http://dx.doi.org/10.26626/978-85-8179-194-4.2023.C002.p.15-42

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Regulation and prediction of dry matter intake

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INTRODUCTION

Dry matter intake (DMI) is the most important variable that affects animal performance (Waldo and Jorgensen, 1981), because it guarantees to the organism adequate nutrients and energy substrates for biochemical reactions that contribute to oscillations in cell metabolism, especially in beef cattle. One must consider the economic importance and complex digestive systems of these animals, which are characterized by unusual metabolic functions (Forbes, 2007).

In beef cattle production, variations in feed intake happen during the growth cycle to maintain a dynamic balance in face of constant challenges from metabolic and environmental needs.

Limitations on feed intake can prevent nutrient requirements to be met. As most of the nutrients of the beef cattle diet are used to meet maintenance requirements, a small change in feed intake can limit the efficiency of the productive processes, resulting in decreased growth rate. The genetic potential for gain will not be reached and the profitability of the livestock-raising activity will be reduced. Furthermore, problems can arise in association with feed stress, resulting in negative health impacts and digestive disturbances.

FEED INTAKE REGULATION BY CATTLE

Neuro-hormonal factors

The brain is the organ that coordinates feeding behavior. According to Konturek et al. (2005), there is an indication that the solitary tract nucleus (STN) in the brain stem works as a gateway for neural signals coming from the gastrointestinal tract to the central intake regulator in the hypothalamus. These authors also suggest that the amygdaloid body, the prefrontal cortex, and the area postrema (chemical receptor trigger zone or “vomit center”) have been responsible for feeding disorders and inadequate energy storage or conservation. The arcuate nucleus (ARC) and the paraventricular nucleus (PVN) are also important centers for feed intake control. The ARC and PVN are sites where several hormones released from the gastrointestinal tract and adipose tissue converge to regulate feed intake and energy expenditure (Crespo et al., 2014).

Hetherington and Ranson (1940) and Anand and Brobeck (1951) were the pioneers to propose a model consisting of the hunger center in the lateral hypothalamic (LHA) and satiety in the ventromedial hypothalamic region. The lateral area of the hypothalamus has neurons that induce the animal to start a new feeding cycle, while stimuli in the ventromedial area induce satiety (Mayer and Thomas, 1967). There are indications that the lateral hypothalamus region, known as the hunger center, would always be ready to induce hunger. Or so, this region would be chronically active, and its activity would be temporarily inhibited by the satiety center in the ventromedial hypothalamus (Konturek et al., 2005). Thus, feed intake could be stimulated by the absence of satiety signals (Allen et al., 2005).

Therefore, the hypothalamic nucleus does not act separately in the context of controlling energy homeostasis, but acts synergistically with other structures; the signals between them are transmitted by specific neuropeptides. The ARC plays an important role in integrating signals that regulate intake (Stanley et al., 2005).

A series of complex systems maintain energy homeostasis to maintain the body weight and provide sufficient energy for all metabolic processes (Dietrich and Horvath, 2009). According to Ketelaars and Tolkamp (1996), feed intake generates benefits and costs. The benefits are related to energy for maintenance and gain, while the costs are related to the oxygen consumed, which generates free radicals responsible for aging. These authors assume that the regulation of feed intake is due to the oxygen economy. On the other hand, Forbes and Provenza (2000) concluded that animals regulate their daily intake to avoid metabolic or physical discomfort.

After feed intake, signals from receptors located in the pharynx and orogastric veins travel to the brainstem, which is part of the central nervous system (CNS). Further, gastric distension mechanisms, chemical stimulation of receptors in the gastrointestinal mucosa and several hormones are released from the gastrointestinal mucus (Konturek et al., 2005). In addition, there are receptors on the wall of the dorsal anterior rumen-reticulum region that can send information, via afferent fibers, projected to the feed intake control centers in the STN (Leek, 1986).

CNS receives (through the STN) several neural impulses and hormones from peripheral organs, especially from the gastrointestinal tract, adipose tissue, and the pancreas. These structures are involved in short and long-term feeding control, managing information on energy expenditure in response to constant alterations in energy balance (Konturek et al., 2005).

Intestinal peptides signal the hypothalamus via the ARC to mediate appetite stimuli (+), which are activated by neurons that secrete neuropeptide Y (YNP) and agouti-related peptide (AgRP), or appetite inhibiting factors (-) through neurons that contain a pro-opiomelanocortin (POMC) precursor of the alpha-melanocyte stimulating hormone (α-MSH) and through peptide from the production of the cocaine and amphetamine regulated transcript (CART) to the hunger center in the LHA and the satiety center in the PVN in the medial hypothalamus (Currie et al., 2005).

In a study about the intake control center in ruminants, Miner (1992) suggested that YNP is a neurotransmitter involved in the intake regulation by the CNS. YNP / AgRP and POMC / CART in the arcuate nucleus of the hypothalamus play key roles in regulating the energy balance. Activation of the YNP / AgRP neurons has an orexigenic effect, promoting feed intake, while the POMC/CART neurons have the opposite effect, that is, anorexigenic. POMC is activated by post transcriptional modifications to the α-MSH. These two neuron circuits receive signals from circulating hormones.

The summary of neural hormonal control on feed control described by Bell et al. (2005) suggests that:

- Leptin is secreted by adipose tissue, and its circulatory levels are proportional to the adipose reserve of the body. Its effects are exercised through the leptin receptor (LEPR), inhibiting the YNP / AgRP neurons and stimulating the POMC / CART neurons.
- The pancreas secretes insulin that has an anorexigenic influence on the ARC, but an increase in insulin plasma levels is stimulated by the YNP.
- Ghrelin is mostly produced (60%) by the stomach and stimulates the YNP / AgRP neurons through receptors that secrete the growth hormone (GH).
- Peptide YY 3-36 (PYY3-36) is secreted in the distal gastrointestinal tract and has an affinity with and bonds to the Y2 (Y2Rs) receptors, producing inhibitory effects on the YNP / AgRP neurons and therefore is a powerful peripheral anorexigenic signal.
- The YNP / AgRP neurons also have an inhibiting effect on the POMC / CART neurons through the release of γ-aminobutyric (GABA) acid, which can be stimulated by the bonding of ghrelin to GH.
- The orexigenic and anorexigenic signals, that are produced by the YNP / AgRP and POMC / CART neurons, respectively, are then sent to second order flow effector neurons, which also receive afferent modifications for signals from dopamine, serotonin, and endocannabinoids; and
- These effector neurons express receptors that include the receptor Y1 (Y1R) and the melanocortin-4 receptor.

Among the anorexigenic peptides, the first recognized feed intake inhibitor was cholecystokinin (CCK), a product of endocrine cells I in the duodenal jejunum. CCK is a physiological mediating hormone for short term feed intake inhibition. It collaborates with signals from gastrointestinal tract mechanoreceptors that are generated by the digestive tract distension and are transmitted to the brain by the afferent vagus nerve (Konturek et al., 2005).

However, in ruminants, there is a long-time interval between feed intake and arrival in the duodenum, where CCK is produced. Thus, CCK is less important in ruminants than in non-ruminant animals. Nevertheless, an increase was observed in the CCK plasma concentrations in cows three hours after feeding (Choi and Palmquist, 1996), indicating that CCK also has some function in feed intake control in ruminants.

These modulators interact to establish a total balance between feed intake and energy expenditure and thus provoke stimuli in the animal to begin or not a new feeding cycle.

Psychogenic factors

Psychogenic regulation of feed intake, such as perception and learning, involves animal behavior in response to inhibiting or stimulating factors in the feed or feed management that are not related to the energy value of the feed, nor to the filling effect. The psychogenic factors that alter feed intake consist of feed flavor, smell, and texture; vision, emotional states, social interactions and animal learning, and the greatest impact on psychogenic feed intake modulation is palatability (Mertens, 1994).

Animal related factors

a) Body weight

Body weight (BW) is a determining factor in cattle DMI. Galyean and Hubbert (1992) observed that initial body weight represented 59.8% of the variation in the DMI in diets with NEm concentrations ranging from 1 to 2.4 Mcal/kg DM. In a wide discussion on DMI prediction models, Pittroff and Kothmann (2001) assessed 12 different equations and, regardless of their degree of complexity and mathematical sophistication, ten of them took into consideration body weight, giving great importance to the inclusion of this variable in DMI prediction equations.

b) Genetic group

According to the NRC (1987), genetic selection for performance has produced animals with greater DMI potential and suggests specific adjustment factors for DMI prediction. Allen (1992) stated that Continental (European) breeds can consume 10% more than British breeds and, based on this information, the AFRC (1993) proposed adjustment factors in DMI prediction for several pure breeds.

The NRC (2000) adopted the adjustments for breed proposed by Fox et al. (1988), where the DMI prediction should be increased by 8% for the Holstein cattle and by 4% for Holstein and British crossbred animals. The NRC (2000) does not suggest changes in the DMI for Zebu cattle.

c) Body composition

The body composition of feedlot cattle is not constant and changes over feedlot time and with an increase in BW. Body composition, specifically the body fat percentage, seems to be the main component that affects DMI (NRC, 1987). According to Grant and Helferich (1991), this is due to the deceleration of muscle growth and adipose tissue development, with the increase in BW. Fox et al. (1988) suggested altering DMI when cattle presented an empty body fat percentage higher than 21.3%. Jorge et al. (1997) observed a higher body fat percentage (24.41%) for Nellore animals compared to crossbred beef (21.62%) and dairy cattle (19.50%). Fox et al. (1988) suggested reducing DMI by 3, 10, 18 and 27% when the empty body fat percentage was 23.8, 26.5, 29.0 and 31.5%, respectively.

d) Sex

Marcondes et al. (2008), Véras et al. (2008) and Lage et al. (2012) did not report influence of sexes (heifers, steers, and bulls) for DMI, but Paulino et al. (2008) observed that DMI was 9.3% greater in heifers compared to bulls, while steers DMI did not differ from either. According to the authors, the higher intake of females occurred because they were young.

For heifers, the NASEM (2016) suggested that the DMI prediction should be decreased by 10% for heifers with medium body condition, because heifers reach physiological maturity before males (NRC, 2000), which could allow greater body fat accumulation at an earlier time-point in comparison to males. As fat indirectly influences DMI through leptin secretion by the adipocytes, a hormone that has been correlated to intake reductions (Nkrumah et al., 2005), it is expected that the DMI capacity of the heifers decreases with an increase in BW. Thus, the sex effect cannot be considered in isolation because the body condition or body fat percentage is directly influenced by the sex. According to Huuskonen et al. (2013), the sex influence on DMI may be confused with other random experimental effects.

Environmental factors

The weather in Brazil is diverse due to factors such as geographic, territorial extension, relief, and air mass dynamics. The latter is extremely important because it acts directly on both temperature and rainfall, causing regional climatic differences. However, the Brazilian cattle herd is found in greater density in the tropical region with temperatures normally above 25ºC because they are concentrated mainly in the states of Mato Grosso, Minas Gerais, Mato Grosso do Sul and Goiás, which together represent more than 40% (Alvares et al., 2013; Teixeira and Hespanhol, 2015).

Regarding the environmental factors, Fox et al. (1988) suggested to reduce DMI prediction by 10% in temperatures ranging from 25 to 35ºC, and when over 35ºC, reducing it by 35%.

Ingvartsen et al. (1992) assessed the effect of day length on DMI capacity and observed that the expected DMI maybe 1.5 to 2% higher on long days and 1.5 to 2% lower on short days.

Management and diet factors

There is a relationship between the energy concentration of the diet and DMI for beef cattle. Based on the concept that in lower digestible diets, that is, with low energy (high-fiber), the DMI is controlled by factors known as ruminal filling and physical impediment of digestive passage, while in higher digestible, high energy (low-fiber) diets, DMI is controlled by the energy requirement of the animal and metabolic factors (NRC, 1987).

The strong correlation between neutral detergent fiber (NDF) and the physical regulation of intake is mainly due to the high volume occupied by the cell wall fraction of forage (Mertens, 1994) and to its characteristics of low density and slower degradation compared to the cell content (Van Soest, 1994; NRC, 2001). Distension in the rumen-reticulum compartment caused by filling stimulates receptors in the muscle layer mainly located at the reticulum and cranial sac level (Allen, 1996, 2000), where mechanoreceptors are excited by mechanical and chemical stimuli and tensoreceptors respond to the distension itself (Allen, 2000), stimulating the end of the feeding period.

However, this approach has been criticized because it presumes that physical and metabolic mechanisms are independent of each other. This consideration is physiologically unlikely, since the regulating signals work in an integrated manner to create a positive or negative signal on voluntary dry matter intake (Detmann et al., 2014).

NDF intake, or its diet concentration, is associated with the physical mechanism (Detmann, 2010), so a single estimate of NDF concentration is not sufficient to understand or predict cattle voluntary intake (Detmann et al., 2014). Thus, separating the total NDF into undigested NDF and potentially degradable NDF (pdNDF) may improve the associations with voluntary intake (Huhtanen et al., 2007; Harper and McNeill, 2015). For tropical conditions, Detmann et al. (2003) suggested that NDF intake above 13.53 g/kg BW would regulate intake by physical mechanisms, but Oliveira et al. (2011) reported that the forage source should be considered and indicated a mean value of 13.2 g/kg BW for corn silage and 9.4 g/kg BW for sugarcane. They also recommended qualitative discrimination of the NDF and lignin fractions for their efficacious use in DMI prediction models.

Regarding tropical conditions, Detmann et al. (2014) related DMI to digestible organic matter content (DOM) and undigested NDF and observed a quadratic effect: $\text{DMI (g/kg)} = -5.50 + 0.092 \times \text{DOM} - 0.00007 \times \text{DOM}^2$ with a maximum point of 658 g DOM/kg DM and a decreasing linear effect: $\text{DMI (g/kg)} = 27.8 - 0.016 \times \text{undigested NDF}$, respectively. These authors observed that the point of equilibrium between physical and chemical regulation of intake for beef cattle occurred with a DMI of 20.86 g/kg BW, and this value was observed for diets with DOM concentration of 660 g/kg DM and undigested NDF of 228 g/kg DM. This shows that DMI is regulated simultaneously by physical and physiological limitations.

Protein deficiency (<7–8% CP) is another diet characteristic that can decrease DMI, because it limits rumen microorganisms from fully using the fibrous carbohydrates in tropical forage (Lazzarini et al., 2009; Sampaio et al., 2009). In a diet poor in nitrogen but rich in forage fiber, the supplementation with nitrogen increases DMI (Galyean and Goetsch, 1993).

Therefore, the factors that control feed intake are complex, truly multifactorial and there is no consensus on how ruminants regulate this important activity (Forbes, 2007).

All these factors should be considered when mathematically predicting the true biological behavior of dry matter intake by beef cattle under tropical conditions. However, no type of equation will be applicable if the feeding conditions (feed availability, stocking rate, space in the pen, access time to feed, feeding frequency, etc.) are limiting intake (Mertens, 1992).

Adaptation for feedlot cattle

Adaptation for the feedlot may influence DMI. Animals from pasture consume high roughage diets and start the feedlot with high proportions of concentrates after long transportation without water and food (Loerch and Fluharty, 1999). Normally, they leave the pastures without or with low concentrate supplementation and start feedlot with high concentrate, often 90% in less than 14 days (Brown et al., 2006; Pereira et al., 2020). Due to these changes, acidosis has been identified as the second biggest health problem in feedlot systems in the last six years (Pinto and Millen, 2018; Silvestre and Millen, 2021). Proper management of this phase may influence intake and performance throughout the feedlot period. According to Estevam et al. (2020), one of the determining factors for the adaptation protocol is the energy content of finishing diets. According to these authors, systems that use less energy in the diets can reduce the adaptation periods without health problems and performance reduction.

Often, cattle are adapted to the feedlot with a gradual increase in the concentrate diet over periods of 14 to 21 days (Bierman and Pritchard, 1996). In Brazil, Silvestre and Millen (2021) indicated that an average of 3 diets are used, with intervals of 7 days, during the period of adaptation to the feedlot. These authors reported that multiple diets, with an increase in the concentrate on defined days, represent 61.1% of the receiving diets formulated during the feedlot, on average for 19 days. In addition, they reported that the smallest part (39.9%) of feedlots use other options during adaptation, such as a single diet with less energy than in the finishing phase for 25 days; two diets for 7-8 days each; finishing diet with feed restriction for 40 days of adaptation; and use multiple diets associated with restriction of intake (Silvestre and Millen, 2021). In that study, most nutritionists suggested starting the adaptation using 36.5% of roughage in the total DM of the diet.

Other factors to be considered in the feedlot adaptation phase are the initial amount of concentrate in the diet and the daily amount of DM. Parra et al. (2019) evaluated adaptation protocols for 7, 14, and 21 days. The animals received 55, 65, and 75% concentrate and finished on diets with 85% concentrate, initially receiving 1.76% of the BW for DMI of the diet, with increments of 200 to 206 g DM/d. These authors concluded that the increase in adaptation time did not influence intake and animal performance. Barducci et al. (2019) evaluated animals adapted for 9 or 14 days. In the adaptation of 9 days, the diets were changed every 3 days, and in the adaptation of 14 days, the changes in the diets occurred on days 4 and 9. Animals started with 55% of concentrate, increasing by 10% in each adaptation phase until 85% in the finishing phase. The adaptation phase did not influence DMI and animal performance.

Bunk management

Bunk management needs to be simple and sensitive to detect changes in diet intake (Schutz et al., 2011), to avoid underperformance, feed losses, and digestive problems. In Brazil, nutritionists use four trough management methods: clear bunk, with 1 to 3% orts, 3 to 5% orts, and 5 to 10% orts (Millen et al., 2009). Clear bunk management is based on the satiety concept without feed losses. In this management, troughs and animal behavior are monitored daily to enable an adequate supply of feed without orts. Bunk management with 1 to 3% or 3 to 5% or even 5 to 10% orts is usually made into scores to simplify the decision about increasing or reducing feed supply. Recently, Brazilian nutritionists have been using less orts. According to Millen et al. (2009), only 25.8% of the nutritionists used clear bunk management, while 48.4% used 1 to 3% orts.

The restriction in feed supply reflects the increase in the cost of diets, which demonstrates the importance of developing precise and accurate equations in the prediction intake that allows maximum performance without feed losses.

PREDICTION OF DRY MATTER INTAKE FOR FEEDLOT CATTLE

To plan an efficient feeding program capable of finding the best feed management to meet nutrient requirements, it is necessary to predict with the highest precision and accuracy the voluntary intake of growing and finishing cattle under *ad libitum* feeding.

A DMI prediction model is a simplified representation of the complex system of voluntary feed intake (Keady et al., 2004). If it were possible to include all the physiological, environmental, diet and management factors that interfere in the DMI, the model obtained could be difficult to interpret biologically.

STATE OF THE ART ON DRY MATTER INTAKE PREDICTION

For a long time, the DMI prediction models proposed by the NRC (1984, 2000) were the most used in Brazil. However, the models proposed by the NRC (1984, 2000) and the NASEM (2016) were developed mainly with *Bos taurus taurus* animals. According to ANUALPEC (2015), 80% of the Brazilian herd consists of Zebu cattle, with an estimated 150 million Zebu. The contribution of Zebu cattle to meat and milk production in Brazil in a self-sustainable production system is due to their characteristics of fertility, rusticity, adaptability to the tropical condition and to the Brazilian meat production systems. Nellore breed is predominant in beef production systems in Brazil.

Fox et al. (1988) observed that the genetic group is recognized as one factor that interferes with DMI. Based on this study, the NRC (1987) and the AFRC (1993) adopted the adjustment factor related to the genetic group in DMI prediction equations, because breeds were identified with greater intake potential than others. Furthermore, steroid stimulants were used in the cattle in the database used for the DMI prediction model proposed by the NRC (1984, 2000). In Brazil, steroid use was prohibited for any purpose in 1961, and currently, Ministerial Regulation nº 51 (Brasil, 1991) is in force and prohibits the production, importation, commercialization, and use of products for purposes of growth and weight gain in slaughter animals. Non-steroid compounds with anabolizing effects are prohibited even for therapeutic purposes.

According to Neal et al. (1984), DMI prediction models should be tested under conditions similar to those that characterize the intended location of use. Therefore, there is no single model that can be applied in every situation, and DMI prediction models need to be developed and validated for tropical conditions. For this, equations to predict beef cattle DMI under Brazilian conditions and with Zebu cattle (Nellore cattle) were carried out and validated by Valadares Filho et al. (2006 a,b), that along with energy, protein and mineral requirements resulted in the publication entitled Nutrient Requirements for Zebu cattle and Tables of Feed Composition – BR-CORTE, described by Valadares Filho et al. (2006b).

Fifteen dissertations and/or theses were used in the BR-CORTE (2006) to develop the database for Zebu animals (mainly Nellore cattle). In the crossbred beef cattle database, 10 dissertations and/or theses were used totalling 273 experimental units. Thus, the following equations were recommended to predict DMI:

- For Zebu cattle:
$DMI\ (kg/d) = -2.4001 + 0.0201 \times BW + 4.8195 \times ADG - 1.5176 \times ADG^2$

- For crossbred beef cattle:
$DMI\ (kg/d) = -1.4105 + 0.0171 \times BW + 5.4125 \times ADG - 1.8691 \times ADG^2$.

where BW = average body weight (kg) and ADG = average daily gain (kg/d). The DMI models proposed indicated that the predictive values were equivalent to those observed under practical feeding conditions for feedlot beef cattle under tropical conditions.

Ribeiro et al. (2008) assessed the DMI based on Zebu genetic group and compared the values observed with those predicted by the NRC (2000), CNCPS 5.0 and BR-CORTE (2006) systems. The authors observed that the Brazilian system (BR-CORTE, 2006) was more accurate for DMI predictions by breed and Zebu cattle overall.

Valadares Filho et al. (2006a) also observed a lack of fit for the models proposed by the NRC (1984, 2000) in predicting DMI for beef cattle under tropical conditions. So, the equations proposed by the NRC (1984, 2000) would not be able to explain the higher percentage in the observed variation in the DMI compared to the equations adopted by the BR-CORTE (Valadares et al., 2006b).

Brazilian researchers collected data from multiple published studies and tried to establish a quantitative model that better explains the observations. Generally, studies differ due to their objectives and ignore these differences in joint data analysis results in an erroneous estimate of the parameters (intercept and slope) of the regression models. Therefore, the use of meta-analysis was proposed in the BR-CORTE, described by (Azevêdo et al. 2010), to integrate the study effect and random effects of the interactions such as components of a mixed model (St-Pierre, 2001) and generate more precise and accurate DMI prediction models. Thus, in the second edition of the Nutrient Requirements of Zebu cattle, BR-CORTE (2010), the database was increased for DMI, and the models used by the NRC were assessed together with new equations to predict DMI, using meta-analysis, which were developed and validated.

The data included 561 observations from 27 theses and/or dissertations (study) that were published at the Federal University of Viçosa and the University of São Paulo. The BR-CORTE (Azevêdo et al. 2010), showed that the equations proposed by the NRC were not adequate to predict DMI for cattle under tropical conditions and the following DMI prediction equations were suggested:

- For Zebu cattle:
$DMI\ (kg/d) = -2.7878 + 0.08789 \times BW^{0.75} + 5.0487 \times ADG - 1.6835 \times ADG^2$.

- For crossbred cattle:
$DMI\ (kg/d) = -2.6098 + 0.08844 \times BW^{0.75} + 4.4672 \times ADG - 1.3579 \times ADG^2$.

where $BW^{0.75}$ = average metabolic body weight (kg) and ADG = average daily gain (kg/d).

Ferreira et al. (2021) evaluated DMI prediction models by BR-CORTE (Azevêdo et al., 2010 and 2016) and NRC (2000) nutritional systems, with 47 feedlot Nellore cattle, bulls, the average initial body weight of 413 kg and 19 months of age. They concluded that the BR-CORTE model (Azevêdo et al., 2016) was more precise to predict DMI of Nellore cattle.

The main research group that acted on the changes regarding DMI prediction for beef cattle in the 8th edition of the NASEM (2016) – Nutrient Requirements of Beef Cattle Model – was led by Professor and Researcher Michael L. Galyean, from the *Texas Tech University, Department of Animal and Food Sciences.*

His research group recently published four articles on this subject. The first was "Evaluation of the National Research Council (1996) dry matter intake prediction equations and relationships between intake and performance by feedlot cattle" by McMeniman et al. (2009). This article aims to assess the NRC (1996) DMI prediction models. From a database containing 3,363 records of collective pens, representing 632,306 animals on three commercial feedlots collected during a period of four years (2003 to 2006), they concluded that the equations proposed by the NRC (1996) were not useful to predict the DMI of commercial feedlot cattle and suggested the need to develop new and more accurate and precise equations.

The second article was "Development and evaluation of feeding-period average dry matter intake prediction equations from a commercial feedlot database" by McMeniman et al. (2010). These authors proposed DMI prediction models that took into consideration sex and previous DMI information at the start of the feedlot.

In the third article, Galyean et al. (2011) published "Predictability of feedlot cattle growth performance". These authors validated the equations proposed by McMeniman et al. (2010) and suggested equations to predict DMI for feedlot beef cattle fed high-concentrate diets.

In the fourth article, "Evaluation of current methods and equation development" by Anele et al. (2014), new equations were developed but, according to these authors, these equations gave only modest improvements for the best of the hypotheses; in some cases, they did not offer any true advantage in comparison to the equations proposed by the NRC (1996) for predicting DMI in growing or finishing beef cattle.

Anele et al. (2014) were disappointed to know that their research managed to improve only a little the prediction capacity for DMI and recognized the difficulty to develop precise DMI predictions for growing and finishing beef cattle. The influence of the complex factors that control DMI makes the difficult to adequately explain DMI biological performance using regression mathematical models and some independent variables.

According to Anele et al. (2014), the NASEM (2016) recommended to continue the use of the equation proposed by the NRC (2000) to predict net energy intake for maintenance (NEIm, Mcal/d) and later estimate the DMI, obtained by dividing the NEIm by the net energy concentration for maintenance of the diet (NEm):

- For *yearlings*:
$NEIm\ (Mcal/d) = BW^{0.75} \times (0.2435 \times NEm - 0.0466 \times NEm^2 - 0.0869)$,

where $BW^{0.75}$ is the average metabolic body weight for the feeding period. For diets with NEm concentration ≤ 0.95 Mcal/kg DM, the NASEM (2016) recommended dividing the result of this equation by 0.95.

However, because the results of this equation under or overestimated the DMI depending on the diet and animal conditions as reported by Anele et al. (2014), the NASEM (2016) recommends that the DMI equation as a function of body weight described by Anele et al. (2014) also could be used to predict DMI in growing or finishing beef cattle:

$DMI\ (\%\ BW) = 1.2425 + 1.9218 \times NEm - 0.7259 \times NEm^2$ ($R^2 = 0.6188$),

where BW = average body weight (kg). The NASEM suggests there is no reason to recommend a single equation to estimate DMI.

Based on the validation study by Galyean et al. (2011), the NASEM (2016) recommends the use of equations described by McMeniman et al. (2010), with adjustments for sex, to estimate the DMI of feedlot cattle fed high-grain diets (≥ 2.06 Mcal/kg NEm and ≥ 1.4 Mcal/kg NEg):

- Steers:
$DMI\ (kg/d) = 3.83 + 0.0143 \times iSBW$.

- Heifers:
$DMI\ (kg/d) = 3.184 + 0.01536 \times iSBW$.

where iSBW, mean initial shrunk body weight.

In the seventh edition of the NRC (2000), the methods described to predict DMI were planned to give a general orientation. There is no one equation that can be applied to all production scenarios. It would be correct to develop specific DMI prediction models for determined production situations. Thus, these models would be capable to explain a greater percentage of the variation observed in the DMI, compared to a generalized model.

Although Brazil has a beef herd of a practically stagnant size, improvement in productive conditions has increased productivity indexes. For these indexes to continue increasing to reduce production costs and make the product more accessible to the consumer, the knowledge generated by research must be constantly updated and validated. This means that the greatest number of variation sources should be known and considered. Likewise, an increase in the number of individual cattle intake data, from research under tropical conditions, means that the statistical procedures to estimate DMI become more sensitive to the variations resulting from various production factors.

DESCRIPTION OF DATABASE USED TO PREDICT NEW MODELS FOR FEEDLOT CATTLE IN EXPERIMENTAL CONDITIONS

Brazil is a country with continental dimensions. There is wide climatic diversity that permits raising cattle of predominantly Zebu breeds and the use of different genetic groups specialized in meat production to obtain benefits from the hybrid vigor to increase herd productivity.

Furthermore, in Brazil, a significant part of the meat produced is from males derived from dairy herds, which are used for growing and finishing animals such as beef cattle. Faced with this genetic diversity among the cattle raised in Brazil and knowing that physiologically there are differences in growth potential and nutrient requirements, the database was separated into three genetic groups to predict new models to estimate DMI for cattle under tropical conditions: Zebu cattle (predominantly Nellore animals), crossbred beef cattle (animals derived from crosses of Zebu with breeds specialized in meat production, predominantly Angus x Nellore) and crossbred dairy cattle (animals derived from crosses of Zebu with breeds specialized in milk production, mainly Holstein).

To generate DMI prediction models capable of being biologically representative and explaining the greater percentage of variation observed in the DMI of cattle under tropical conditions, mainly in commercial conditions, Menezes et al. (2022) used BR-CORTE (Azevêdo et al., 2016) database with Zebu breeds bulls and included 479 (56.452 Zebu breeds) pens in one commercial feedlot. The proposed equation was evaluated and compared with a 2.1 equation proposed in the BR-CORTE (Azevedo et al., 2016), and equations proposed by McMeniman et al. (2010), Anele et al. (2014), and Silva et al. (2021) in two other independent commercial feedlots with 222 and 231 pens, totaling 23,531 and 6,384 animals. The equations validated were the 2.1 in the BR-CORTE and the equation proposed by Menezes et al. (2022). However, the equation proposed by Menezes et al. (2022) was more precise in predicting DMI. Therefore, in this edition, we used the equation proposed by Menezes et al. (2022) using a total of 1128 experimental units of zebu breeds, derived from research and commercial feedlot with high management systems on growing or finishing cattle, with recorded individual or in group intake that also respected an adaptation period to minimize the impact of compensatory growth on DMI.

Descriptive analysis (Triola, 1999) (Table 2.1) of the data gave the dataset profile from the central tendency and dispersion means. In general, the total amplitudes of the different variables present in the database used to develop the DMI prediction equations (Table 2.1) represented the Brazilian characteristics of feedlot beef cattle production systems, so there are variations from low to high initial BW, final BW, ADG, DMI and variations in the NDF and CP intakes. Thus, representative projections were faced with the universe of diets used for cattle for beef production under tropical conditions and their interactions with genetic groups and interference in the DMI regulation patterns.

The Pearson correlation coefficient was used to measure the intensity of the linear relationship between DMI and the other quantitative variables. The correlation analysis showed that the greatest coefficients found were those that explained the linear relationship between the DMI and the cattle weights and performance, with positive and significant coefficients ($P<0.05$). The variables related to the diets (NDF and CP, g/kg), not only had low correlation coefficients, regardless of the genetic group assessed, but the NDF did not present significant coefficients ($P>0.05$) and CP was only significant for the Zebu and crossbred dairy genetic groups. In face of the results of the Pearson correlation, $BW^{0.75}$ and ADG were adopted as variables to be used in the DMI prediction models.

According to St-Pierre (2001), the study effect needs to be verified on the database. Study effect was observed

($P<0.0001$) and this was considered in further analysis.

Equations were developed to predict DMI as a function of the genetic groups.

Zebu cattle:
DMI (kg/d) = -2.1948 + 0.08338× $BW^{0.75}$ + 3.9328 × ADG – 0.9030 × ADG^2
(R^2 = 0.859) (Equation 2.1)

Crossbred beef cattle:
DMI (kg/d) = – 0.6273 + 0.06453 × $BW^{0.75}$ + 3.871 × ADG – 0.614 × ADG^2
(R^2 = 0.626) (Equation 2.2)

Crossbred dairy cattle:
DMI (kg/d) = – 2.8836 + 0.08435 × $BW^{0.75}$ + 4.5145 × ADG – 0.9631 × ADG^2
(R^2 = 0.788) (Equation 2.3)

The negative coefficient for the ADG^2 (kg/d) variable for all fitted equations indicated that the DMI estimates presented a plateau. The explanation for this fact may be directly related to the energy concentration of the diets used. Starting from the principle that to reach maximum ADG, the diet energy concentration must have been high, inhibiting DMI, which suggests the theory of energy intake regulation proposed by Mertens (1994).

Considering the importance of this effect, the NASEM (2016) proposed equations that included NEm and NEm^2 variables. However, due to the practical difficulties of determining NEm before knowing which feeds will make up the diet, Thornton et al. (1985) developed a model to predict DMI that included initial body weight and days on feedlot (DOF). According to these authors, the initial DMI increases gradually as a function of DOF until it reaches a plateau and then decreases in the last DOF due to an increase in the body fat content of the animals. Fat starts to concentrate slowly in the carcass at the beginning of the feeding period but accumulates rapidly at the end of it (Simpfendorfer, 1974).

VALIDATING DRY MATTER INTAKE PREDICTION EQUATIONS

The research results from mean values (independent experiments) published from 2005 until October 2014 in the *Revista Brasileira de Zootecnia, Boletim da Indústria Animal, and the Arquivo Brasileiro de Medicina Veterinária and Zootecnia* were compiled and used to build a database to validate the DMI prediction equations for Zebu cattle and crossbred beef and dairy cattle finished in feedlot under tropical conditions (Table 2.2).

Table 2.2 shows the dispersion of the variables used in the database to validate the DMI prediction equations. The minimum and maximum values for BW, ADG and DMI indicate that many diets were used. It can be observed that the selection criterion used was representative because it did not interfere in the mean values of the variables used to develop the DMI prediction equations. It is important to point out that in this database for validation, there are data from different Brazilian states that give larger representation of the national herd.

The ratios obtained between the observed and predicted values by the equations as a function of the genetic groups: Zebu, crossbred beef and dairy cattle (Table 2.3), show that the probability values both for the intercept and slope do not differ ($P>0.05$) from zero and 1, respectively. That is, the DMI values (Table 2.3) predicted by the equations developed are equivalent to the DMI observed in practical beef cattle feeding conditions, in feedlot under tropical conditions. Table 2.4 shows the dry matter intake estimated for Zebu, crossbred beef and dairy cattle finished in a feedlot, obtained for different body weight and gain.

Table 2.1 - Descriptive statistics of the variables used to predict dry matter intake and nutrient intake for Zebu cattle under experimental and commercial conditions, and for crossbred beef and dairy cattle under experimental conditions

Variable	N	Mean	SD	Minimum	Maximum
Zebu cattle					
Feedlot, days	1128	102	36.9	42.0	271
Initial body weight, kg	1128	330	70.0	110	499
Final body weight, kg	1128	450	91.3	125	652
ADG, kg/d	1128	1.23	0.49	-0.36	2.00
Intake					
Dry matter, kg/d	1128	8.41	2.10	1.29	13.2
NDF, kg/d	951	2.88	0.71	0.79	7.61
iNDF, kg/d	388	1.24	0.55	0.13	2.43
Crude protein, kg/d	951	1.03	0.19	0.29	1.74
TDN, kg/d	949	6.03	1.14	1.00	10.2
Crossbred beef cattle					
Feedlot, days	270	112	35.6	55.0	232
Initial body weight, kg	270	352	55.3	215	580
Final body weight, kg	270	455	78.6	220	607
ADG, kg/d	270	1.22	0.48	-0.19	2.37
Intake					
Dry matter, kg/d	270	8.57	1.94	2.46	12.5
NDF, kg/d	188	3.25	1.24	0.83	6.97
iNDF, kg/d	30	0.81	0.16	0.50	1.09
Crude protein, kg/d	163	1.15	0.28	0.30	1.67
TDN, kg/d	141	5.52	1.50	1.74	9.22
Crossbred dairy cattle					
Feedlot, days	409	107	53.7	30.0	242
Initial body weight, kg	409	323	77.3	139	494
Final body weight, kg	409	429	87.5	206	661
ADG, kg/d	409	1.06	0.52	-0.13	2.64
Intake					
Dry matter, kg/d	409	8.03	2.41	2.18	15.1
NDF, kg/d	265	2.86	1.17	0.65	6.14
iNDF, kg/d	30	0.98	0.26	0.42	1.44
Crude protein, kg/d	264	0.99	0.35	0.18	2.01
TDN, kg/d	138	5.64	1.63	2.53	9.45

N: number of experimental units; SD: standard deviation; ADG: average daily gain; NDF: neutral detergent fiber; iNDF: indigestible NDF; TDN: total digestible nutrients.

Table 2.2 - Descriptive statistics of the variables used to validate the equations developed to predict dry matter intake for Zebu cattle, and crossbred beef and dairy cattle in feedlot under experimental conditions

Variable	N	Mean	SD	Minimum	Maximum
Zebu cattle					
Feedlot, d	78	95.4	27.5	56.0	194
Initial body weight, kg	78	364	43.5	251	438
Final body weight, kg	78	479	37.2	404	583
ADG, kg/d	78	1.20	0.24	0.63	1.75
Dry matter intake, kg/d	78	8.79	1.06	6.04	10.8
Crossbred beef cattle					
Feedlot, d	111	103	29.6	21.0	199
Initial body weight, kg	111	326	62.8	18	463
Final body weight, kg	111	464	48.2	340	579
ADG, kg/d	111	1.38	0.25	0.76	2.15
Dry matter intake, kg/d	111	8.83	1.44	6.11	12.7
Crossbred dairy cattle					
Feedlot, d	48	81.8	12.3	56.0	102
Initial body weight, kg	48	259	94.4	67.9	380
Final body weight, kg	48	336	116	151	499
ADG, kg/d	48	0.95	0.38	0.14	1.72
Dry matter intake, kg/d	48	6.69	2.24	2.80	11.1

N: number of experimental units; SD: standard deviation; ADG: average daily gain.

Table 2.3 - Statistics for the ratio between the observed and predicted values by the equations for Zebu, and crossbred beef and dairy cattle in feedlot

Variable	**Zebu**	**Crossbred beef cattle**	**Crossbred dairy cattle**
Intercept	-0.602	-1.5386	0.6697
P-value[1] (H_0: a = 0)	0.655	0.2022	0.0710
Slope	1.052	1.1316	0.9449
P-value[2] (H_0: b = 1)	0.729	0.3150	0.3112
r^2	0.426	0.4087	0.8704
Mean bias	-0.137	-0.3329	0.3189
CCC	0.544	0.5262	0.9234
MSEP	0.698	1.3306	0.7557
Decomposition of the MSEP			
Mean bias	0.0188 (2.70%)	0.1108 (8.33%)	0.1017 (13.46%)
Systemic error	0.0011 (0.15%)	0.0113 (0.85%)	0.0146 (1.93%)
Random error	0.6777 (97.2%)	1.2085 (90.82%)	0.6395 (84.62%)

CCC = concordance correlation coefficient; MSEP = mean square error of prediction; [1]Probability value for the hypothesis test where the value of parameter a = 0 (Neter et al., 1996). [2] Probability value for hypothesis test where the value of parameter b = 1 (Neter et al., 1996).

Table 2.4 - Dry matter intake estimated for Zebu, crossbred beef and dairy cattle finished in feedlot obtained for different body weights and weight gains

Body weight (kg)	Weight gain (kg/d)	Dry matter intake (kg)		
		Zebu cattle (Equation 2.1)	**Crossbred beef cattle** (Equation 2.2)	**Crossbred dairy cattle** (Equation 2.3)
200	0.75	4.68	5.36	4.45
	1.00	5.27	6.06	5.15
	1.25	5.74	6.68	5.74
	1.50	6.11	7.23	6.21
	1.75	6.36	7.70	6.55
250	0.75	5.49	5.99	5.26
	1.00	6.08	6.69	5.97
	1.25	6.55	7.31	6.56
	1.50	6.91	7.85	7.02
	1.75	7.16	8.32	7.37
300	0.75	6.26	6.58	6.04
	1.00	6.85	7.28	6.75
	1.25	7.32	7.90	7.33
	1.50	7.68	8.45	7.80
	1.75	7.93	8.92	8.15
350	0.75	6.99	7.15	6.79
	1.00	7.58	7.85	7.49
	1.25	8.06	8.47	8.08
	1.50	8.42	9.02	8.55
	1.75	8.67	9.49	8.89
400	0.75	7.70	7.70	7.51
	1.00	8.29	8.40	8.21
	1.25	8.77	9.02	8.80
	1.50	9.13	9.57	9.27
	1.75	9.38	10.0	9.61
450	0.75	8.39	8.24	8.20
	1.00	8.98	8.93	8.91
	1.25	9.46	9.56	9.50
	1.50	9.82	10.10	9.96
	1.75	10.1	10.6	10.3
500	0.75	9.06	8.75	8.88
	1.00	9.65	9.45	9.59
	1.25	10.1	10.08	10.17
	1.50	10.5	10.6	10.6
	1.75	10.7	11.1	11.0

VALIDATION OF DRY MATTER INTAKE PREDICTION EQUATIONS FOR ZEBU AND CROSSBRED BEEF CATTLE IN COMMERCIAL FEEDLOTS

DMI, BW, and ADG data from Zebu and crossbred beef animals were collected in three commercial feedlots with individual intake per group and used for validation. Data were collected in Minas Gerais (16°01'54"S 43°47'28"W), Goias (15°25'19.61"S 51°32'17.04"W) and Mato Grosso (16°45'30"S 54°23'03"W). Data from 231 and 222 stalls were compiled, totaling 29,915 Nellore animals and 27, 76, and 20 stalls with crossbred beef cattle, totaling 11,713 animals (Table 2.5). The feeding management in the commercial feedlot used the average adaptation period to the finishing diets for 21 days. The observed values were compared with the values predicted by Equation 2.1 using the regression model: Y = a + b*x. Where: Y = represents the observed response values; X = represents the predicted values; a = represents the intercept of the Equation, and b = represents the slope of the Equation. The regression was evaluated with the following statistical hypotheses (Neter et al., 1996): H_0 = a = 0 and b = 1; Ha = No H_0. The database used to generate Equations 2.1 covers data from commercial feedlots and allows its use in predicting their intake. The values for intercept and slope did not differ (P>0.05) from 0 and 1, respectively (Table 2.6). Therefore, predicted and observed values in commercial and large experimental feedlots in tropical conditions are the same.

Table 2.5 - Descriptive statistics of the variables used to validate the equations 2.1 and 2.2 to predict dry matter intake

Variable	N	N animals	Mean	DP	Minimum	Maximum
Feedlot. 1 **(Zebu cattle)**[1]						
Feedlot, d	231	6.384	103	14.8	70	127
Initial body weight, kg	231	6.384	426	37.0	344	570
Final body weight, kg	231	6.384	593	45.6	527	763
ADG, kg/d	231	6.384	1.62	0.21	1.08	2.24
Dry matter intake, kg/d	231	6.384	9.14	0.76	7.14	12.2
Feedlot. 2 **(Zebu cattle)**[1]						
Feedlot, d	222	23.531	129	30.8	66.0	206
Initial body weight, kg	222	23.531	309	42.9	229	523
Final body weight, kg	222	23.531	497	35.9	386	714
ADG, kg/d	222	23.531	1.49	0.190	1.02	2.32
Dry matter intake, kg/d	222	23.531	11.0	0.79	8.79	13.2
Feedlot. 3 **(Crossbred beef cattle)**						
Feedlot, d	27	2469	116	5.51	110	126
Initial body weight, kg	27	2469	397	28.79	363	453
Final body weight, kg	27	2469	625	29.77	572	681
ADG, kg/d	27	2469	1.956	0.185	1.600	2.186
Dry matter intake, kg/d	27	2469	11.7	0.517	10.2	12.3
Feedlot. 4 **(Crossbred beef cattle)**						
Feedlot, d	76	8707	153	38.16	66	235
Initial body weight, kg	76	8707	294	70.52	221	486
Final body weight, kg	76	8707	517	80.08	440	829
ADG, kg/d	76	8707	1.500	0.325	1.087	2.423
Dry matter intake, kg/d	76	8707	9.31	1.429	7.39	12.2
Feedlot. 5 **(Crossbred beef cattle)**						
Feedlot, d	20	537	105	24.0	62.3	150
Initial body weight, kg	20	537	412	31.1	361.1	462
Final body weight, kg	20	537	539	23.4	502.7	592
ADG, kg/d	20	537	1.223	0.133	0.970	1.506
Dry matter intake, kg/d	20	537	9.45	0.680	8.30	11.19

N: number of experimental units; SD: standard deviation.
[1]Adapted data published by Menezes et al., (2022).

Table 2.6 - Statistics for the ratio between the observed values of feedlots 1, 2, 3, 4 and 5 and those predicted by equations 2.1 (feedlots 1 and 2) for zebu beef cattle and 2.2 (feedlots 3, 4 and 5) for crossbred beef cattle

Variable	[3]Feedlot. 1	[3] Feedlot. 2	Feedlot. 3	Feedlot. 4	Feedlot. 5
Intercept	-0.051	1.05	-0.721	0.400	1.317
P-value[1] (H_0: a = 0)	0.934	0.076	0.501	0.682	0.660
Slope	1.04	0.886	1.051	0.936	0.905
P-value[2] (H_0: b = 1)	0.598	0.075	0.648	0.505	0.715
r^2	0.511	0.465	0.785	0.561	0.411
Mean bias	0.327	-0.001	-0.236	-0.250	0.225
CCC	0.600	0.659	0.860	0.680	0.535
MSEP	0.414	0.317	0.482	0.286	0.198
Decomposition of the MSEP					
Mean bias	0.107 (25.8%)	0.000 (0.00%)	0.056 (11.6%)	0.063 (21.9 %)	0.051 (25.6 %)
Systemic error	0.0004 (0.090%)	0.005 (1.43%)	0.004 (0.75%)	0.001 (0.471%)	0.001 (0.564 %)
Random error	0.3068 (74.11%)	0.312 (98.6%)	0.422 (87.7%)	0.222 (77.7 %)	0.146 (73.8 %)

CCC: concordance correlation coefficient; MSEP = mean square error of prediction; [1]Probability value for the hypothesis test where the value of parameter a = 0 (Neter et al., 1996). [2] Probability value for hypothesis test where the value of parameter b = 1 (Neter et al., 1996);[3] Adapted data published by Menezes et al. (2022).

Prediction and validation of dry matter intake in diets with fixed roughage: concentrate ratio

High-concentrate diets have recently become economically viable due to the increase in roughage production costs, temporary reductions in concentrate prices and increased supply of industry by-products (Cervieri et al., 2009). In Brazil, finishing diets have increased concentrate levels in recent years. Studies carried out between 2009 and 2014 showed an increase of 11% in the proportion of concentrate in feedlot diets (71.2% and 79%, respectively) (Millen et al., 2009; Oliveira and Millen, 2014). In a study carried out by Pinto and Millen (2018), it was pointed out that 87.9% of feedlots in the country used more than 71% concentrate in the diet, and of these, 54.6% used more than 80%. In a recent study, Silvestre and Millen (2021) found that the average inclusion of concentrate in the feedlot diet is 83.2%. With the increasing use of diets with high concentrate levels for feedlot cattle in Brazil, adequate nutritional management has become necessary, so it is fundamental to predict DMI.

Data that is considered valid for selection were those that included information regarding sex, initial and final body weight (BW), dry matter intake (DMI), average daily gain (ADG) and concentrate or roughage level in the total diet.

The descriptive statistic of the data used to validate the DMI prediction of cattle fed a fixed concentrate level diet is shown in Table 2.7. The following equations were got for the genetic groups:

Zebu cattle:

$$DMI\ (kg/d) = -1.303 + 0.0029 \times CL - 0.00005 \times CL^2 + 0.0843 \times BW^{0.75} + 2.243 \times ADG - 0.271 \times ADG^2 \quad (R^2 = 0.797) \quad \text{(Equation 2.4)}$$

Crossbred beef cattle:

$$DMI\ (kg/d) = -4.8196 + 0.0081 \times CL - 0.00011 \times CL^2 + 0.1239 \times BW^{0.75} + 2.8189 \times ADG - 0.775 \times ADG^2 \quad (R^2 = 0.717) \quad \text{(Equation 2.5)}$$

where CL = concentrate level in the diet (% total diet DM); $BW^{0.75}$ = mean metabolic body weight; ADG = average daily gain, in kg/d.

An independent database was used to validate the results with 106 experimental units for Zebu and 137 for crossbred beef cattle (Table 2.8). The data were obtained from publications between 2005 and 2015 in the *Revista Brasileira de Zootecnia, Arquivo Brasileiro de Medicina Veterinária e Zootecnia, Semina; Ciências Agrárias*, Acta Scientiarum: Animal Sciences, *Revista de*

Ciência Agronômica, Journal of Animal Science and Boletim.

When selecting this database, there was no concern to establish selection for high-concentrate diets, so, to verify the sensitivity of the prediction model for different proportions of concentrate in the diet were evaluated. This can be seen in the descriptive statistics for the validation database (Table 2.8).

The results observed in Table 2.9 indicated that the DMI prediction equation with fixed concentrate content can be used safely. Thus, considering that the diet formulator knows which concentrate level will be used in the diet, or has a fixed roughage: concentrate ratio, the BR-CORTE suggested that this equation can be used.

Based on Equations 2.4 and 2.5, the Table 2.10 shows the estimated dry matter intake for Zebu and crossbred beef cattle finished in feedlot obtained for different body weights and weight gains, considering three concentrate contents (30, 60 and 90%) in the diet.

Table 2.7 - Descriptive statistics of the variables used to develop dry matter intake prediction equation for cattle fed fixed concentrate level diet

Item	N	Mean	SD	Minimum	Maximum
Zebu cattle					
Dry matter intake, kg/d	983	7.55	2.07	2.05	13.8
Body weight, kg	983	362	88.3	133	647
Metabolic body weight, kg	983	82.9	15.8	39.2	128.2
Average daily gain, kg/d	983	0.97	0.41	-0.14	2.26
Concentrate level, %	983	45.6	24.0	0.00	85.0
Crossbred beef cattle					
Dry matter intake, kg/d	432	8.22	1.73	2.75	12.9
Body weight, kg	432	383	61.8	231	538
Metabolic body weight, kg	432	86.4	10.6	59.3	112
Average daily gain, kg/d	432	1.32	0.34	0.48	2.44
Concentrate level, %	432	61.9	21.6	25.0	100

N: number of experimental units; SD: standard deviation.

Table 2.8 - Descriptive statistics of the variables used to validate dry matter intake prediction by cattle fed different concentrate levels

Variable	N	Mean	SD	Minimum	Maximum
Zebu cattle					
Dry matter intake, kg/d	106	8.68	1.61	2.96	12.3
Body weight, kg	106	416	53.5	223	494
Metabolic body weight, kg	106	91.9	9.18	57.7	105
Average daily gain, kg/d	106	1.19	0.30	0.15	1.75
Concentrate level, % total diet DM	106	62.1	20.3	0.00	95.4
Crossbred beef cattle					
Dry matter intake, kg/d	137	8.98	1.47	6.11	13.60
Body weight, kg	137	394	48.2	265	520
Metabolic body weight, kg	137	88.3	8.18	65.6	109
Average daily gain, kg/d	137	1.40	0.27	0.76	2.17
Concentrate level, % total diet DM	137	55.0	17.9	11.0	100

N: number of experimental units; SD: standard deviation.

Table 2.9 - Statistics for the ratio between the observed and predicted values by the DMI prediction equations for cattle fed with different concentrate levels

Variable		Zebu	Crossbred beef cattle
Intercept		-1.3568	-1.5386
	P-value[1] (H_0: a = 0)	0.0623	0.2022
Slope		1.1577	1.1316
	P-value[2] (H_0: b = 1)	0.0582	0.3150
r^2		0.6552	0.4087
Mean bias		0.0105	-0.3329
CCC		0.7602	0.5262
MSEP		0.9254	1.3306
	Mean bias	0.0001 (0.01%)	0.1717 (12.30%)
	Systemic error	0.0315 (3.41%)	0.0040 (0.29%)
	Random error	0.8938 (96.58%)	1.2203 (87.41%)

CCC = concordance correlation coefficient; MSEP = mean square error of prediction; [1]Probability value for the hypothesis test where the value of parameter a = 0 (Neter et al., 1996). [2] Probability value for hypothesis test where the value of parameter b = 1 (Neter et al., 1996).

Prediction and validation of dry matter intake by pasture-raised cattle receiving supplementation

Brazil is a country with continental dimensions, and it is the fifth in the world in terms of territorial extension, with an area of 8.5 million km^2 where 172.3 million hectares are pasture (IBGE, 2007). It also has a great diversity of climate and vegetation, which along with the territorial extension enables the beef production systems to be characterized by using forage as the diet base. Most of the Brazilian beef production system is produced with animals under pasture conditions and of the 41.5 million cattle slaughtered in Brazil, only 15.62% were finished in the feedlot in 2020 (ABIEC, 2021).

According to Paulino et al. (2005), sustainable pasture for beef cattle production should be highlighted, because this resource is the main and the most economical source of nutrients for the animals.

Predicting intake for pasture-raised cattle is not an easy task. In their revision, Coleman et al. (1999) observed that the DMI of cattle on pasture varies as a function of the forage quality and physical characteristics and the physiological state of the animal.

According to Lardy et al. (2004), the main limitation to establish DMI prediction models for cattle on pasture is that the main studies were carried out with indirect estimates using external and internal markers to predict DMI. Furthermore, animals on pasture can assess the forage available and select a diet that meets their nutrient needs (Coleman and Sollenberger, 2007; Launchbaugh and Doherty, 2007). Thus, their selectivity ends up interfering in the possibility of quantifying the diet chemical composition of animals on pasture and predicting exactly which nutrients are ingested by these animals.

Therefore, it should be considered that the DMI prediction estimates for cattle on pasture are more complex than those for animals in feedlot and good sense should prevail when using the equations developed. Pasture should be understood as a highly complex production component because it supplies substrates to the animal and can vary qualitatively and quantitatively over the year, influenced mainly by abiotic factors, e.g., rainfall, temperature, and solar radiation (Detmann et al., 2004).

Using tropical grasses as the only protein and energy source is not feasible to meet the nutrient requirements of growing or finishing cattle (Moore, 1999) because pastures rarely contain all the essential nutrients in adequate proportions to meet the nutrient requirements of the animal. Therefore, feeding systems combining base forage and concentrate supplement are necessary to make nutritional adjustments and improve animal production on pasture.

Moore (1980) reported three possible effects to be identified between supplementation and forage intake: additive, associative and substitutional. In the first, forage intake remains constant, regardless of the level of supplementation, but the total intake increases at the same proportion as the supplemented level; in the associative effect, the total intake also increases, but forage intake decreases; while in the substitutional, the total intake remains constant, but forage intake decreases and is substituted by supplement intake.

Table 2.10 - Dry matter intake for Zebu and crossbred beef cattle finished in feedlot obtained for different body weights and weight gains, considering three concentrate levels (30, 60 and 90%)

Body weight (kg)	Weight gain (kg/d)	Concentrate (%)	Dry matter intake (kg)	
			Zebu (Equation 2.4)	Crossbred beef cattle (Equation 2.5)
200	0.5	30	4.28	3.13
		60	4.23	3.08
		90	4.09	2.82
	1.0	30	5.19	3.96
		60	5.15	3.90
		90	5.01	3.65
	1.5	30	5.98	4.40
		60	5.93	4.34
		90	5.79	4.09
300	0.5	30	5.87	5.47
		60	5.82	5.42
		90	5.68	5.17
	1.0	30	6.79	6.30
		60	6.74	6.25
		90	6.60	5.99
	1.5	30	7.57	6.74
		60	7.52	6.69
		90	7.38	6.43
400	0.5	30	7.33	7.62
		60	7.28	7.57
		90	7.15	7.32
	1.0	30	8.25	8.45
		60	8.20	8.40
		90	8.07	8.14
	1.5	30	9.03	8.89
		60	8.99	8.84
		90	8.85	8.58
500	0.5	30	8.71	9.64
		60	8.66	9.59
		90	8.52	9.33
	1.0	30	9.62	10.47
		60	9.58	10.42
		90	9.44	10.16
	1.5	30	10.41	10.91
		60	10.36	10.86
		90	10.22	10.60

The replacement effect obtained with supplementation is directly proportional to the forage quality, where it is greater with high-quality compared to low-quality forage (Minson, 1990). With the replacement, values lower than 1.0 g/g are assumed, and a reduction is observed in pasture intake, but there is an increase in total intake (Costa et al., 2011).

Currently, most of the national beef herd is Nellore or comes from their crosses. However, the number of animals coming from dairy farms is increasing due to the high demand for meat and the lower exchange ratio of the 'arroba' of these animals in the acquisition.

Given the importance of estimating the DMI of cattle in tropical conditions raised on pasture and receiving supplementation, BR-CORTE (Azevedo et al., 2016) suggested the use of a specific prediction model considering the DMI of the supplement (DMIs, kg/d) for Nellore animals. However, with the increase in pasture-raised crossbred dairy cattle, in this version, an Equation was suggested to cover these animals and the database of Zebu animals was expanded.

Wide variation in the data was observed in the information regarding the descriptive statistics of the database (Table 2.11), so that prediction equations could be generated for more varied production systems.

The following DMI intake equation was established for Zebu on pasture, receiving supplementation, under tropical conditions:

Zebu cattle supplemented on pasture:

$$DMI\ (kg/d) = -\,0.4684 + 0.7732 \times DMIs + 0.0742 \times BW^{0.75} + 0.7953 \times ADG - 0.9047 \times ADG^2 \quad (R^2 = 0.638) \quad \text{(Equation 2.6)}$$

Crossbred dairy cattle supplemented on pasture:

$$DMI\ (kg/d) = 0.9951 + 0.7732 \times DMIs + 0.0742 \times BW^{0.75} + 0.7953 \times ADG - 0.9047 \times ADG^2 \quad (R^2 = 0.624) \quad \text{(Equation 2.7)}$$

where DMIs is the supplement intake, in kg/d; $BW^{0.75}$ average metabolic body weight, in kg and ADG, average daily gain, in kg/d.

To validate this Equation, an independent database from the journals was used: *Revista Brasileira de Zootecnia, Arquivo Brasileiro de Medicina Veterinária e Zootecnia, Semina: Ciências Agrárias*, Asian Australasian Journal of Animal Science, Bioscience Journal, Acta Scientiarum. Animal Sciences, Enciclopédia Biosfera, Research, Society and Development, Tropical Animal Health and Production and *Pesquisa Agropecuária Brasileira.*

The total size of the variables presented in the database for validating the intake prediction for Zebu cattle raised on pasture (Table 2.12) represents Brazilian characteristics of extensive beef cattle pasture and supplemented production systems and it is sufficiently representative to validate the equation.

Then, the responses to the predicted and observed values were exact and precise: the equation correctly estimated the DMI represented by the non-significance of the intercept and slope and by the low value of the mean square prediction error (Table 2.13), indicating that it could be applied to pasture-raised and supplemented animals.

It should be noted that equations 2.6 and 2.7 should be used to predict DMI in animals rearing or receiving moderate levels of concentrate (up to 5.32 and 3.5 kg/d for zebu and crossbred dairy animals, respectively), and that present moderate weight gains (up to 1.34 and 1.35 kg/d for zebu and crossbred dairy animals, respectively). It should be considered that most of the data used to build this Equation were obtained in periods of drought.

Table 2.11 - Descriptive statistics of the variables used to predict dry matter intake for pasture-raised Zebu and Crossbred dairy cattle

Variable	N	Mean	SD	Minimum	Maximum
Zebu cattle					
Body weight, kg	1069	278	92.0	102	568
Metabolic body weight, kg	1069	67.3	16.6	32.1	116
Average daily gain, kg/d	1069	0.53	0.32	-0.39	1.56
Dry matter intake, kg/d	1069	5.18	2.01	1.34	14.1
Supplement, kg/d	1069	0.83	0.76	0.00	5.92
Crossbred dairy cattle					
Body weight, kg	229	332	75.0	199	541
Metabolic body weight, kg	229	77.5	13.1	53	112
Average daily gain, kg/d	229	0.55	0.17	0.28	1.08
Dry matter intake, kg/d	229	7.33	1.72	4.02	11.37
Supplement, kg/d	299	0.69	0.41	0.16	1.75

N: number of experimental units; SD: standard deviation.

Table 2.12 - Descriptive statistics of the variables used to validate dry matter intake for pasture-raised Zebu and Crossbred dairy cattle

Variable	N	Mean	SD	Minimum	Maximum
Zebu cattle					
Body weight, kg	174	311	86.7	133	474
Metabolic body weight, kg	174	73.5	15.8	39.2	102
Average daily gain, kg/d	174	0.56	0.26	-0.18	1.34
Dry matter intake, kg/d	174	6.65	2.18	1.98	12.3
Supplement, kg/d	174	1.06	1.14	0.00	5.32
Crossbred dairy cattle					
Body weight, kg	42	297	68.0	194	417
Metabolic body weight, kg	42	71.3	12.3	51.9	92.3
Average daily gain, kg/d	42	0.59	0.21	0.11	1.05
Dry matter intake, kg/d	42	7.00	1.73	4.74	10.24
Supplement, kg/d	42	0.87	1.00	0.00	3.50

N: number of experimental units; SD: standard deviation.

Table 2.13 - Statistics for the ratio between the observed and predicted values by the DMI for pasture-raised Zebu and Crossbred dairy cattle

Variable		
Zebu cattle		
Intercept		0.470
	P-value[1] (H_0: a = 0)	0.170
Slope		1.05
	P-value[2] (H_0: b = 1)	0.376
r^2		0.670
Mean bias		0.761
CCC		0.741
MSEP		2.13
Decomposition of the MSEP		
	Mean bias	0.580 (27.19%)
	Systemic error	0.007 (0.33%)
	Random error	0.007 (72.47%)
Crossbred dairy cattle		
Intercept		-0.882
	P-value[1] (H_0: a = 0)	0.153
Slope		1.10
	P-value[2] (H_0: b = 1)	0.237
r^2		0.771
Mean bias		-0.168
CCC		0.851
MSEP		0.665
Decomposition of the MSEP		
	Mean bias	0.028 (4.23%)
	Systemic error	0.018 (2.72%)
	Random error	0.018 (93.06%)

CCC = concordance correlation coefficient; MSEP = mean square error of prediction; [1]Probability value for the hypothesis test where value of parameter a = 0 (Neter et al., 1996). [2] Probability value for hypothesis test where value of parameter b = 1 (Neter et al., 1996).

In intensive finishing on pasture (TIP), in which the animal intake the same amount of concentrate on pasture that is supplied when feedlot, BR-CORTE suggests using Equation 2.1 to predict DMI.

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Intakes estimated by equations 2.6 and 2.7 can be seen in Table 2.14, where it is possible to observe variations in combinations between body weight, average daily gain and supplement intake

Table 2.14 - Estimated dry matter intake for pasture-finished cattle of different body weights, weight gains and supplement intakes (DMIs)

Body weight (kg)	Weight gain (kg/d)	DMIs	DMI (Eq. 2.6)	DMI (Eq. 2.7)
200	0.00	0.00	3.48	4.94
		0.80	4.10	5.56
		1.60	4.71	6.18
	0.50	0.00	3.65	5.11
		0.80	4.27	5.73
		1.60	4.89	6.35
	1.00	0.00	3.37	4.83
		0.80	3.99	5.45
		1.60	4.61	6.07
300	0.00	0.00	4.88	6.34
		1.20	5.81	7.27
		2.40	6.74	8.20
	0.50	0.00	5.05	6.52
		1.20	5.98	7.44
		2.40	6.91	8.37
	1.00	0.00	4.77	6.23
		1.20	5.70	7.16
		2.40	6.63	8.09
400	0.00	0.00	6.17	7.63
		1.60	7.41	8.87
		3.20	8.64	10.11
	0.50	0.00	6.34	7.80
		1.60	7.58	9.04
		3.20	8.81	10.28
	1.00	0.00	6.06	7.52
		1.60	7.30	8.76
		3.20	8.53	10.00
500	0.00	0.00	7.38	8.84
		2.00	8.92	10.39
		4.00	10.47	11.93
	0.50	0.00	7.55	9.01
		2.00	9.10	10.56
		4.00	10.64	12.11
	1.00	0.00	7.27	8.73
		2.00	8.81	10.28
		4.00	10.36	11.82

FINAL CONSIDERATIONS

The equations for predicting dry matter intake for feedlot cattle in tropical conditions are:

Zebu cattle: $DMI\ (kg/d) = -2.1948 + 0.08338 \times BW^{0.75} + 3.9328 \times ADG - 0.9030 \times ADG^2$ (Equation 2.1)

Crossbred beef cattle: $DMI\ (kg/d) = -0.6273 + 0.06453 \times BW^{0.75} + 3.871 \times ADG - 0.614 \times ADG^2$ (Equation 2.2)

Crossbred dairy cattle: $DMI\ (kg/d) = -2.8836 + 0.08435 \times BW^{0.75} + 4.5145 \times ADG - 0.9631 \times ADG^2$ (Equation 2.3)

Alternatively, the equations below can be used when the concentrate level used in the diet formulation is known:

Zebu cattle: $DMI\ (kg/d) = -1.303 + 0.0029 \times CL - 0.00005 \times CL^2 + 0.0843 \times BW^{0.75} + 2.243 \times ADG - 0.271 \times ADG^2$ (Equation 2.4)

Crossbred beef cattle: $DMI\ (kg/d) = -4.8196 + 0.0081 \times CL - 0.00011 \times CL^2 + 0.1239 \times BW^{0.75} + 2.8189 \times ADG - 0.775 \times ADG^2$ (Equation 2.5)

The following equation is indicated to predict dry matter intake for **Zebu cattle raised on pasture**:

Zebu cattle: $DMI\ (kg/d) = -0.4684 + 0.7732 \times DMIs + 0.0742 \times BW^{0.75} + 0.7953 \times ADG - 0.9047 \times ADG^2$ (Equation 2.6)

Crossbred dairy cattle: $DMI\ (kg/d) = 0.9951 + 0.7732 \times DMIs + 0.0742 \times BW^{0.75} + 0.7953 \times ADG - 0.9047 \times ADG^2$ (Equation 2.7)

ACKNOWLEDGMENT

We would like to thank professor Danilo Domingues Millen of the *Universidade Estadual Paulista - Campus Dracena* (UNESP), professor Telma Berchielli of the *Universidade Estadual Paulista - Campus Jaboticabal* (UNESP), professor Ivanor Nunes do Prado of the *Universidade Estadual de Maringá* (UEM), and professor Fabiano Alvim Barbosa of the Veterinary School at the *Universidade Federal de Minas Gerais* (EV- UFMG), Professor Robério Rodrigues Silva of the State University of Southwest Bahia, Professor Ériton Egídio Lisboa Valente of the State University of West Paraná, Nutripura Nutrição Animal LTDA, Grande Lago feedlot, and Cara Preta feedlot for providing data on individual intake and in group of cattle from research at these institutions.

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