NUTRITIONAL REQUIREMENTS OF NELLORE COWS AND CALVES

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INTRODUCTION

In tropical countries, beef production is based primarily on Zebu cattle breeds (*Bos indicus*), mostly Nellore and hybrids of this species with *Bos taurus* (Yokoo et al., 2010; Chizzotti et al., 2008). It is estimated that Brazil has more than 55 million of beef cows. Most of these are Zebu cattle, which are responsible for supplying the entire beef market with their products (Anualpec, 2008). However, few studies in Brazil have examined the nutritional requirements of the breeding herd, particularly those of cow-calf pairs. For other categories of cattle, especially bulls and steers in the growth and fattening stages, a reasonable number of studies have been performed, providing a foundation for broader studies that have developed nutritional recommendations for this stage of the beef production cycle (Valadares Filho et al., 2006; Chizzotti et al., 2008).

The importance of the breeding sector in the efficiency of beef production cannot be underestimated. About 31% of the beef-cattle herd is made up of beef cows (Calegare, 2004), and about 70-75% of the dietary energy intake in beef production is directed toward maintenance (Ferrel and Jenkins, 1985) rather than directly to meat production (Kelly et al., 2010). The breeding herd, which consists of cow-calf pairs, uses about 65-75% of the energy required for the entire production cycle. Therefore, roughly 50% of the energy required for animal production up to the point of slaughter is used for the maintenance of cows.

The energy demands for maintenance can vary between 20 and 30%, based on genetic differences among individuals of one breed or among animals of different breeds or genotypes. Energy demand is a moderately to highly heritable characteristic (Carstens et al., 1988). The total energy requirement for maintenance is a function of the metabolizable energy intake necessary to maintain an unchanging level of body energy. It has been proposed that protein turnover, ion pumping (Na^+ and K^+, for example) and the uncoupling of oxidative phosphorylation in the mitochondria (proton leakage) are responsible for approximately 60-70% of the total energy required for maintenance. This percentage essentially represents the energetic inefficiency of the animals (Bottje and Carstens, 2009). Therefore, selective tools could be adopted to identify and utilize animals that have lower maintenance requirements (Di Constanzo et al., 1991), thus improving the efficiency of beef production.

To improve the economic and environmental sustainability of beef-production systems, animals that use available resources more efficiently should be identified (Kelly et al., 2010). In fact, current genetic evaluation programs use differences in maintenance requirements among individuals to produce more efficient and productive animals according to the specific requirements of each production system (Evans et al., 2002).

According to Webster (1979), animals' energetic requirements include maintenance and production, which, in turn, includes growth, lactation and gestation (from the final third of the gestation period onward, a stage when the fetus grows rapidly and effectively changes the nutritional requirements of the cow).

The demands of various organs define the partitioning of nutrient use for synthesis or catabolism (Reynolds, 2002). Tissues with high metabolic rates have priority in substrate targeting. For lactating cows, the udder tissue (mammary glands) has a high priority for nutrient allocation, which in turn is determined by blood flow and by nutrient concentrations in the blood. The use of amino acids is connected to the protein-synthesis capacity of the mammary tissue (Metcalf et al., 1996).

While associating this process with greater heat production by lactating cows, Reynolds and Tyrrel (2000) have found that the maintenance requirements of these animals are 22-41% greater than those of non-lactating animals. In a study of grazing taurine cows (a Simmental x Hereford crossbreed), Brosh et al. (2010) have observed that the heat production of lactating animals is about 31.84% greater than that of non-lactating cows.

Body size can also affect nutritional demands. Ferrel and Jenkins (1984) have demonstrated that larger cows have greater nutritional requirements during both lactating and dry periods and that the offspring of larger cows also have greater nutritional demands. On the other hand, calves whose mothers produced more milk consume less feed. This correlation is important to consider when adopting new technologies in a breeding system that is characterized by high production costs and lower returns.

Jenkins and Ferrel (1993) have observed that cows that consume less feed wean lighter calves. However, such cows are more efficient in the amount of energy intake per kilogram of calf produced.

Studies designed to analyze nutritional requirements are not simple and are even more difficult when dealing with lactating cows. The intrinsic experimental difficulties in determining nutritional requirements include the involvement between cows and calves, which makes it necessary to measure milk production both as a part of the energetic output of the cow and of the metabolizable energy inputs consumed by the calf. The composition of the milk and the body composition of the animals must also be measured.

Measurement of milk production can be done either directly or indirectly. The most common methods are manual milking (Gifford, 1953), weighing of the calf before and after intake (Knapp and Black, 1941), mechanical milking after oxytocin application (Anthony et al., 1959) and measuring the concentration of deuterium monoxide in milk (Freetly, 2006).

Genetic potential for milk production and growth is positively correlated with metabolizable energy requirements for maintenance (ME_m) when different genotypes are evaluated under normal management conditions (Ferrel and Jenkins, 1985).

Measurements of milk production establish the amount of energy discharged through the milk, making it possible to estimate the appropriate time to supplement the calves, i.e., when the nutrient supply through milk is no longer sufficient to supply the calves needs to obtain the desired weight gain.

MILK PRODUCTION AND COMPOSITION OF LACTATING NELLORE COWS

Henriques et al. (2009) have evaluated various models to estimate the milk production of lactating Nellore cows and have recommended the use of a model described by Jenkins and Ferrell (1984) and modified by Detmann (personal communication). According to this model, $MY = 5.9579 + 0.4230 \times S \times e^{(-0.1204xS)}$, where MY is daily milk yield, S is the week of lactation and ASD is the asymptotic standard deviation (Figure 1).

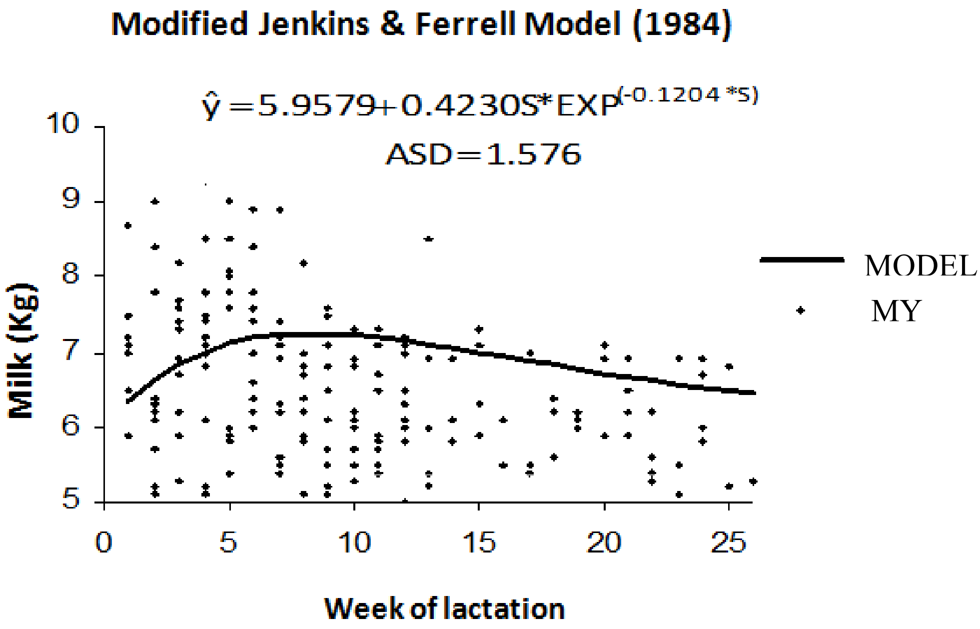

Figure 1 - Estimated milk yield (MY) as a function of the week of lactation (adapted from Henriques et al., 2009).

The milk production peak (7.25 kg/day) occurs after roughly 8.5 weeks of lactation (Figure 1), corroborating the values reported in the NRC (2000). For lactating Nellore cows, Restle et al. (2003) have found a maximum production of 5.4 kg/day on the 84th day of lactation.

Fonseca (2009) has observed that the milk produced by primiparous Nellore heifers contains, on average, 3.7% crude protein, 3.88% fat, 4.74% lactose and net energy (NE) value of 0.75 Mcal /kg (Table 1). These values are similar to those reported in the NRC (2000) (3.4% and 4% for fat and protein, respectively). However, both protein content values are greater than the 3.16% found by Cerdotés et al. (2004) for Nellore, Charolais and Nellore x Charolais crossbred cows and less than the 4.28% found by Porto (2009) for Nellore cows. The fat and lactose contents found by Fonseca (2009) are also lower than those found by Restle et al. (2003) (5.00% and 5.14%, respectively) and greater than those found by Porto (2009) (3.55% and 3.99%).

For the total solids content, Restle et al. (2003) and Porto (2009) have found intermediate values of 13.78% and 12.52%, respectively. However, Senna et al. (1996) have found an average value of 3.3% for fat content and values between 11.6% and 12.2% for total solids (TS). Silva et al. (1995) have verified that the TS of milk from Nellore cows shows quadratic behavior across the lactation period, reaching its maximum value (14.1%) on the 117th day. The overall average found by Fonseca (2009) is 13.78%, close to that found by Cruz et al. (1997) (14.58%). Oscillations in TS content reflect changes in the sum of other milk components, principally fat. Among milk components, fat varies the most during lactation. Generally, the fat percentage in milk increases gradually with the duration of the lactation period, thus being negatively correlated with milk production (Lamond et al., 1969; Rutledge et al., 1971).

For SNF (solids non fat) content, some authors have noted slow declines until the end of lactation (Maynard et al., 1984; Schmidt and Van Veck, 1976).

For lactose, which is the major milk carbohydrate synthesized in mammary glands, Senna (1996) has found values of 5.1% for Nellore cows.

According to Holloway et al. (1975) and Bowden (1981), milk composition may be influenced by the cow's genetic makeup and by the stage of lactation at the time of measurement.

Table 1 - Average milk composition of Nellore cows between 0 and 180 days of lactation

Item	0-180 days
NE_l (Mcal/kg)	0.75 ± 0.01
CP (%)	3.71 ± 0.20
Fat (%)	3.88 ± 0.06
Lactose (%)	4.74 ± 0.04
Total solids (%)	13.31 ± 0.21

CP = crude protein; NE =net energy.

Based on information from Fonseca (2009), which models the lactation curve of Nellore cows from milk production data obtained by weighing calves before and after intake, together with the average composition of the milk and the nutritional requirements of calves at the pre-weaning stage, it is possible to determine the point at which milk alone can no longer supply the nutrients needed for the calf's growth. Considering energy and protein as the most limiting nutrients, milk cannot supply all the necessary energy for the calf to gain about 800 g/day from the 9th week of life (roughly 63 days of age). On the other hand, protein becomes the limiting factor from the 15th week (roughly 105 days) onward, which is about 105 to 135 days before weaning. Therefore, for Nellore calves to reach a weight of about 200 kg at weaning, supplementation via creep feeding is necessary from the second month of life onward, unless cows that produce more milk for the calf are used (Table 2).

Table 2 - Milk production of Nellore cows, availability of ME and MP from milk, total ME and MP requirements for maintenance and weight gain of suckling Nellore calves and milk needed to supply the ME demands of calves according to week of lactation and animal weight

W	Calf weight	ME from Milk	MP from milk	ME_t	MP_t	MN
1	35.60	4.63	160.71	2.91	154.87	3.98
2	41.20	4.85	168.06	3.25	156.79	4.45
3	46.80	5.01	173.63	3.58	158.65	4.89
4	52.40	5.12	177.72	3.90	160.49	5.32
5	58.00	5.21	180.59	4.20	162.29	5.75
6	63.60	5.26	182.46	4.50	164.09	6.16
7	69.20	5.29	183.54	4.80	165.87	6.56
8	74.80	5.30	183.97	5.09	167.66	6.95
9	80.40	5.30	183.88	5.37	169.44	7.34
10	86.00	5.29	183.39	5.65	171.23	7.72
15	114.00	5.12	177.65	6.98	180.34	8.09

W = week of lactation; calf weight in kg based on a birth weight of 30 kg and average daily gain of 0.8 kg/day; ME through milk = amount of metabolizable energy delivered to the calf through milk (Mcal/day); MP through milk = amount of metabolizable protein delivered to the calf through milk (g/day); ME_t = total metabolizable energy requirements of the calf (for maintenance + weight gain); MP_t = total metabolizable protein requirements of the calf (for maintenance + weight gain); MN = milk needed (kg/day) to supply the total ME requirements of the calf.

ENERGY REQUIREMENTS OF LACTATING COWS AND CALVES

Based on the findings of Fonseca (2009), the relationships between empty body weight (EBW) and body weight (BW) were 0.894 and 0.9622 for cows and calves, respectively. However, the ratios between empty body weight gain (EBG) and average daily body weight gain (ADG) were 0.936 and 0.958 for cows and calves, respectively.

The net energy requirements for the maintenance of cows (NE_m) were obtained from the equation $HP = 97.84 \times e^{0.0024 \times MEI}$, $s_{XY} = 0.5578$, as shown in Figure 2, where HP = heat production and MEI = metabolizable energy intake. To calculate HP, the energy retained in the body of cows, as determined by the comparative slaughter technique, and the energy secreted in the milk was subtracted from MEI. Therefore, when MEI is equal to zero, the equation above yields a value of 97.84 kcal/kg $EBW^{0.75}$, which corresponds to the fasting heat production i.e.,the net energy requirement for maintenance (NE_m).

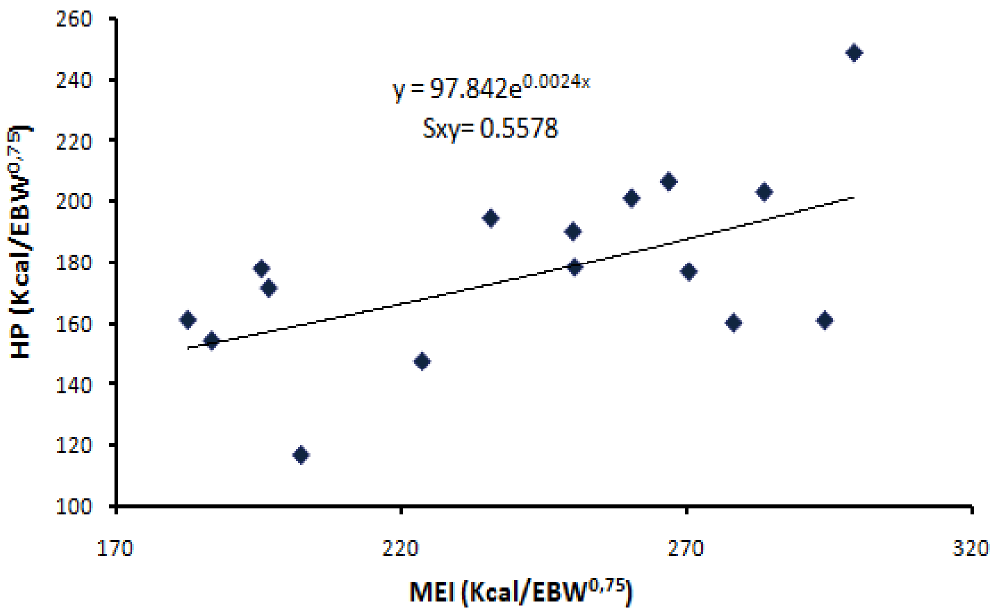

Figure 2 - Relationship between heat production (HP) and metabolizable energy intake (MEI).

The NRC (2000) has established a NE_m requirement of 77 Kcal/ $BW^{0.75}$, based on data obtained by Lofgreen and Garret (1968), recommending a 10% reduction for *Bos indicus* animals and a 20% increase for lactating cows. Therefore, when adopting the recommendations of the NRC (2000), the net energy requirement for maintenance of lactating Nellore cows should be 83.16 Kcal/ $BW^{0.75}$ (77 x 0.9 = 69.3 x 1.2 = 83.16).

Paulino (2006) has found a value of 79.35 Kcal/$EBW^{0.75}$/day as the net energy requirement for maintenance of growing female cattle. However, Buskirk et al. (1992) have found a NE_m value of 72.5 kcal/$PV^{0.75}$ for Angus cows. The BR-CORTE system, described by Valadares Filho et al. (2006), recommends a value of 78.5 Kcal/$EBW^{0.75}$ as the net requirement for maintenance of male and female Zebu cattle. Considering a 20% increase for lactating cows (NRC, 2000), the value obtained is 94.2 Kcal/$EBW^{0.75}$ (1.2 x 78.5), consistent with the 97.84 Kcal/$EBW^{0.75}$ found in this study. The value of 97.84 Kcal/$EBW^{0.75}$ corresponds to 90 Kcal/ $BW^{0.75}$.

The metabolizable energy requirements for maintenance (ME_m) were calculated by setting the retained energy (RE) equal to zero in the equation RE (Kcal/EBW$^{0.75}$) = 61.958 – 0.442 MEI (Kcal/EBW$^{0.75}$), resulting in a value of ME_m = 140.17 kcal/kg$^{0.75}$ (Figure 3). Thus, the efficiency of metabolizable energy use for maintenance (k_m) was 0.70 (97.84/140.17) and that for weight gain (k_g), corresponding to the slope of the line in Figure 3, was 0.44. Flatt et al. (1967) have found a k_g of 0.64 for lactating Holstein cows. However, a variety of different k_g values have been reported in the literature.

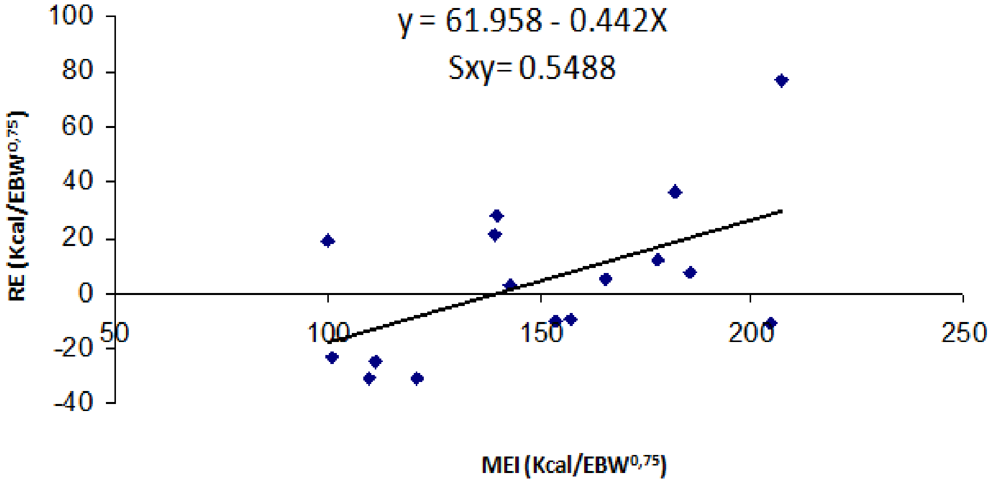

Figure 3 - Retained energy (RE) as a function of metabolizable energy intake (MEI).

Freetly et al. (2006) have found a ME_m of 146 kcal/BW$^{0.75}$ and an efficiency of ME use for maintenance of 72% for lactating primiparous beef cows (composed of ¼ each Hereford, Angus, Redpoll and Pinzgauer). The efficiency of energy use from the mobilization of body reserves for milk production obtained by Freetly et al. (2006) is 78%, while the CSIRO (2007) and the AFRC (1993) consider this efficiency to be 84%. Solis et al. (1988) have found metabolizable energy values for maintenance of 98 Kcal/EBW$^{0.75}$/day for non-lactating Brahman cows, while Calegare et al. (2007) have found an ME_m of 141.3 Mcal/EBW$^{0.75}$ and Freetly et al. (2006) have found an ME_m of 146 kcal/BW$^{0.75}$ for lactating Nellore cows, similar to the results (140.17 Mcal/Kg$^{0.75}$) obtained in the present study.

It is important to note that the few previous studies of the nutritional demands of zebu female cattle in Brazil have been performed in feedlot conditions (Fonseca, 2009; Marcondes et al., 2009; Calegare et al., 2007; Chizzotti et al., 2007; Paulino, 2006), in which the animals are kept in pens. Feedlot facilitates greater experimental control to obtain important variables (such as the metabolizable energy intake) needed to develop estimates. Grazing animals are likely to require extra expenditure of energy. Thus, it is probable that the energy demand for maintenance of animals kept in feedlot underestimates that of grazing animals. In a grazing situation, animals' heat production is influenced by a series of interconnected factors, including the availability and quality of forage, environmental conditions and animal behavior in the pasture (Brosh et al., 2010). According to studies of grazing animals, in which heat production is estimated from heart rate data, the energetic expenditure related to locomotion activities in the horizontal and vertical planes in pasture areas corresponds to between 8.0% and 11.2% of the total energy production (Brosh et al., 2010). The increase in maintenance requirements of breeding herds due to pasture activities should be studied in Brazil to facilitate understanding of the variation in the energetic efficiency of animals (Kelly et al., 2010).

Table 3 shows the energy requirements for maintenance of lactating Nellore cows, expressed as net energy (NE_m), metabolizable energy (ME_m) and total digestible nutrients (TDN) (obtained by dividing the ME_m requirements by 0.82 and then by 4.409).

Table 3 - Maintenance energy requirements of lactating Nellore cows

BW	ME_m (Mcal/day)	NE_m (Mcal/day)	TDN (Kg/day)
300	9.29	6.50	2.57
350	10.42	7.29	2.88
400	11.53	8.07	3.19
450	12.59	8.81	3.48

ME_m = 140.17 Kcal/$EBW^{0.75}$; EBW/BW = 0.894; k_m= 0.70; BW = body weight; ME_m = metabolizable energy for maintenance; NE_m = net energy for maintenance; TDN = total digestible nutrients for maintenance.

To calculate the net energy requirements for weight gain (NE_g) of lactating Nellore cows, we used the equation described by Fonseca (2009): $NE_g = a \times b \times EBW^{b-1}$, (where a = 0.8133 and b = 1.2389). The NE_g, ME_g and TDN requirements for weight gain of lactating Nellore cows are shown in Table 4.

Table 4 - Energy requirements to body weight gain for lactating Nellore cows

Body Weight	Requirements		
	NE_g (Mcal/kg)	ME_g (Mcal/kg)	TDN (kg/kg)
300	3.58	8.14	2.25
350	3.72	8.45	2.34
400	3.84	8.73	2.41
450	3.95	8.98	2.48

EBW = 0.894.BW; EBG = 0.936 x ADG; k_g = 0.44; ME_g = metabolizable energy for gain; TDN = total digestible nutrients.

We calculated the metabolizable energy (ME_l) requirement for lactation as 1.07 Mcal/kg of milk yield, considering the average value obtained for the milk of Nellore cows as 0.75 Mcal of net energy/kg and dividing by an efficiency of 0.70. This procedure assumes that the efficiency of ME for lactation (k_l) is equal to the efficiency with which ME is used for maintenance (k_m), as predicted by the NRC (2001). Thus, the digestible energy (DE) requirement per kilogram of milk yield was 1.30 Mcal (1.07/0.82), and the TDN was 0.295 kg/kg of milk (1.30/4.409).

For comparison purposes, calculating the energy value of 4% fat-corrected milk using the equation given by the NRC (2001) to estimate the energy content of milk [Energy (Mcal/kg) = 0.0929 x Fat (%) + 0.0547 x CP (%) + 0.0395 x Lactose (%)], we obtained a value of 0.76 Mcal/kg of milk. The ME requirement for lactation changed to 1.09 Mcal/kg of milk, corresponding to 0.300 kg of TDN/kg of milk. This value is close to the 0.341 kg of TDN/kg of milk yield (corrected to 4% fat) cited by Moe et al. (1971).

Therefore, we recommend the value of 0.76 Mcal per kg of milk corrected to 4% fat, or 0.30 kg of TDN, as the energy requirement to produce one kilogram of milk from Nellore cows.

Assuming that a lactating Nellore cow has a body weight of 350 kg, produces an average of 6 kg of milk/day and gains 1 kg of body weight per day, the energetic requirements of the animal for NE_m would be 7.28 Mcal/day (97.84 x $(0.894 \times 350)^{0.75}$/1000) and 10.40 Mcal/day (7.28/0.70) for ME_m. The TDN requirement for maintenance can be obtained by dividing the ME_m by 0.82 and then by 4.409.

Therefore, the TDN requirement for the animal described above would be 2.88 kg of TDN/day (10.40/0.82/4.409). The net energy requirement to gain 1 kg of body weight would be 3.72 Mcal (0.8133 x 1.2389 x $(350 \times 0.894)^{0.2389}$ x 0.936), equivalent to 2.34 kg of TDN. The ME requirement for lactation (considering milk with 4% fat) would be 6.54 Mcal/day (0.76/0.7 = 1.09 x 6 kg), equivalent to 1.80 kg TDN/day (0.30 x 6 kg). Therefore, the total TDN requirement of this cow would be 7.02 kg.

The loss of energy related to the mobilization of body reserves was determined from the body composition of reference cows that were slaughtered soon after birth and cows that were fed to maintenance level during the first 90 days (i.e., those that lost weight during this period). Thus, average negative retained energy was -2.053 Mcal per day, which was divided by the average loss of body weight (0.483 kg/day) to obtain an average value of 4.25 Mcal/kg of body weight loss. Other sources recommend values of 5.82 Mcal/kg mobilized (NRC, 2000), 6 Mcal/ kg (NRC, 1989), 6.4 Mcal/kg and 5.5 Mcal/kg for British and European breeds, respectively (CSIRO, 1990), 6 Mcal/kg (INRA, 1989) and 4.54 Mcal/kg (AFRC, 1993). However, the databases of these international organizations are mostly derived from taurine animals.

The ME requirements for maintenance of calves were not estimated in this study; we used the value of 0.1 Mcal/$BW^{0.75}$ for Zebu cattle cited by Valadares Filho et al. (2006). We obtained an equation for the retained energy (RE) as a function of the empty body weight and empty weight gain of Nellore calves (Fonseca, 2009): $RE = 0.0932 \times EBW^{0.75} \times EBG^{0.9157}$. Based on these data, which to our knowledge are the only available data to date for Nellore calves slaughtered in the pre-weaning stage, we calculated the nutritional energy requirements shown in Table 5. To convert the net energy requirement for gain (NE_g) into the metabolizable energy requirement for gain (ME_g), we used two efficiency factors: one for milk intake (k_g = 0.69) and one for the intake of solid feeds (k_g = 0.57) (NRC, 2001). Thus, k_g during the period from 0 to 90 days was considered to be 0.66 (77 x 0.69 + 23 x 0.57), corresponding to animals weighing up to 100 kg, and k_g during the period from 90 to 180 days (> 100 kg of weight) was considered to be 0.62 (43 x 0.69 + 57 x 0.57), where 77% and 23% are the percentages of dry matter (DM) from milk and solid feeds ingested by calves during the earlier period and 43 and 57% are the percentages of DM intake from milk and solid feeds during the latter period (Fonseca, 2009). The DE requirements were calculated as ME/0.96 (NRC, 2001; for suckling calves), and the TDN requirements were calculated as DE/4.409.

The daily TDN requirement of a Nellore calf weighing 150 kg ,with average daily body weight gain of 0.75 kg were calculated as NE_g = 2.87 Mcal/day ($NE_g = 0.0932 \times (150 \times 0.9622)^{0.75} \times (0.75 \times 0.958)^{0.9157}$). The ME_g requirement would be 4.63 Mcal/day (2.87/0.62), and the TDN requirement for weight gain would be 1.09 kg/day (4.63/0.96/4.409). Considering the ME_m requirement of 4.29 Mcal/day ($0.1 \times (150)^{0.75}$), the TDN requirement for maintenance would be 1.01 kg/day (4.29/0.96/4.409). Thus, the total TDN requirement would be equivalent to 2.10 kg/day.

Table 5 - Daily energy requirements for suckling Nellore calves (0 to 180 days of age)

BW	ADG	ME_m	TDN_m	NE_g	ME_g	TDN_g	TDN_t
100	0.25	3.16	0.75	0.77	1.17	0.28	1.03
	0.50			1.46	2.21	0.52	1.27
	0.75			2.12	3.21	0.76	1.51
	1.00			2.75	4.17	0.99	1.74
125	0.25	3.74	0.88	0.91	1.38	0.33	1.21
	0.50			1.73	2.62	0.62	1.50
	0.75			2.50	3.79	0.90	1.78
	1.00			3.25	4.92	1.16	2.04
150	0.25	4.29	1.01	1.05	1.69	0.40	1.41
	0.50			1.98	3.19	0.75	1.76
	0.75			2.87	4.63	1.09	2.10
	1.00			3.73	6.02	1.42	2.43
175	0.25	4.81	1.14	1.18	1.90	0.45	1.59
	0.50			2.22	3.58	0.85	1.99
	0.75			3.22	5.19	1.23	2.37
	1.00			4.19	6.76	1.60	2.74
200	0.25	5.32	1.26	1.30	2.10	0.50	1.76
	0.50			2.45	3.95	0.93	2.19
	0.75			3.56	5.74	1.36	2.62
	1.00			4.63	7.47	1.76	3.02

EBW = BW x 0.9622; EBG = 0.958 x ADG; K_g = 0.66 (50 to 100 kg); K_g = 0.62 (125 to 200 kg); ME_m = 0.1 Mcal/$BW^{0.75}$ (BR-CORTE, 2006); DE = ME/0.96; TDN = ED/4.409; BW = body weight; ME_m = metabolizable energy for maintenance (Mcal/day); ME_g = metabolizable energy for weight gain (Mcal/day); ME_{total} = total metabolizable energy requirements (Mcal/day); TDN = total digestible nutrients; TDN_m = TDN for maintenance; TDN_g = TDN for weight gain; TDN_t = total TDN requirements.

PROTEIN REQUIREMENTS OF LACTATING NELLORE COWS AND THEIR CALVES

The net protein requirements for weight gain (NP_g) of primiparous Nellore cows were calculated from the equation $NP_g = a \times b \times EBW^{b-1}$, where a = 0.4612 and b = 0.8161 (Fonseca, 2009).

To convert net protein requirements for weight gain into metabolizable-protein requirements for weight gain (MP_g), the efficiency (k) was calculated using the equation described in NRC (2000), where k = 83.4 – 0.114 x EBW for cows with EBW less than 300 kg. Thus, the value calculated for cows with body weight of 300 kg using the above equation was 0.53. A constant efficiency of 0.49 was adopted for cows with EBW greater than or equal to 300 kg, according to NRC (2000).

The metabolizable protein requirements for maintenance (MP_m) were calculated as $MPm = 4.0 \times BW^{0.75}$, as recommended by the BR-CORTE system (Valadares Filho et al., 2006).

Microbial crude protein production (MCP) was calculated by considering microbial synthesis of 120 g/kg of TDN, according to the value suggested in the first version of BR-CORTE. The rumen degradable protein (RDP) requirements were calculated as 1.11 x MCP (Valadares Filho et al., 2006), and the rumen undegradable protein (RUP)requirements were obtained from the equation RUP = (total metabolizable protein requirements – (MCP x 0.64))/0.80.

The data in Table 6 show that the total MP requirement for lactating cows weighing 300 kg and gaining 1 kg/day was 526.08 g/day (Table 7), which is close to the value of 508.54 g cited by the BR-CORTE system (Valadares Filho et al., 2006). However, data from the BR-CORTE system (Valadares Filho et al., 2006) are based on growing females. The difference between the value obtained here and that cited by the BR-CORTE system may be a consequence of the tissue replacement (balance between synthesis and degradation) that occurs in lactating cows after the negative energetic balance, when they begin to deposit body tissues more intensively.

Table 6 - Daily protein requirements of lactating Nellore cows

BW	ADG	MP_m(g)	NPg	MP_g(g)	MP_t(g)	RDP(g)	RUP(g)	CP(g)
300	0.25	288.34	31.50	59.43	347.77	416.92	134.23	551.15
	0.50		63.00	118.87	407.21	492.84	153.81	646.65
	0.75		94.50	178.30	466.64	567.43	174.34	741.77
	1.00		126.00	237.74	526.08	642.02	194.88	836.90
350	0.25	323.68	30.62	62.49	386.16	462.20	149.58	611.78
	0.50		61.23	124.96	448.64	539.46	172.00	711.46
	0.75		91.85	187.45	511.12	618.05	193.46	811.51
	1.00		122.46	249.92	573.60	695.30	215.88	911.18
400	0.25	357.77	29.87	60.96	418.74	504.83	159.59	664.42
	0.50		59.75	121.94	479.70	586.08	177.23	763.31
	0.75		89.62	182.90	540.67	666.00	193.84	859.84
	1.00		119.49	243.86	601.63	745.92	214.44	960.36
450	0.25	390.81	29.23	59.65	450.47	546.12	169.49	715.61
	0.50		58.47	119.33	510.13	628.70	184.54	813.24
	0.75		87.70	178.98	569.79	711.29	199.60	910.89
	1.00		116.93	238.63	629.45	793.87	214.65	1008.52

EBW = 0,894 x BW; EBG = 0,936 x ADG; k = 0,49 for EBW ≥ 300 kg and k = 0,53 for EBW = 300 kg; MP_m = 4g / $BW^{0,75}$; MP_g = NPg/k; MP_m = metabolizable protein requirements for maintenance; MP_g = metabolizable protein requirements for gain; MP_t = total requirements of metabolizable protein; RDP (rumen degradable protein) = 120 x TDN requirements (kg/d) x 1.11; RUP (rumen undegradable protein) = (MP_{total} – MCP x 0,64)/0,8; CP = RDP + RUP, CP= crude protein requirements.

In the first edition of the BR-CORTE system (Valadares Filho et al., 2006), the total protein requirements (maintenance + gain) of a non-lactating female with a body weight of 300 kg and gaining 1 kg/day were reported to be 619.53, 189.17 and 808.70 g of RDP, RUP and CP, respectively. These values are very close to those found in the present experiment for lactating cows with the same weight and weight gain (642.02, 194.88, and 836.90 g for RDP, RUP and CP, respectively) (Table 6). It should be noted that the requirements for milk production are not considered in these values.

The net protein requirements for weight gain of Nellore calves were calculated from the equation developed by Fonseca (2009): $NP_g = a \times b \times EBW^{b-1}$, where a = 0.135 and b = 1.0351 (Table 7).

To convert net protein requirements for gain into metabolizable protein requirements (MP_g), the efficiency (k) was calculated using the equation described in NRC (2000), where k = 83.4 – 0.114 x EBW.

The metabolizable protein requirements for maintenance (MP_m) were calculated as MPm = 4.0 x $BW^{0.75}$, as recommended by BR-CORTE (Valadares Filho et al., 2006).

Therefore, for a calf with a body weight of 150 kg and a gain of 0.75 kg/day, the net protein requirements for gain would be 119.55 g/day: $NP_g = 0.135 \times 1.0351 \times (150 \times 0.9622)^{0.0351} \times (0.75 \times 0.958 \times 1000)$. The metabolizable protein requirements for gain would be 178.43 g (119.55/0.67), while the MP_m requirements would be 171.45 = $4 \times (150)^{0.75}$. The RDP requirements would be 279.72 g/day (120 x 2.10 x 1.11), and the RUP requirements would be 235.75 (349.88 - 120 x 2.10 x 0.64)/0.8. Crude protein requirements would therefore be 515.47 g/day (279.72 + 235.75).

Table 7- Daily protein requirements of suckling Nellore calves

BW	ADG(kg)	MP_m(g)	NPg (g)	MP_g(g)	MP_t	TDN	RDP(g)	RUP(g)	CP(g)
100	0.25	126.49	39.29	54.57	181.06	1.03	137.2	127.45	264.65
	0.50		78.57	109.13	235.62	1.27	169.16	172.61	341.77
	0.75		117.86	163.69	290.18	1.51	201.13	217.84	418.97
	1.00		157.14	218.25	344.74	1.74	231.77	263.89	495.66
125	0.25	149.53	39.59	56.56	206.09	1.23	163.84	139.55	303.39
	0.50		79.19	113.13	262.66	1.54	205.13	180.49	385.62
	0.75		118.78	169.69	319.22	1.83	243.76	223.36	467.12
	1.00		158.38	226.26	375.79	2.12	282.38	265.84	548.22
150	0.25	171.45	39.85	59.48	230.93	1.39	185.15	155.22	340.37
	0.50		79.70	118.96	290.41	1.76	234.43	194.05	428.48
	0.75		119.55	178.43	349.88	2.10	279.72	235.75	515.47
	1.00		159.40	237.91	409.36	2.43	323.68	278.42	602.10
175	0.25	192.46	40.25	62.40	254.86	1.59	211.79	165.94	377.73
	0.50		80.51	124.81	317.26	1.99	291.71	205.54	497.25
	0.75		120.76	187.21	379.67	2.37	348.98	247.07	596.05
	1.00		161.01	249.61	442.07	2.74	402.26	289.55	691.81
200	0.25	212.73	40.25	65.98	278.71	1.76	234.43	179.43	413.86
	0.50		80.51	131.98	344.71	2.19	291.71	220.65	512.36
	0.75		120.76	197.97	410.70	2.62	348.98	261.86	610.84
	1.00		161.01	263.95	476.68	3.02	402.26	305.93	708.19

TDN = requirements of total digestible nutrients. EBW = 0,9622 x BW; EBG = 0,958 x ADG; k = 83,4 – 0,114 x EBW; k = 0,72; 0,70; 0,67 and 0,61 for 100; 125; 150; 175 and 200 kg of BW, respectively; MP_m (metabolizable protein requirements for maintenance)= 4 g x $BW^{0,75}$; MP_g (metabolizable protein requirements for gain)= NPg/k; MP_{total} (total requirements of metabolizable protein) = MP_m + MP_g ; RDP (rumen degradable protein) = 120 x TDN x 1,11; RUP (rumen undegradable protein) = (MP_{total} – MCP x 0,64)/0,8; CP = RDP + RUP, CP= crude protein requirements.

Fonseca (2009) has reported an average CP content of 3.73% in the milk of manually milked Nellore cows. When this value is multiplied by 0.95 [the true protein percentage in milk adopted by the AFRC (1993)], a value of 3.54% or 35.4 g of true protein per kg of milk is obtained. Considering an efficiency of metabolizable-protein use for lactation of 0.67 (NRC, 2001), a value of 52.8 g of metabolizable protein (MP) per kg of milk is obtained, corresponding to the MP requirement for milk production. This value is greater than the 44.8 g of MP per kg of milk shown for milk with an average CP content of 3.15% (NRC, 2001; AFRC, 1993). These results suggest that the metabolizable protein requirement of lactating Nellore cows is 52.8 g/kg of milk.

This value can be converted into the RDP, RUP and CP requirements by using the same factors recommended for weight gain of the cows.

In a review of the efficiency of metabolizable protein use, Schroeder and Titgemeyer (2008) have stated that in the majority of reviewed papers, the efficiencies of digestible-protein utilization for body-protein gain observed in calves are variable but less than the fixed value of 67% adopted by the NRC (2001). This efficiency may be affected by a series of factors, including the amount of protein and energy intake, body weight, age and genotype of the animal and frequency of feeding (Schroeder and Titgemeyer, 2008).

MINERAL REQUIREMENTS OF LACTATING NELLORE COWS AND THEIR CALVES

The mineral requirements for maintenance of cows and calves were calculated according to the data presented in Table 8.

The net macromineral requirements for weight gain of Nellore cows (Table 10) were calculated from the equation $Y = a \times b \times EBW^{b-1}$, where a = 0.0987 and b = 0.5516 for phosphorous; a = 0.0021 and b = 0.6773 for magnesium; a = 0.0015 and b = 0.9425 for sodium; and a = 0.0040 and b = 0.7858 for potassium. Because the data were not appropriately adjusted for calcium, the coefficients recommended by the BR-CORTE (2006) system (a = 0.0609 and b = 0.7777) were adopted.

Table 8 - Endogenous loss and mineral bioavailability for cattle

Mineral (kg)	Endogenous Losses	Bioavailability (%)
Calcium	15.4 mg/kg BW[1]	50[1]
Phosphorous	16 mg/kg BW[1]	68[1]
Magnesium	3.0 mg/kg BW[1]	17[2]
Sodium	6.8 mg/kg BW	91[2]
Potassium	Fecal – 2.6 g/kg MS consumed[2] Urinary – 37.5 mg/kg BW Saliva – 0.7 g/100 kg BW Through the skin – 1.1 g	100[2]

[1] Data obtained from the NRC (2000); [2] Data obtained from the ARC (1980).

For a cow of 350 kg BW and gaining one kilogram per day, the net calcium maintenance requirement would be 5.39 g/day (15.4 x 350/1000) and the dietary requirement would be 10.78 g/day (5.39/0.50), corresponding to the net requirement divided by the bioavailability of the mineral (Table 9). The net daily requirement for weight gain would be 12.36 g ($0.7777 \times 0.0609 \times (350 \times 0.894)^{-0.2223} \times 0.936 \times 1000$) and the dietary requirement would be 24.72 g (12.36/0.50), thus totaling 17.75 g/day (5.39 + 12.36) for the net calcium requirement and 35.5 g/day (10.78 + 24.72) for the total dietary calcium requirement (Table 10). The total dietary macromineral requirements for lactating Nellore cows are shown in Table 11.

Table 9 - Daily net and dietary macromineral requirements for the maintenance of lactating Nellore cows (g/day)

	Body weight (kg)			
Requirements	300	350	400	450
		Calcium		
Net	4.62	5.39	6.16	6.93
Dietary	9.24	10.78	12.32	13.86
		Phosphorous		
Net	4.80	5.60	6.40	7.20
Dietary	7.06	8.24	9.41	10.59
		Potassium		
Net	33.09	38.42	43.76	49.09
Dietary	33.09	38.42	43.76	49.09
		Sodium		
Net	2.04	2.38	2.72	3.06
Dietary	2.24	2.62	2.99	3.36
		Magnesium		
Net	0.90	1.05	1.20	1.35
Dietary	5.29	10.78	12.32	13.86

Dry matter intake = 2.39% of BW (Fonseca, 2009).

Table 10 - Daily net and dietary macromineral requirements for a body weight gain of one kilogram in lactating Nellore cows (g/day)

	Body weight (kg)			
Requirements	300	350	400	450
		Calcium		
Net	12.79	12.36	11.99	11.68
Dietary	25.58	24.72	23.98	23.36
		Phosphorus		
Net	4.15	3.88	3.65	3.46
Dietary	6.10	5.71	5.37	5.09
		Magnesium		
Net	0.22	0.21	0.20	0.19
Dietary	0.19	1.24	1.18	1.12
		Sodium		
Net	0.96	0.95	0.94	0.94
Dietary	1.06	1.04	1.03	1.03
		Potassium		
Net	0.89	0.86	0.84	0.81
Dietary	0.89	1.86	1.84	0.81

$Y = a \times b \times EBW^{b-1}$; $EBW = BW \times 0.894$; Dry matter intake = 2.39% of BW.

Table 11 - Total daily dietary macromineral requirements (for maintenance and gain of one kilogram of body weight) of lactating Nellore cows (g/day)

	Body weight (kg)			
Requirements	300	350	400	450
Calcium	34.82	35.50	36.30	37.22
Phosphorus	13.16	13.95	14.78	15.68
Magnesium	6.58	12.02	13.50	14.98
Sodium	3.30	3.66	4.02	4.39
Potassium	33.98	39.28	44.60	49.90

The net macromineral requirements for weight gain of Nellore calves (Table 13) were calculated from the equation Y = a x b x EBW $^{b-1}$, where a = 0.00894 and b = 0.9629 for phosphorus; a = 0.00045 and b = 0.9827 for magnesium; a = 0.00126 and b = 0.9791 for sodium; and a = 0.00165 and b = 0.9364 for potassium. Because the data were not appropriately adjusted for calcium, the coefficients recommended by the BR-CORTE (2006) system (a = 0.0609 and b = 0.7777) were adopted.

For a suckling Nellore calf of 150 kg BW and gaining 0.75 kg/day, the net calcium maintenance requirement would be 2.31 g/day (15.4 x 150/1000) and the dietary requirement would be 4.62 g/day (2.31/0.50), corresponding to the net requirement divided by the bioavailability of the mineral (Table 12). The daily net requirement for weight gain would be 11.26 g (0.7777 x 0.0609 x (150 x 0.9622)$^{-0.2223}$ x (0.75 x 0.958 x 1000), while the dietary requirement would be 22.52 g (11.26/0.50), thus totaling 13.57 g/day (2.31 + 11.26) for the net requirement and 27.14 g/day (4.62 + 22.52) for the calcium dietary requirement (Table 13). For phosphorus, the net and dietary requirements for maintenance would be 2.40 g/day (16.0 x 150/1000) and 3.53 g/day (2.40/0.68), respectively. The daily net phosphorous requirement for weight gain would be 5.14 (0.00894 x 0.9629 x (150 x 0.9622) $^{-0.0371}$ x (0.75 x 0.958 1000) and the dietary requirement would be 7.56 g/day (5.14/0.68), thus totaling 7.54 g/day (2.40 + 5.14) and 11.09 g/day (3.53 + 7.56) for the net and dietary phosphorous requirements, respectively. Table 14 shows the total net and dietary macromineral requirements of suckling calves.

Table 12 - Daily net and dietary macrominerals requirements for maintenance of suckling Nellore calves (g/d)

	Body weight (kg)				
Requirements	100	125	150	175	200
			Calcium		
Net	1.54	1.93	2.31	2.70	3.08
Dietary	3.08	3.86	4.62	5.40	6.16
			Phosphorus		
Net	1.60	2.00	2.40	2.80	3.20
Dietary	2.35	2.94	3.53	4.12	4.71
			Magnesium		
Net	0.30	0.38	0.45	0.53	0.60
Dietary	1.76	2.21	2.65	3.09	3.53
			Sodium		
Net	0.68	0.85	1.02	1.19	1.36
Dietary	0.75	0.93	1.12	1.31	1.49
			Potassium		
Net	11.66	14.30	16.94	19.58	22.22
Dietary	11.66	14.30	16.94	19.58	22.22

Dry matter intake = 2,35 % BW (Fonseca, 2009).

Table 13 - Daily net and dietary macrominerals requirements for weight gain of suckling Nellore calves (g/d)

		Body weight (kg)				
ADG (kg/d)		100	125	150	175	200
		Calcium				
0.50	Net	8.22	7.82	7.51	7.26	7.04
	Dietary	16.44	15.64	15.02	14.52	14.52
0.75	Net	12.33	11.73	11.26	10.89	10.57
	Dietary	24.66	23.46	22.52	21.78	21.14
1.00	Net	16.44	15.64	15.02	14.51	14.09
	Dietary	32.88	31.28	30.04	29.02	28.18
		Phosphorus				
0.50	Net	3.48	3.45	3.43	3.41	3.39
	Dietary	5.12	5.07	5.04	5.01	4.99
0.75	Net	5.22	5.18	5.14	5.11	5.09
	Dietary	7.68	7.62	7.56	7.51	7.49
1.00	Net	6.96	6.90	6.86	6.82	6.78
	Dietary	10.24	10.15	10.09	10.03	9.97
		Magnesium				
0.50	Net	0.27	0.27	0.27	0.27	0.26
	Dietary	1.59	1.59	1.59	1.59	1.53
0.75	Net	0.81	0.80	0.80	0.80	0.79
	Dietary	4.76	4.71	4.71	4.71	4.47
1.00	Net	1.07	1.07	1.07	1.06	1.06
	Dietary	6.29	6.29	6.29	6.24	6.24
		Sodium				
0.50	Net	0.20	0.19	0.19	0.19	0.19
	Dietary	0.22	0.21	0.21	0.21	0.21
0.75	Net	0.29	0.29	0.29	0.29	0.29
	Dietary	0.32	0.32	0.32	0.32	0.32
1.00	Net	0.39	0.39	0.39	0.39	0.39
	Dietary	0.43	0.43	0.43	0.43	0.43
		Potassium				
0.50	Net	0.55	0.55	0.54	0.53	0.53
	Dietary	0.55	0.55	0.54	0.53	0.53
0.75	Net	0.83	0.82	0.81	0.80	0.79
	Dietary	0.83	0.82	0.81	0.80	0.79
1.00	Net	1.11	1.09	1.08	1.07	1.06
	Dietary	1.11	1.09	1.08	1.07	1.06

$Y = a \times b \times EBW^{b-1}$; EBW = BW x 0,894; Dry matter intake = 2.35 % BW

Table 14 - Total daily macrominerals requirements (maintenance + weight gain) of suckling Nellore calves

	Body weight (kg)				
ADG(kg/d)	100	125	150	175	200
			Calcium		
0.25	11.30	11.68	12.12	12.66	13.20
0.50	19.52	19.50	19.64	19.92	20.68
0.75	27.74	27.32	27.15	27.18	27.30
1.00	35.96	35.14	34.66	34.42	34.34
			Phosphorus		
0.25	4.91	5.48	6.04	6.62	7.21
0.50	7.47	8.01	8.57	9.13	9.70
0.75	10.03	10.56	11.09	11.63	12.2
1.00	12.59	13.09	13.62	14.15	14.68
			Magnesium		
0.25	3.35	3.80	4.24	4.68	5.06
0.50	3.35	3.80	4.24	4.68	5.06
0.75	6.52	6.92	7.36	7.80	8.00
1.00	8.05	8.50	8.94	9.33	9.77
			Sodium		
0.25	0.86	1.04	1.23	1.42	1.60
0.50	0.97	1.14	1.33	1.52	1.70
0.75	1.07	1.25	1.44	1.63	1.81
1.00	1.18	1.36	1.55	1.74	1.92
			Potassium		
0.25	11.94	14.57	17.21	19.85	22.48
0.50	12.21	14.85	17.48	20.11	22.75
0.75	12.49	15.12	17.75	20.38	23.01
1.00	12.77	15.39	18.02	20.65	23.28

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