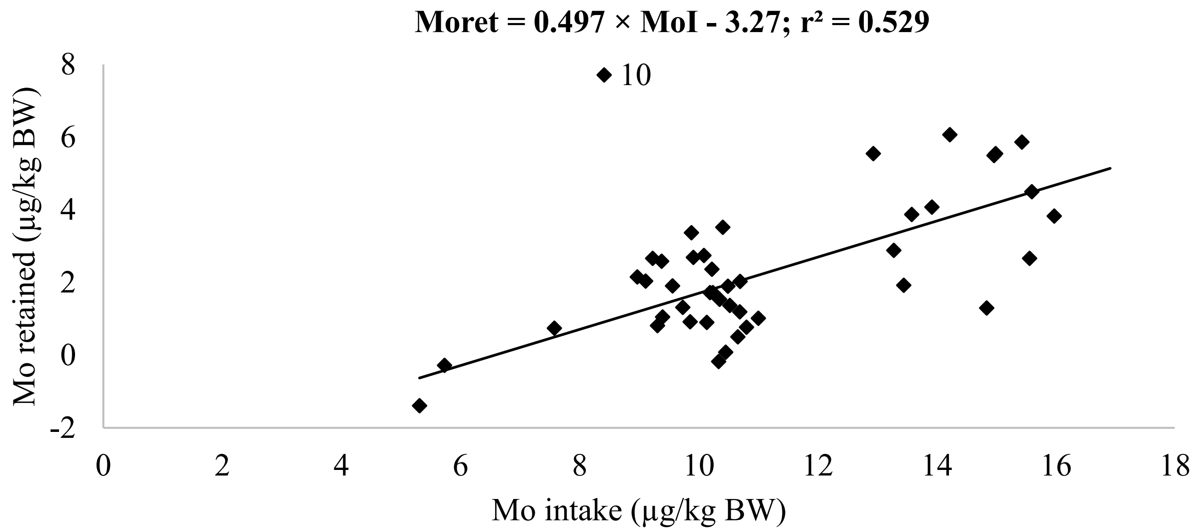

Figure 10.14 - Correlation between Mo retained (Moret) and Mo intake (MoI) in beef cattle. Data from Zanetti et al. (2017 - **10**).

Additionally, Zanetti et al. (2017) estimated the NRGCo and suggested the following equation:

$$NRGMo = EBG \times (0.00353 \times EBW^{0.4063})$$

where EBG is the empty body gain (kg/d) and EBW is the empty body weight (kg).

Iodine

Iodine (I) is an important component of thyroid hormones (thyroxine, T3, and triiodothyronine, T4), which regulates the energy metabolism rate in animals. Iodine is mostly absorbed as iodide (between 70 and 80%) in the rumen, presenting considerable secretion in the abomasum (Miller et al., 1988). However, its secretion in the abomasum is highly reabsorbed in the small and large intestines (NRC, 2000).

As for Cl, the dietary I requirements are not yet defined. The NRC (2000) suggested that 0.5 mg/kg DM could be adequate. According to the ARC (1980), dietary requirements of I can be estimated by measuring the thyroid hormone secretion rates. However, as there are no relevant studies of this mineral developed in Brazil, the BR-CORTE suggests the adoption of the recommendations from the NRC (2000) (0.5 mg/kg DM).

TOXICITY

When provided in large amounts, some inorganic elements can cause several adverse health issues in cattle. For the formulation of rations, we recommend that maximum dietary mineral levels are set at 120% of the dietary requirements to ensure a balance of dietary minerals without detrimental absorption and to avoid unnecessary losses. However, this balance is not always possible in practical conditions, The toxic mineral values obtained from the literature are presented in Table 10.13.

TABLES OF MINERAL REQUIREMENTS FOR BEEF CATTLE

Based on the estimated net requirements for maintenance and NRG, as well as the retention coefficient, net mineral requirements were obtained (Table 10.14).

Table 10.13 - Toxic mineral levels in beef cattle

Macromineral	Toxic level	Trace element	Toxic level
Calcium[1]	44 g/kg DM	Copper[4]	115 mg/kg DM
Potassium[4]	30 g/kg DM	Manganese[2]	1,000 mg/kg DM
Magnesium[1]	4 g/kg DM	Selenium[3]	5.0 mg/kg DM
Sodium[1]	65 g/kg DM	Zinc[3]	500 mg/kg DM
Sulfur[1]	4 g/kg DM	Cobalt[4]	1.0 mg/kg BW
		Chromium[2]	50 mg/kg DM
		Fluoride[3]	30 mg/kg DM
		Iodine[2]	50 mg/kg DM
		Molybdenium[3]	6.0 mg/kg DM
		Vanadium[2]	30 mg/kg DM

[1]NRC (2000); [2]McDonald et al. (2002); [3]McDowell (1992); [4]NASEM (2016). DM = dry matter.

Table 10.14 - Summary of the recommendations for calculation of net requirements of macrominerals and trace minerals for beef cattle

Mineral	Net requirements for maintenance	Retention coefficient	Net requirements for growth (NRG)[1]	EBW in the plateau
	mg/kg body weight	%	g/d	kg
Ca	11.7	56.8	Zebu cattle: $NRGCa = EBG \times (147 \times EBW^{-0.50})$	462
			Crossbred cattle: $NRGCa = EBG \times (66.0 \times EBW^{-0.32})$	453
P	13.5	67.8	Zebu cattle: $NRGP = EBG \times (38.6 \times EBW^{-0.36})$	445
			Crossbred cattle: $NRGP = EBG \times (25.4 \times EBW^{-0.25})$	479
Mg	5.9	35.5	Zebu cattle: $NRGMg = EBG \times (0.3466 \times EBW^{0.0113})$	-
			Crossbred cattle: $NRGMg = EBG \times (1.0597 \times EBW^{-0.2386})$	-
Na	6.3	37.1	Zebu cattle: $NRGNa = EBG \times (5.594 \times EBW^{-0.2998})$	-
			Crossbred cattle: $NRGNa = EBG \times (1.977 \times EBW^{-0.058})$	-
K	23.5	48.4	Zebu cattle: $NRGK = EBG \times (0.9463 \times EBW^{0.1216})$	-
			Crossbred cattle: $NRGK = EBG \times (0.3418 \times EBW^{0.3200})$	-
S	10.4	77.3	$NRGS = EBG \times (0.03 \times EBW^{0.8900})$	-
	mg/kg body weight	%	mg/d	
Cu	95.6	73.5	$NRGCu = EBG \times (1.25 \times EBW^{0.33})$	-
Co	13.5	86.8	$NRGCo = EBG \times (0.045 \times EBW^{-0.023})$	-
Cr	22.9	78.4	$NRGCr = EBG \times (0.23 \times EBW^{0.61})$	-
Fe	2,942	73.4	$NRGFe = EBG \times (10.4 \times EBW^{0.24})$	-
Mn	184.9	43.9	$NRGMn = EBG \times (0.07 \times EBW^{0.80})$	-
Mo	3.27	49.7	$NRGMo = EBG \times (0.0035 \times EBW^{0.41})$	-
Se	3.72	48.7	$NRGSe = EBG \times (1.07 \times EBW^{-0.07})$	-
Zn	334.4	66.8	$NRGZn = EBG \times (1.16 \times EBW^{0.86})$	-

[1]EBG = empty body gain (kg/d); EBW = empty body weight (kg); NRG = net mineral requirement for growth, where mineral Ca = calcium, P = phosphorus, Mg = magnesium, Na = sodium, K = potassium, S = sulfur, Cu = copper, Co = cobalt, Cr = chromium, Fe = iron, Mn = manganese, Mo = molybdenum, Se = selenium, Zn = zinc.

Therefore, considering a 400-kg Nellore bull with ADG of 1.0 kg/d, the dietary requirements of macrominerals and trace elements can be calculated as follows:

$SBW = 0.8915 \times BW^{1.0151} = 0.8915 \times 400^{1.0151} = 390.4$ kg
$EBW = 0.8126 \times SBW^{1.0134} = 0.8126 \times 390.4^{1.0134} = 344$ kg
$EBG = 0.963 \times ADG^{1.0151} = 0.963 \times 1.0^{1.0151} = 0.963$ kg

• Calcium:
Maintenance: $11.7 \times BW = 11.7 \times 400 = 4{,}680$ mg = 4.68 g/d
Growth: $EBG \times (147 \times EBW^{-0.50}) = 0.963 \times (147 \times 344^{-0.50}) = 7.63$ g/d
Total net requirements = maintenance + growth = 4.68 + 7.63 = 12.31 g/d
Dietary requirements = total net requirements/retention coefficient = 12.31/0.568 = 21.67 g/d

• Phosphorus:
Maintenance: $13.5 \times BW = 13.5 \times 400 = 5{,}400$ mg = 5.40 g/d
Growth: $EBG \times (38.6 \times EBW^{-0.36}) = 0.963 \times (38.6 \times 344^{-0.36}) = 4.54$ g/d
Total net requirements = maintenance + growth = 5.40 + 4.54 = 9.94 g/d
Dietary requirements = total net requirements/retention coefficient = 9.94/0.678 = 14.66 g/d
Ca/P ratio =21.67/14.66 = 1.48

• Magnesium:
Maintenance: $5.9 \times BW = 5.9 \times 400 = 2{,}360$ mg = 2.36 g/d
Growth: $EBG \times (0.3466 \times EBW^{0.0113}) = 0.963 \times (0.3466 \times 344^{0.0113}) = 0.36$ g/d
Total net requirements = maintenance + growth = 2.36 + 0.36 = 2.72 g/d
Dietary requirements = total net requirements/retention coefficient = 2.72/0.355 = 7.66 g/d

• Sodium:
Maintenance: $6.3 \times BW = 6.3 \times 400 = 2{,}511$ mg = 2.52 g/d
Growth: $EBG \times (5.594 \times EBW^{-0.2998}) = 0.963 \times (5.594 \times 344^{-0.2998}) = 0.94$ g/d
Total net requirements = maintenance + growth = 2.52 + 0.94 = 3.46 g/d
Dietary requirements = total net requirements/retention coefficient = 3.46/0.371 = 9.33 g/d

• Potassium:
Maintenance: $23.5 \times BW = 23.5 \times 400 = 9{,}400$ mg = 9.40 g/d
Growth: $EBG \times (0.9463 \times EBW^{0.1216}) = 0.963 \times (0.9463 \times 344^{0.1216}) = 1.85$ g/d
Total net requirements = maintenance + growth = 9.40 + 1.85 = 11.25 g/d
Dietary requirements = total net requirements/retention coefficient = 11.25/0.484 = 23.24 g/d

• Sulfur:
Maintenance: $10.4 \times BW = 10.4 \times 400 = 4{,}160$ mg = 4.16 g/d
Growth: $EBG \times (0.03 \times EBW^{0.89}) = 0.963 \times (0.03 \times 344^{0.89}) = 5.23$ g/d
Total net requirements = maintenance + growth = 4.16 + 5.23 = 9.39 g/d
Dietary requirements = total net requirements/retention coefficient = 9.39/0.773 = 12.19 g/d

• Copper:
Maintenance: $95.6 \times BW = 95.6 \times 400 = 38{,}240$ μg = 38.24 mg/d
Growth: $EBG \times (1.25 \times EBW^{0.33}) = 0.963 \times (1.25 \times 344^{0.33}) = 8.27$ mg/d
Total net requirements = maintenance + growth = 38.24 + 8.27 = 46.51 mg/d
Dietary requirements = total net requirements/retention coefficient = 46.51/0.735 = 63.28 mg/d

• Iron:
Maintenance: $2{,}942 \times BW = 2{,}942 \times 400 = 1{,}176.800$ μg = 1,177 mg/d
Growth: $EBG \times (10.4 \times EBW^{0.24}) = 0.963 \times (10.4 \times 344^{0.24}) = 40.7$ mg/d
Total net requirements = maintenance + growth = 1,177 + 40.7 = 1,218 mg/d
Dietary requirements = total net requirements/retention coefficient = 1,218/0.734 = 1,659 mg/d

Manganese:
Maintenance: 184.9 × BW = 184.9 × 400 = 73,960 μg = 73.96 mg/d
Growth: EBG × (0.07 × $EBW^{0.80}$) = 0.963 × (0.07 × $344^{0.80}$) = 7.21 mg/d
Total net requirements = maintenance + growth = 73.96 + 7.21 = 81.17 mg/d
Dietary requirements = total net requirements/retention coefficient = 81.17/0.439 = 184.9 mg/d

• Selenium:
Maintenance: 3.72 × BW = 3.72 × 400 = 1,488 μg = 1.49 mg/d
Growth: EBG × (1.07 × $EBW^{-0.07}$) = 0.963 × (1.07 × $344^{-0.07}$) = 0.68 mg/d
Total net requirements = maintenance + growth = 1.49 + 0.68 = 2.17 mg/d
Dietary requirements = total net requirements/retention coefficient = 2.17/0.487 = 4.46 mg/d

• Zinc:
Maintenance: 334.4 × BW = 334.4 × 400 = 133,760 μg = 133.8 mg/d
Growth: EBG × (1.16 × $EBW^{0.86}$) = 0.963 × (1.16 × $344^{0.86}$) = 169.6 mg/d
Total net requirements = maintenance + growth = 133.8 + 169.6 = 303.4 mg/d
Dietary requirements = total net requirements/retention coefficient = 303.4/0.668 = 454.2 mg/d

• Cobalt:
Maintenance: 13.5 × BW = 13.5 × 400 = 5,400 μg = 5.40 mg/d
Growth: EBG × (0.045 × $EBW^{-0.023}$) = 0.963 × (0.045 × $344^{-0.023}$) = 0.038 mg/d
Total net requirements = maintenance + growth = 5.40 + 0.038 = 5.438 mg/d
Dietary requirements = total net requirements/retention coefficient = 5.438/0.868 = 6.26 mg/d

• Chromium:
Maintenance: 22.9 × BW = 22.9 × 400 = 9,160 μg = 9.16 mg/d
Growth: EBG × (0.23 × $EBW^{0.61}$) = 0.963 × (0.23 × $344^{0.61}$) = 7.81 mg/d
Total net requirements = maintenance + growth = 9.16 + 7.81 = 16.97 mg/d
Dietary requirements = total net requirements/retention coefficient = 16.97/0.784 = 21.65 mg/d

• Molybdenum:
Maintenance: 3.27 × BW = 3.27 × 400 = 1,310 μg = 1.31 mg/d
Growth: EBG × (0.0035 × $EBW^{0.4063}$) = 0.963 × (0.0035 × $344^{0.41}$) = 0.037 mg/d
Total net requirements = maintenance + growth = 1.31 + 0.037 = 1.347 mg/d
Dietary requirements = total net requirements/retention coefficient = 1.347/0.497 = 2.71 mg/d

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