Evaluation of the NRC (2000) Beef Model for Predicting Performance and Energy Requirements of Cattle Fed under Western Canadian Environmental Conditions

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Saskatoon, Saskatchewan

Canada

Khalil Mohamad Fayez Sahtout

ABSTRACT

The NRC (2000) beef model is widely used to evaluate nutrient requirements and feeding programs for cattle. The objectives of this study were to assess the accuracy and precision of the NRC (2000) beef model in predicting dry matter intake (DMI), shrunk weight gain (SWG), net energy of maintenance (NE_m) and gain (NE_g) requirements and also to determine the relationship of body condition score (BCS) and ultrasound subcutaneous fat thickness (USF) to total body fat of steers fed under western Canadian environmental conditions. Data used for this study was from Basarab et al. (2003). The study was conducted over two years using a total of 176 steers. The DMI, SWG, NE_m and NE_g for each steer were modeled using the NRC (2000) beef model under actual environmental and thermoneutral conditions. Retained energy (NE_g) was calculated for each animal based on initial and final body composition. Actual NE_m utilized was calculated by subtracting NE_g adjusted for the efficiency of metabolizable energy used for gain (k_g) from total metabolizable energy consumed and by adjusting for the efficiency by which metabolizable energy is used for maintenance (k_m). The accuracy of predicted values was evaluated by means comparison, regression and residual analysis, concordance correlation coefficient (CCC) and reliability index methods. Dry matter intake was over predicted ($P<0.05$) while SWG was under predicted ($P<0.05$). Regression between observed and predicted DMI and SWG were significant ($P<0.05$ adjusted $r^2=0.47$ or 0.51, respectively), but different ($P<0.05$) from the isopleth indicating inaccurate prediction with general over/under prediction, respectively. Regression between observed and predicted NE_m and NE_g were not significant ($P>0.05$) under all methods investigated with a general over prediction for NE_m and under prediction for NE_g under actual environmental and thermoneutral conditions. Cattle NE_g was under predicted, possibly explaining why SWG was under predicted. Potential reasons for this inaccuracy includes failure to account for specific physiological and behavioral adjustments such as changes in organ size, passage rate, hide thickness influencing the NE_m calculation and in the case of NE_g due to the lack of precise knowledge of actual composition of gain by growing steers due to lack of specificity of initial body composition. Body condition score and USF had a comparably strong

relationships to total body fat ($P<0.05$, adjusted $r^2 = 0.55$ or 0.56, respectively), suggesting potential for their use in improving composition of gain predictions ($P<0.05$).

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Head of the Department of Animal and Poultry Science
University of Saskatchewan, 51 Campus Drive
Saskatoon, Saskatchewan S7N 5A8

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ABBREVIATIONS

BCS:	Body condition score
CCC:	Concordance correlation coefficient
COMP:	Previous plane of nutrition
CNCPS:	Cornell net carbohydrate and protein system
DIP:	Degradable intake protein
DMI:	Dry matter intake
DNA:	Deoxyribonucleic acid
EQSBW:	Equivalent shrunk body weight
FBF:	Final body fat
FHP:	Fasting heat production
FSBW:	Final shrunk body weight
LCT:	Lower critical temperature.
MC:	Mean component
ME:	Metabolizable energy
MSE:	Mean square error
NE:	Net energy
NE_g:	Net energy of gain
NE_m:	Net energy of maintenance
NRC:	National research council
RC:	Random or residual component
RE:	Retained energy equivalent to NE_g.
RI:	Reliability index
SC:	Slope component
SWG:	Shrunk weight gain
SRW:	Standard reference weight
S_{y*x}:	Root mean square error (Variation in y given x)
TDN:	Total digestible nutrients
UDP:	Undegradable intake protein
USF:	Ultrasound subcutaneous fat thickness

1.0. INTRODUCTION

The majority of the operational cost of a cattle operation is feed (Herd et al. 2003). In North America, the majority of cattle are finished on a high grain diet. It is estimated that between 70 to 75% of the energy consumed by cattle is used for maintenance (Ferrell and Jenkins, 1985; Kaliel and Kotowich, 2002). To minimize this cost, a number of nutritional models have been developed. Nutritional models are comprised of equations that describe various physiological functions of the animal (Tedeschi et al. 2005). The goal of a nutritional model is to predict the physiological changes in an animal as a result of current and future decisions on feeding and management.

Early models were either empirical or mechanistic. An empirical model is based on observations to give numerical values (Theodorou and France, 1999). Mechanistic models look at every component within a system and attempt to identify cause and mechanism at each stage (Theodorou and France, 1999).

Early European models examined feed intake, the cellulose and fat content of the feed, and incorporated nutrient intake into regression equations to predict feed intake (Theodorou and France, 1999). These early models lacked accuracy but provided a basis for future research. Models then became based on metabolizable energy (ME). The ME based models provided a higher accuracy than previous models but nevertheless they had drawbacks. The ME system was used by the NRC beef model prior to 1984 as well as the British ARC (1980) model. These models had some inaccuracy in their predictions but they provided the basis for the development of models based on net energy. The Australian CSIRO (2007) model is still based on ME.

Nutritional models developed over time due to a number of advances. These included near infrared reflectance spectroscopy for forage quality determination, changes in forage storage and conservation procedures, studies on the utilization of crop residues in feeding systems, digestive kinetics and nutrient availability in the rumen and post ruminal gastro-intestinal tract and a greater understanding of the digestibility of forages (Fahey and Hussein, 1999). With all these advances, current nutrition models have become more complex and have become part of most livestock operations around the world.

The model investigated in this project is the NRC (2000) beef model. This model is based on net energy which is partitioned into energy needed for maintenance, gain and lactation. These separations in theory should increase the accuracy of the model. The reason for this is that energy needed for maintenance is much more efficiently used than that for gain (Garrett and Johnson, 1983; Lofgreen and Garrett, 1968). In fact, there is a curvilinear relationship between the energy needed for maintenance and that for gain (Garrett, 1979).

The NRC (2000) beef model uses equations adopted from the California Net Energy System which used comparative slaughter techniques to predict energy requirements (Garrett et al. 1959; Lofgreen and Garrett, 1968). This model predicts the requirements of the growing animal by partitioning it into maintenance (NE_m) and gain (NE_g) components (Tedeschi et al. 2005). Separating NE between maintenance, gain and lactation allowed the system to adequately take into account differences in efficiency (Figure 2.2) of energy used between these parameters (Ferrell and Oltjen, 2008).

The NRC (2000) beef model is composed of two levels. The first level uses tabular feed energy values and the metabolizable protein system (degradable intake protein; DIP and undegradable intake protein; UDP) of Burroughs et al., (1974). Total digestible nutrients (TDN) are determined through either digestibility trials, estimated by prediction equations, or obtained from tables of reference values (NRC, 2000). Level two simulates rumen degradation to predict TDN and partitions protein more thoroughly. Both level one and level two converge at TDN and microbial protein (MP) when starting on predictions of DMI and NE_m and SWG. The NRC (2000) beef model attempts to account for a variety of animal, environmental, and management factors by looking at a number of variables, including body condition score (BCS), use of anabolic implants, type of breeds and feeding system. In addition, the model standardizes today’s cattle to those used in developing the equations for the NRC (1984) model by determining a standard reference weight (SRW). The SRW is the weight that cattle reach when achieving a target percent of body fat. These adjustments are used to make today’s cattle similar to those used in the initial development of the net energy (NE) system and to help differentiate cattle from each other in terms of how fat or thin they are at the time of feeding. To assist users, the NRC (2000) beef model incorporates a computer simulation program that uses mathematical equations to predict outcome with inputs provided by users.

The use of a nutritional model to evaluate management options and target performance helps producers predict and calculate future feed expenditures, determine management practices, and perhaps most importantly decide when to market the animal. The objective of the following literature review is to provide background information dealing with the following topics:

1. Model development
2. NRC (2000) beef model and the CNCPS model
3. Ultrasound subcutaneous fat thickness and body condition score

2.0. LITERATURE REVIEW

To develop a model, data about the system in question must be collected; equations that predict that data must be developed and then the laws governing the model must be established. The model will then have to be tested with a second set of data in a process called validation (Lewandowski, 1981).

Models can be designed for a number of reasons such as for better understanding, for scenario analysis and for optimization. Aspects to look at during model assessment include its usefulness as well as reliability in accurately predicting real world outcomes and ease of predicting these outcomes (Lewandowski, 1981).

This review will discuss cattle nutritional models which are a set of equations that are integrated to describe different physiological functions within the animal (Tedeschi et al. 2005). Model complexity will increase as the model attempts to describe a greater range of physiological functions (Chalupa et al. 2010). The complexity of a model will be a function of the degree that it attempts to describe metabolism and physiological changes. Table 2.1 indicates the different levels of model complexity. A complex model may need very few inputs or a large number of inputs.

Table 2.1: Model complexity chart adopted from Chalupa et al. (2010).

The level of complexity	Description of complexity
1	A group of organisms (For example a herd of cattle)
2	A single organism (i.e a cow, a sheep, a bull, etc)
3	Organs (Liver, heart, kidney, etc)
4	Tissues, (Tubules, nephrons, etc)
5	Cell (Liver cells, heart cell, muscle cell, etc)
6	DNA production, protein production

Nutritional models have two major objectives. The first is to describe observations that have been documented by researchers (Tedeschi et al. 2005). The second is to explain mechanisms that occur within the body (Tedeschi et al. 2005). These two objectives have been addressed in many different ways resulting in the development of a diverse set of models.

With so many models developed, it will be impractical to discuss all of them in this thesis and thus only a few will be chosen. One model that has intrigued the author is that published by Bywater et al. (1988). This model utilized DNA production parameters to predict animal growth rate. This model was designed to evaluate a number of parameters for growth of mammalian tissues (Bywater et al. 1988). The model used equations that were initially calculated using rats as a model and modified accordingly for cattle and sheep (Bywater et al. 1988). This model was shown to have a strong correlation for predicting growth when compared to models such as the NRC (1984) or the ARC (1980) (Bywater et al. 1988). In fact, when compared to the NRC (1984) the Bywater et al. (1988) model had a higher accuracy and precision in predicting gain for growing calves. The Bywater et al. (1988) model can predict DNA production of a growing animal. This was why this model can only be used for weaned calves and lambs. The model described by Bywater et al. (1988) provided evidence that the use of a small molecule such as DNA could be used to predict the growth of an entire animal. Such findings can be used in establishing a nutritional model.

Models such as that developed by Bywater et al. (1988) utilized mass balance and Michaelis-Menten kinetics to look at the substrate levels of a system such as DNA transcription and translation, enzyme activity, protein synthesis and degeneration, cell replication and apoptosis to reach a steady state (Chalupa et al. 2010). These scientific models have three assumptions. The first is that in vivo metabolic pathways can be modeled from in vitro experimental data (Chalupa et al. 2010). The second is that metabolic processes at the cellular level can be correlated to the level of organs and thus can be used to model whole animal growth (Chalupa et al. 2010). The third assumption is that such models can be used to predict outcome of different management practices (Tedeschi et al. 2005). These assumptions are used as guidelines for developing nutritional models.

Production models which are based on scientific models are used extensively in the commercial sector. The use of such models allowed the user to predict the animal’s response to different inputs such as changes in feed, environment, and management practices (Chalupa et al. 2010).

As the name suggests, production models are based on data obtained from individual animals, individual pens or a herd (Chalupa et al. 2010). Over time, production models have become less static and much more dynamic as well as mechanistic, incorporating mathematical strategies (Chalupa et al. 2010). Examples of production models that used a mechanistic as well as an empirical approach include the Cornell Net Carbohydrate and Protein System (CNCPS) and the National Research Council (NRC) beef models. Both of these models are used extensively in North America. Other models that are used outside of North America having both a dynamic and a mechanistic approach include the Dutch model DVE/OEB (Tamminga et al. 1994), the British AFRC model (AFRC, 1990; 1992), Australian CSIRO model (CSIRO, 1990) and the French INRA model (INRA, 1989).

The mathematical model can incorporate knowledge of feed type, feed intake, energy or protein content of different feeds that were absorbed in the rumen or escaped the rumen and overall microbial growth under different conditions (Tedeschi et al. 2005). To accomplish this in a production model there are a number of approaches that can be utilized which include classical algebraic equations, predictive empirical relationships, dynamic equations and mechanistic based models (Tedeschi et al. 2005). These approaches are generally used in combination and thus all production models can be categorized by the mathematical approach used. The NRC (2000) beef model for example uses an empirical approach in Level one while in Level two uses both an empirical and a mechanistic approach. Table 2.2 lists different approaches that could be used in developing a nutritional model.

Currently, nutrition models used by industry uses a combination of approaches listed in Table 2.2 (Tedeschi et al. 2005). These models must be accurate enough for the farmer to trust and predict economically important outcomes. The inputs needed for the model must be available to the farmer. Most models try to answer one question: what are the energy and protein requirements at different stages of animal production? Other questions that a model can attempt to answer include what will be the intake requirements to achieve a specified goal or what is the performance of the animal under conditions indicated by the user.

2.1 ENERGY REQUIREMENTS

Energy is defined as the capacity to perform work (Coad, 1982). Using this definition energy can be examined by looking at biochemical reactions or at overall physiological changes such as growth, reproduction and lactation. In the biochemical principles, the energy equation describing the oxidation of glucose to CO_2 and H_2O and the reversal being photosynthesis is indicated in equation 2.1 (Mitchell, 1996):

$$C_6H_{12}O_6 + 6O_2 \rightarrow \text{Energy} + 6CO_2 + 6H_2O \qquad (2.1)$$

From left to right equation 2.1 indicates the aerobic breakdown of glucose to CO_2 and H_2O in mammalian tissue where energy is liberated to make 38 molecules of adenosine triphosphate (ATP) per mole of glucose. From right to left, equation 2.1 depicts the photosynthesis pathway in which energy represents sunlight. For animals, not all carbon sources are glucose; for example the most common forms for ruminants are starch, cellulose, and hemicelluloses (Wolin, 1960). These compounds can be used to produce glucose but mammals do not have all the necessary enzyme and thus require microbial activity.

Starch and cellulose can be hydrolyzed to form glucose which can be fermented by rumen bacteria anaerobically to release energy in the form of two to three ATP molecules, volatile fatty acids (VFA) and heat (Baldwin, 1970). A consequence of this activity in the rumen is that heat is given off, known as the heat of fermentation. This heat and the gas produced during fermentation represent a considerable loss in energy that the animal could have used for productive purposes.

These losses can contribute to the reduction in efficiency in converting feed to meat. To determine the amount of energy from the feed that will be used for productive purposes requires a number of steps as disclosed below. The first will be to determine the total energy content of the feed referred to as the gross energy.

Gross energy (GE) can be determined with a bomb calorimeter (Pond et al. 2005). Gross energy is defined as the amount of heat produced when a feed is completely oxidized (Pond et al. 2005). Gross energy does not provide information on how much energy is absorbed or lost by the animal. Digestible energy (DE) is GE minus fecal energy (FE) losses (Figure 2.1). Digestible energy is the most common method of measuring the amount of nutrients absorbed, but DE doesn't account for a number of major losses associated with digestion and metabolism such as heat loss due to digestion and gas production due to fermentation and urinary losses (NRC, 2000).

To account for gas, urinary and fecal losses, metabolizable energy (ME) must be calculated. The type of gas lost in ruminants is composed of methane due to fermentation and CO_2. Metabolizable energy (ME) is composed of two components: heat produced due to metabolic and fermentative activity (HI) and the amount of energy retained (RE) within the animal. This is indicated by the following equations (Lofgreen and Garrett, 1968):

$$ME = RE + HI \qquad \textbf{(2.2)}$$

$$HI = (Heat\ of\ fermentation) + (Metabolic\ function) + (Heat\ of\ digestion) \qquad \textbf{(2.3)}$$

At maintenance, the animal retains no energy and thus retained energy (RE) would equal zero. At maintenance the equation would be according to equation 2.4 which is different than equation 2.2.

$$\mathrm{ME} = \mathrm{HI} \qquad \textbf{(2.4)}$$

The HI is the amount of heat released during digestion, fermentation and from metabolic functions (Armstrong and Blaxter, 1957). The heat increment is affected by the diet as well as the environment (Brokken, 1971). Net energy takes into account the HI and the gas lost. Heat increment (Equation 2.3) and the gas lost (Equation 2.5) can be a substantial loss of energy.

$$57.5\ (\mathrm{C_6H_{12}O_6}) \rightarrow 65\ \text{acetate} + 20\ \text{propionate} + 15\ \text{butyrate} + 60\ \mathrm{CO_2} + 35\ \mathrm{CH_4} + 25\ \mathrm{H_2O} + \text{Heat} \qquad (2.5)$$

Table 2.2: Mathematical approaches used in model development (Adapted from Tedeschi et al. 2005)

Category	Description
Dynamic vs Static	A dynamic based model will incorporate time as a factor while static will ignore time
Empirical vs mechanistic	An empirical model used a set of data so as to create a best fit equation (to be used) to predict future data while the mechanistic approach will attempt to use data of biological function dealing with cells or entire organs to produce equations that allow prediction of future effects dealing with an entire organism.
Continuous vs Discrete	A continuous-based model uses time to be continuous in nature while describing different parameters within a model while a discrete based model makes time to be a point in space within the model and thus fixed.
Spatially homogeneous vs heterogeneous	Spatially homogeneous models utilize space as an entity while a heterogeneous-based model looks at space as though it was in motion such as enzyme kinetics

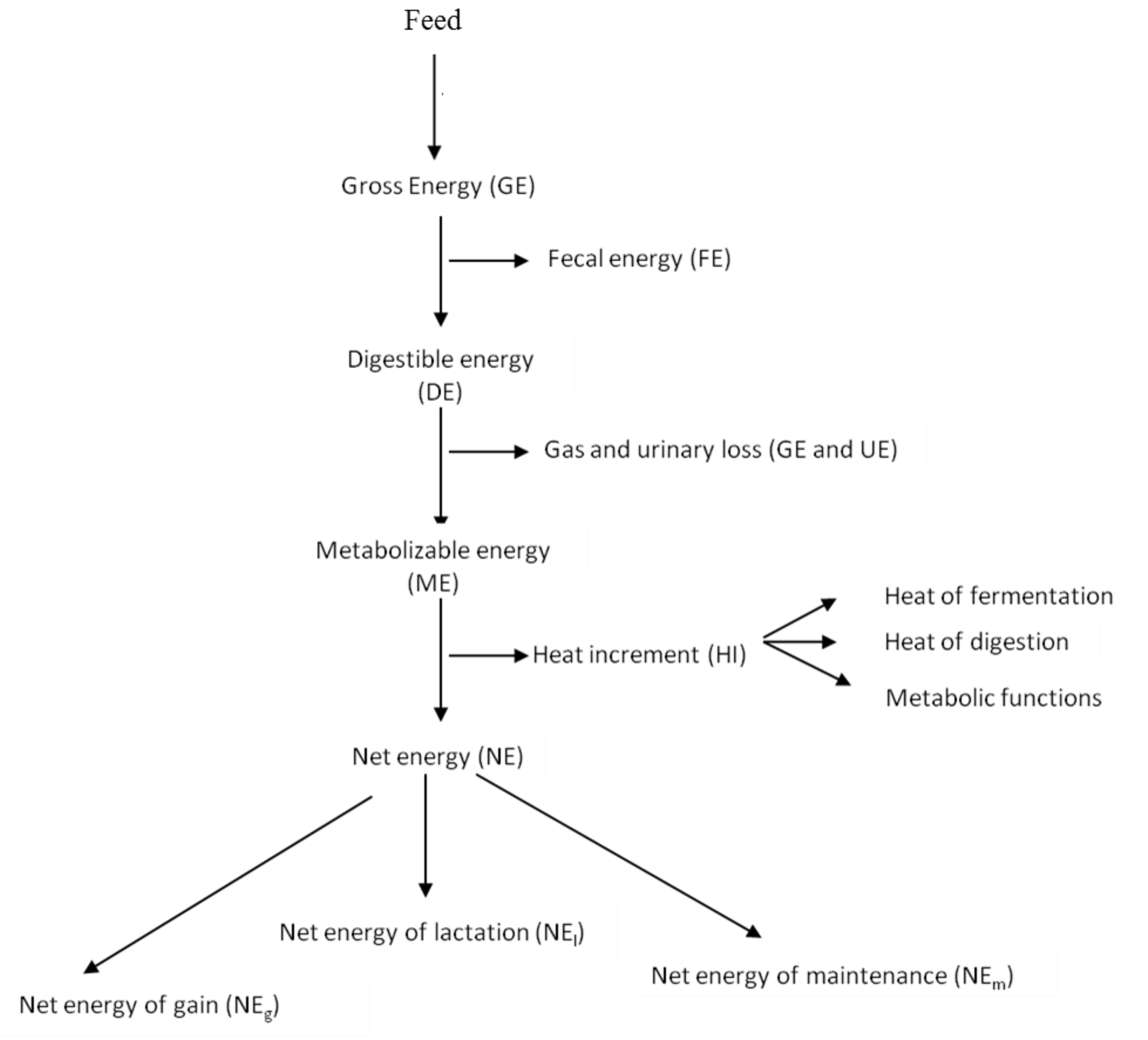

Figure 2.1: Different ways of partitioning energy requirements (CSIRO, 2007)

Equation 2.5 adapted from Wolin (1960) is a theoretical equation where microbial activity results in production of methane and heat of fermentation. This reduces the amount of energy that the animal can obtain from their feed source.

Prediction of energy requirements between cattle types has determined that carcass composition, organ size and hide thickness is significantly different between beef and dairy breeds (Garrett, 1971). The differences also explain why beef cattle were more efficient in gaining fat than dairy breeds (Garrett, 1971). These differences have become incorporated in the NRC (2000) beef model by adding the breed adjustment factor when predicting NE_m.

For any breed of cattle, it is more energetically efficient to deposit fat than protein when both were being gained simultaneously primarily due to the high rate of protein turnover but for weight efficiency it’s the reverse due to the observed gain in water when protein is gained (Garrett and Johnson, 1983).

The NRC (2000) beef model has developed two different equations for DMI of which one is for calves and the second is for yearlings to take into account the changes in feed intake which are higher in yearlings compared to calves. Amount of feed consumed and the level of intake both affected the rate of digestion and thus the rate of fermentation which changes the heat increment (Garrett and Johnson, 1983). Energy needs can change due to age of animal, sex, lactation, environmental conditions and breed. The NRC (2000) beef model adjusts NE_m by calculating COMP which is defined as the previous plane of nutrition. As indicated, breed, environment and age of animal were taken into account by the NRC (2000) beef model. The most important aspect of the model is its ability to calculate net energy of maintenance (NE_m) and gain (NE_g or RE) requirements.

2.1.1 FACTORS THAT IMPACT THE ABILITY TO PREDICT ENERGY REQUIREMENTS

The curvilinear relationship is in the efficiency of use of RE with diminishing efficiency occurring with increasing RE (Figure 2.2). The intersection between energy used for maintenance and energy used for gain is the point where the amount of energy used is equivalent to the amount of energy lost. The y-intercept is referred to as the fasting heat production. The NRC (2000) beef model defines NE_m to be equal to FHP.

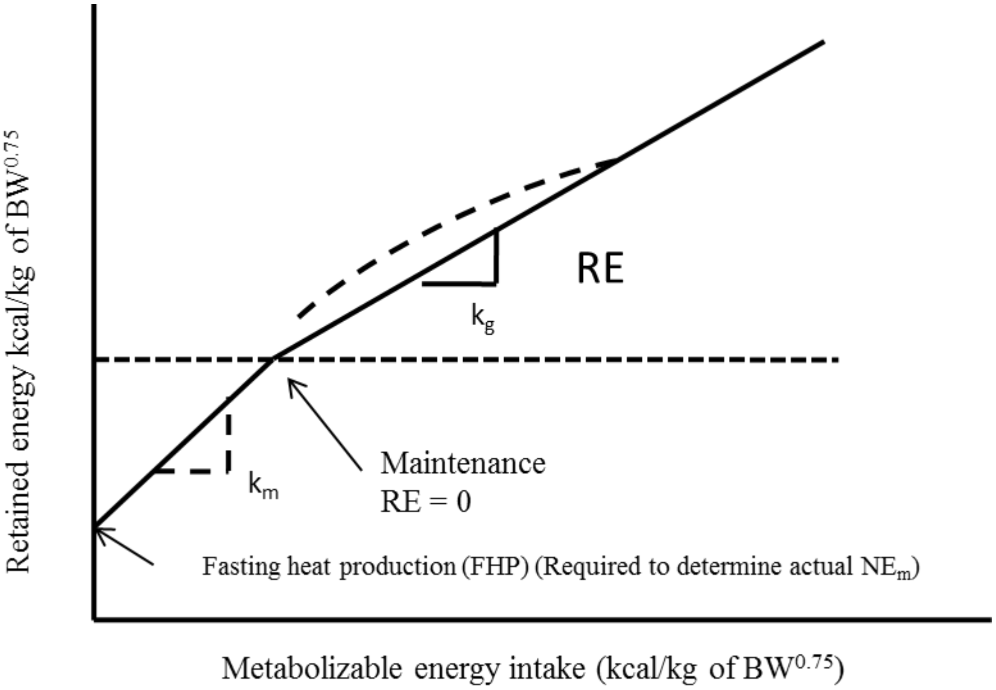

Figure 2.2: An illustration of efficiency of metabolizable energy use for maintenance (k_m) and gain (k_g) starting with fasting heat production (FHP) (CSIRO, 2007)

Net energy of maintenance is needed for homeostasis which can be defined as the mechanism involved in maintaining the physiological consistency required for an animal to survive (Bauman and Currie, 1980). Physiological consistency is the need for the animal to continually maintain its internal body temperature, blood pH, remove metabolic waste and provide energy for cellular function.

This energy requirement will change according to a number of factors. The first is the environment. Under conditions where temperature is below the lower critical temperature, the animal would require more feed to maintain its internal body temperature of 39°C (Mader, 2011). The level of mud in the pen will impact NE_m requirements; the higher the mud depth the higher the NE_m as it reduces the insulation ability of the animal and increases the energy needed to maintain body temperature (Mader, 2011). The NRC (2000) beef model suggests corrections for mud depth but the computer model does not provide any place to indicate the mud depth. The interaction of breed with environment can impact energy requirement (Sant'Ana, 2011). The NRC (2000) beef model adjusts for changes in energy requirement of maintenance by looking at both the environmental impact, previous plane of nutrition and internal and external tissue insulation as well as the effective ambient temperature.

2.1.2 THE NET ENERGY (NE) AND SYSTEMS BASED ON NE

Models based on NE and not ME will in theory allow better partitioning of energy for maintenance and gain (Lofgreen and Garrett, 1968). Separation of NE_m and NE_g is more accurate than developing a model based on a single NE value. The reason for this is that energy needed for maintenance is more efficiently used than that for gain (Garrett and Johnson, 1983; Lofgreen and Garrett, 1968).

Figure 2.2 illustrates a number of important parameters. The fasting heat production (FHP) estimates basal metabolic rate and thus can exclude the energy needed for digestion, tissue deposition and motion (Baker et al. 1991). Maintenance energy needs can be measured through a number of approaches. As stated by Koong et al. (1985) these include:

1. Identifying FHP.
2. Feeding at constant levels for a prolonged feeding trial and determining changes in body energy or weight.

3. Feeding animals at two or more levels and performing regression analysis by extrapolating changes in weight or retained energy through the use of comparative slaughter technique.

The NRC (2000) beef model used previous research such as that carried out by Lofgreen and Garrett in the early 70's in developing the NE_m equation. These studies identified differences in efficiency for ME used for maintenance and for gain.

Efficiency of ME used for maintenance (k_m) and for gain (k_g) (Figure 2.2) changes according to source of ME (Garrett, 1980). The NRC (2000) beef model used k_m in adjusting NE_m so that different ME can be used in the model. As judged by slope in Figure 2.2, the efficiency of ME used for maintenance was higher than that for gain. This implies that it was more efficient to use energy for maintenance than for gain. This difference in efficiency (Figure 2.2) is corrected for by the NRC (2000) beef model by establishing two separate curvilinear equations for NE_m and NE_g.

2.1.3 DETERMINING NET ENERGY (NE)

There are a number of different approaches used in determining NE. They can include indirect or direct calorimetric methods. Direct calorimetry measured heat loss that can occur due to the following phenomena: radiation, convection, conduction and evaporation of water. The indirect calorimetric method measured gaseous exchange of oxygen, carbon dioxide (Blaxter, 1989) and deuterium H_2O.

In the calorimetric approach, two groups of animals are fed at two different levels. The net energy of gain is determined as being equal to the difference in the amount of energy retained at the two different levels of intake (Lofgreen et al. 1962). This method of experimentation is referred to as the difference trial (Lofgreen et al. 1963; Lofgreen et al. 1962). This approach attempted to explain the energy gained by the change in feed energy quality and quantity (Lofgreen and Otagaki, 1960).

2.1.4 THE COMPARATIVE SLAUGHTER TECHNIQUE

The comparative slaughter technique allows a large numbers of animals to be examined but accuracy per animal basis will be less than with the direct calorimetric approach. In North America, the comparative slaughter technique was used to develop the various equations used in NE based models such as the California Net Energy System (CNES) (Know and Handley, 1973), NRC (1984 to 2000) and the CNCPS (Version 5.0).

The comparative slaughter technique allowed the researcher to identify total body fat, protein, ash and energy content. The comparative slaughter technique was based on feeding a number of groups of animals, diets that vary in energy but composed of the same ingredients for a period of time and then slaughtering the animal and comparing it to an initial group of live animals that were slaughtered at start of the feeding period. This indicates that only the initial group of animals and the final group of animals are directly compared.

Seventy two comparative slaughter trials (Garrett, 1979) were carried out to develop the base NE_m equation that is utilized by the NRC (2000) beef model. The base equation is:

$$NE_m = 0.077 \times BW^{0.75} \tag{2.6}$$

The NRC (2000) beef model adds adjustment to equation 2.6 to take into account factors such as the environment that the base equation does not consider. The comparative slaughter technique was also used to assess the efficiency of different breeds of cattle for growth (Garrett, 1971). For example it was found that the Hereford breed have a higher efficiency of protein gain as well as fat when compared to the Holstein breed (Garrett, 1971).

It has been established that net energy of a feed was affected by three factors; level of feed intake, site of digestion (Garrett and Johnson, 1983) and species (Garrett et al. 1959). As the level of intake increased, net energy value decreased as there is an increase in rate of passage and a reduction in rate of fermentation (Lofgreen and Garrett, 1968).

2.2 GROWTH CURVE

Growth is defined as the addition of new cells which is generally measured by changes in weight and can be due to cell multiplication (hyperplasia), an increase in cell size (hypertrophy) and incorporation of components from the surrounding environment (Owens et al. 1993). All animals follow a sigmoidal growth curve (Figure 2.3). Initially an animal will have a higher proportion of bone and muscle, after which the deposition of fat increases (Berg and Butterfield, 1976). Maturity is defined as the point where an animal reaches maximum bone and protein mass and further changes in weight are characterized by either a decrease or an increase in fat deposition (Berg and Butterfield, 1976).

There are a number of factors that will affect the growth rate of cattle which the NRC (2000) beef model attempts to model. The factors that can affect gain are mature body size, feed quality and quantity, implant strategy, compensatory growth and the environment.

2.2.1 CATTLE SIZE

Cattle of different frame sizes will have different rates of fat and protein deposition as well as different mature body size (Owens et al. 1993). Frame size can impact carcass composition at slaughter. If the animals of different frame sizes are slaughtered at the same weight, then the degree of fatness will change (Figure 2.3) (Owens et al. 1993). Frame size can describe skeletal size within a specified age and allow a producer to identify the live weight when the animal reaches a specific level of fatness (Cartwright, 1970). The level of fat will differ between types of cattle slaughtered at different end points will impact carcass quality (May et al. 1992). Figure 2.3 shows differences in weight of cattle and two different frame sizes. These cattle will have different percent of fat at different stages of growth (i.e. different weights or days on feed). The NRC (2000) beef model has taken this into consideration by calculating equivalent shrunk body weight as a scaling tool. Equivalent shrunk body weight (EQSBW) is calculated according to formula 2.7 (NRC, 2000):

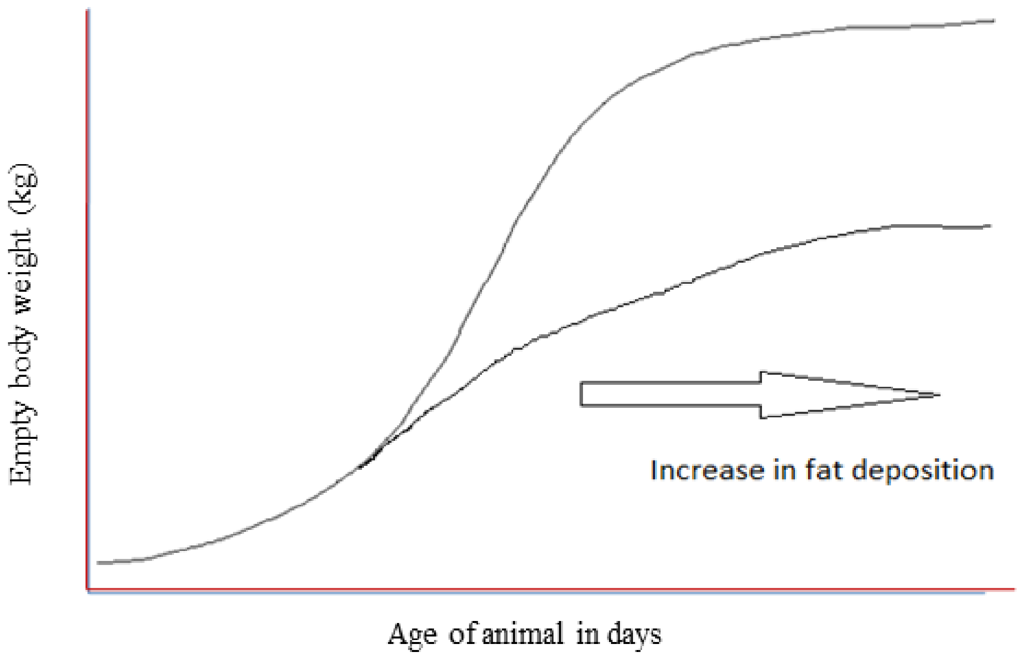

Figure 2.3: Growth curve adapted from Cartwright (1970) where the solid lines represent the changes in fat deposition between an animal with a medium frame (the curve that plateaus at lower weight) and a large frame animal (the curve that plateaus at a higher weight) depending on the weight of it

$$EQSBW = SBW * \left(\frac{SRW}{FSBW}\right) \quad (2.7)$$

In equation 2.7, SBW is shrunk body weight in kg, SRW is standard reference weight in kg and FSBW is final shrunk body weight in kg. This equation attempted to scale cattle for potential differences in mature sizes and thus allowing the model to accurately account for differences in change in composition of gain at the specific size examined and this will correct for differences in cattle size so as to become similar to those studies published by Garrett (1979) which was used in producing the NRC (1984) beef model. This change in composition of gain will impact NE_g per kg of SBW gain. The NRC (2000) beef model used the NRC (1984) equations to predict NE_m and NE_g with appropriate adjustment to new research findings since 1984.

2.2.2 NUTRITION AND COMPENSATORY GROWTH

Restricting feed intake can impact the growth rate of the animal (Owens et al. 1993). Changing the duration or timing of restriction can alter weight and tissue deposition thus affecting the overall characteristic of the cattle when arriving at the feedlot (Owens et al. 1993). The NRC (2000) beef model does not adjust for the effect of restricted feed intake rather it assumes voluntary feed and specific growth curve. The producer can however put the feed intake desired into the model to calculate retained energy to see the effect on gain. In such cases it does assume that energy needed for maintenance does not change unless there was a change in the previous BCS. Body condition score is used to calculate previous plane of nutrition (COMP) in the NRC (2000) beef model. According to the NRC (2000) beef model, three aspects will impact an animal's growth: previous plane of nutrition, feed quality as well as the stage of growth of the animal.

Tissue composition changes as an animal grows as indicated in Figure 2.3. The supply of nutrients must be changed according to changes in composition (Owens et al. 1993). Producers can increase the fat content prior to reaching maturity by reducing crude protein and increasing the energy content of the diet (Greathouse, 1985). Medium framed animals can be allowed to grow slower for a longer period of time on a lower energy diet to build up their frame size while a larger framed animal can be placed on a much higher energy diet earlier to later maturity as well as latter fat deposition (Old and Garrett, 1985).

Another nutritional aspect that has to be considered is compensatory growth. Block et al. (2001) indicated that the NRC (2000) beef model may not be able to accurately account for this. Compensatory growth occurs when feed and energy was restricted consequently growth was restricted (Old and Garrett, 1985). In the period after this restriction where ad libitum feed is provided, growth rate will be higher than if no restricted feed intake was practiced (Old and Garrett, 1985). In fact cattle that were on a low plane of nutrition during winter and then placed on a high plane of nutrition will experience the highest rate of gain (Sainz et al. 1995).

2.2.3 HORMONAL STIMULUS

There are a number of implants that are available on the market that could be used to alter the rate of growth, change the rate and proportion of muscle and lean tissue deposition and thus change the efficiency of growth (Old and Garrett, 1985). Ionophores on the other hand increase the efficiency of energy use. The NRC (2000) beef model uses an anabolic implant adjustment factor (ADTV) for cattle with and without implants. There are two locations in the model were ADTV is incorporated into the equation. The first is when calculating intake needed for maintenance (I_m) and when calculating DMI.

2.2.4 ENVIRONMENTAL EFFECTS ON GROWTH

The environment has two major impacts on an animal. These include changes in animal behavior as well as its energy required for maintenance. The NRC (2000) beef model has equations to correct for the environmental impact on energy required for maintenance. This section will discuss aspects of the environment and its potential impact on animal growth and energy needed.

The thermoneutral zone defined by Forbes (1995) and Lindstedt and Boyce (2011) is the range of ambient temperatures where no energy is needed to maintain body temperature at homeostasis. If the temperature drops below the thermoneutral zone, then energy is needed to increase body temperature (i.e shivering). The lower end of the thermoneutral zone is referred to as the lower critical temperature (LCT) which is when an animal needs to use energy to maintain its body temperature.

Fox et al., (2004) defined the LCT as the point in which normal body metabolism and fermentation does not provide sufficient heat to maintain metabolism and thus further body heat must be generated using energy reserves. From this, one other important aspect has to be considered. The smaller the animal, the more the energy required by the animal to maintain body temperature (Lindstedt and Boyce, 2011).

The NRC (2000) beef model has developed a number of equations to modify the prediction of DMI and SWG under actual environmental conditions by considering the internal and external insulation level, surface area, hair depth and hide thickness. The NRC (2000) beef model calculates LCT by the following equation:

$$\mathrm{LCT} = 39 - (\mathrm{IN} * \mathrm{HE} * 0.85) \tag{2.8}$$

$$\mathrm{IN} = \mathrm{TI} + \mathrm{EI} \tag{2.9}$$

$$\mathrm{EI} = (7.36 - 0.296 * \mathrm{WIND} + 2.55 * \mathrm{HAIR}) * \mathrm{MUD2} * \mathrm{HIDE} \tag{2.10}$$

Equation 2.8 to 2.10 are used to determine LCT of which “IN is insulation value in °C/Mcal/m^2/day, TI is tissue internal insulation value °C/Mcal/m^2/day, EI is external insulation value °C/Mcal/m^2/day, and HE is heat production (Mcal/day)”. The wind, hair, MUD2 and HIDE are adjustment values that are indicated within the NRC (2000) beef model. If LCT was identified to be higher than current temperature then adjustments to prediction of DMI and SWG would be performed.

Temperature per se is not the most important issue affecting the animal, but the wind and rain can make temperature more stressful. The use of wind breaks and bedding can reduce the impact of the environment. Wind breaks designed for feedlots reduce wind speed by at least 75% (Brown, 1997), which reduces the amount of cold stress on the animal.

2.3 STATISTICAL APPROACHES FOR ASSESSING NUTRITIONAL MODELS

The development of a nutritional model is intended to improve the predictability of an animal’s performance, improve efficiency and profitability. A number of questions have to be answered regarding the NRC (2000) beef model before it will be widely used by industry. The first and most important question “is the model accurate and valid to predict the required outcome” (Analla, 1998; Oreskes, 1998)? The second question is “what is the purpose of the model and how is it related to the real world” (Lewandowski, 1981; Oreskes, 1998)? The third question that should be taken into consideration is “if it is more important to the user that the model be accurate, precise or both” (Oreskes, 1998)? The fourth is “is it possible to extrapolate the model for individual variables? In fact for a model to be considered useful in the scientific world as well as by industry, it should have the capability to extrapolate above and below the data used in developing the model and the estimates for extremes should be reasonably accurate (Snee, 1977; Oreskes, 1998).

After a model is produced that can answer the above questions, it must be evaluated with a new data set. This data set should not be involved in the development of the model. When models are being evaluated, there are two types of errors that should be considered. A type I error is when you reject a model when it is valid (Mayer et al. 1994). A type II error is when you accept a model when it is not valid (Mayer et al. 1994).

Lewandowski (1981) proposed that different validation procedures have to be used for the various types of model design. Evaluation has two basic components. The first is the model and the second is the system or real world data (Lewandowski, 1981). There is no one way to evaluate a model. The following is a discussion of a number of different statistical tests used in model evaluation.

Concordance correlation coefficient assesses similarity. Others attempt to explain sources of errors. The objective in this study is to use these statistical approaches and identify when the observed and predicted values are the same. Each statistical approach have weaknesses and thus it is necessary to use more than one approach.

2.3.1 REGRESSION ANALYSIS

Regression analysis is the most common statistical method used in identifying the strength of a model to the data set. In fact, if a model agrees with the data, a linear regression must have an intercept equal to zero and slope of unity (i.e: not significantly different from the isopleth) (Analla, 1998). Regression analysis cannot be used for comparative purposes between different models nor can it identify the type of error (Analla, 1998). Regression analysis is capable of rejecting models which are invalid to the data set (Mayer et al. 1994). This method tests the relationship between real and predicted data and will illustrate the overall model validity (Mayer et al. 1994).

Harrison (1990) indicates that there are a number of reasons why models should be validated using regression analysis. The first is the output from the model is expected to be similar to the data. The second is that when placing actual data on the y-axis and predicted data on the x-axis, a 45° line should be obtained if actual data is the same as predicted data. The third is that the less the data is agreeing with the model, the larger the deviation from the 45° line.

All model validation procedures include a regression approach to identify how reliable the model is (Lewandowski, 1981). Reliability is defined as how much of the prediction is similar to observed data (Lewandowski, 1981). Regression analysis also provides the coefficient of determination (r^2) which provides the amount of variation explained by the regression and can allow the description of the strength of the relationship between observed and predicted.

2.3.2 CORRELATION COEFFICIENT AND COEFFICIENT OF DETERMINATION

The correlation coefficient (r) is used for hypothesis testing within a data set (Houghton and Turlington, 1992). The correlation coefficient was defined as “percentage of variance common to two variables” (Steiger and Ward, 1987). It is impacted by size of sample and where the sample came from within a population. This can have an impact on its usability when assessing different trials to their applicability to the model. Correlation coefficient is reportedly not affected by bias (Miller et al. 2004). Correlation coefficient can be converted to coefficient of determination.

Coefficient of determination is defined as “the percentage of variance in one variable that can be explained from a second variable” (Steiger and Ward, 1987). Coefficient of determination value is affected by sample size (Ali, 1987). In regression analysis, r^2 is used to determine how good the fit of the regression line is to the data points.

In multiple regression analysis the more variables are added into a regression equation, r^2 will get closer to one even if the addition of the new variable doesn’t have a strong relationship (Srivastava and Srivastava, 1995). To solve this problem, adjusted-r^2 is calculated. This calculation incorporates a correction for the degrees of freedom (Srivastava and Srivastava, 1995). Adjusted r^2 has a lower bias than r^2 (Srivastava and Srivastava, 1995). When four or more explanatory variables are incorporated into the equation, the adjusted r^2 becomes superior to r^2 (Srivastava and Srivastava, 1995).

2.3.3 CONCORDANCE CORRELATION COEFFICIENT

The issue with the regression approach is that it does not identify accuracy or precision. Models could be accurate but not precise, as well as the reverse. The difference between accuracy and precision, in terms of the model, can be described as follows. Accuracy pertains to the model being able to predict the values to the middle of the target. Precision, on the other hand, denotes the idea that the model does not predict in the middle of the target but predicts on a specific location of the target. When the model predicts in the middle of the target and continuously does so it is then termed to be both precise and accurate. From this definition, a model can be accurate and not precise or the reverse or both.

To identify if the model is accurate or precise the concordance correlation coefficient (CCC) can be used. The CCC has the ability to measure the degree to which two values in a sample fall on to the 45°line (Lin, 1989). The CCC statistical approach was developed to assess the accuracy and precision of laboratory methodology or equipment. A CCC value of one is defined as perfect agreement, while a value of zero represents no agreement. The CCC value is a combination of precision and accuracy (Lin, 2000). The CCC value can thus be split into precision and accuracy. Under CCC, the Pearson Correlation Coefficient is used to calculate precision which indicates how close the data is with the isopleth (Slope of one and an intercept of zero) (Lin, 2000). For accuracy, CCC is calculated by calculating the coefficient of accuracy as follow (Lin, 1989):

$$C_b = \left[\frac{\left(v + \frac{1}{v} + \mathrm{u}^{2}\right)}{2}\right]^{-1} \tag{2.11}$$

$$v = \frac{\sigma_1}{\sigma_2} = \text{scale shift} \tag{2.12}$$

$$u = \frac{(u_1 - u_2)}{\sqrt{\sigma_1 \sigma_2}} = location\ \ shift\ according\ to\ scal \qquad (2.13)$$

The coefficient of accuracy and the Pearson correlation coefficient are expressed on a scale of 0 indicating no agreement to 100%, representing perfect agreement (Lin, 2000).

2.4 NRC (2000) BEEF MODEL

The NRC (2000) beef model is an important management tool for beef operators in North America. This model allows the user to predict animal response in terms of DMI and SWG to different inputs such as changes in feed, environment and managemental practices (Chalupa et al. 2010). The accurate prediction of DMI and ADG is necessary if feedlot operators were to predict important production parameters such as days on feed, cost of gain, feed supplied and profitability per pen (Rosoler et al. 1997).

The NRC (2000) beef model used an empirical approach for Level one to directly predict TDN, however in Level two, the NRC (2000) beef model used a mechanistic approach for predicting TDN from sub models but both level one and two have the same animal requirements. This model predicted the energy requirements of the growing animal by partitioning it into maintenance (NE_m) and gain (NE_g) requirements *(*Tedeschi et al. 2005). Separating NE between maintenance and gain allowed the system to adequately take into account differences in efficiency of energy used between these two parameters (Ferrell and Oltjent, 2008).

Level one of the NRC (2000) beef model uses tabular feed energy values and the metabolizable protein system of Burroughs et al. (1974) (TDN, DIP and UIP). Total digestible nutrient values can be obtained from tables or can be calculated from equations such as the Pennsylvania State or the Weiss equations (NRC, 2000).

Level two of the model is more complex and was based on the Cornell Net Carbohydrate and Protein System (CNCPS). The CNCPS is composed of sub models that use animal, environment, management practices, and absorption of nutrients, tissue utilization and feed characteristics as well as rumen fermentation parameters (Delahoy and Muller, 2009; Ferrell and Oltjent, 2008; Fox et al. 1992; Russell et al. 1992; Sniffen et al. 1992). Level two is based both on empirical and mechanistic approaches to model development (Chalupa et al. 2010). Level two attempts to simulate rumen fermentation (Chalupa et al. 2010).

The two levels of the NRC (2000) beef model allows for a better characterization of the feed, animal type as well as environmental factors that are likely to affect productivity (Block et al. 2001).The NRC (2000) beef model incorporated computer simulation software to help the user evaluate performance of cattle for a given ration but does not produce a new ration from a set of ingredients (Chalupa et al. 2010). There are a number of software programs developed that are based on the NRC (2000) beef model that can be used to develop feed rations. An example would be "Cowbytes®" distributed by Alberta Agriculture and Rural Development.

The NRC (2000) beef model predicts voluntary DMI under actual environmental conditions. For gain, the NRC (2000) beef model calculates either shrunk weight gain (SWG) or empty body gain (EBG). Shrunk weight gain is determined by weighing an animal after a period of no longer than 24 hours without feed but with access to water (Berg and Butterfield, 1976). Empty body gain refers to gain due to changes in empty body weight which was defined as the weight of the animal less the content of the gastrointestinal tract (Berg and Butterfield, 1976).

The reason that SWG and not average daily gain (ADG) was used is due to the fact that ADG does not take into account the changes in the amount of feed and fluids within the gastrointestinal tract of ruminants throughout the day (Lofgreen et al. 1962). The model adjusts for potential variation by converting it to EBG or SWG matter on which equation chosen by the user. The NRC (2000) beef model also predicts the protein requirements of the animal as well as mineral requirements.

2.4.1 ASSESSING THE ACCURACY AND PRECISION OF THE NRC (2000) BEEF MODEL

A number of studies have been conducted to assess the accuracy and precision of the NRC (2000) beef model. These studies evaluated the accuracy and precision for both DMI and SWG predictions under actual environmental conditions.

2.4.2 PREDICTION OF DRY MATTER INTAKE (DMI) AND SHRUNK WEIGHT GAIN (SWG)

The level one of the NRC (2000) beef model requires that the energy content of the diet be accurately estimated to allow accurate prediction of DMI and SWG while the level two attempts to estimate the energy availability from the feed to the animal. Overall the NRC (2000) beef model is an energy based model. Okine et al. (2003) evaluated a number of different forages produced in Alberta and found that the use of the Weiss equation was the best for predicting energy content of forage. Okine et al. (2003) performed four feedlot trials, an in vivo digestibility and a laboratory analysis of feed to predict DE to determine the accuracy and precision of the NRC (2000) beef model. These writers reported that DMI was inaccurately predicted by the model. The model under predicted DMI (Okine et al. 2003). These authors recommended that when using the NRC (2000) beef model, actual DMI should be used as that will improve the accuracy of SWG prediction (Okine et al. 2003).

Another factor that can lead to inaccurate prediction of DMI is inaccurate prediction of $\mathrm{NE_m}$ requirement which is used to predict DMI and SWG. The NRC (2000) beef model predicts DMI using the following equation:

$$\mathrm{DMI} = \left(\frac{\left(\mathrm{SBW}^{0.75} * \left(0.2435\mathrm{NE_m} - 0.0466\mathrm{NE_{ma}}^2 - 0.0869\right)\right)}{\mathrm{NE_{ma}}}\right) * \left((\mathrm{BFAF}) * (\mathrm{BI}) * (\mathrm{ADTV}) * (\mathrm{TEMP1}) * (\mathrm{MUD1})\right) \tag{2.14}$$

Where “DMI is in kg/d, SBW is shrunk body weight in kg, $\mathrm{NE_m}$ is net energy of maintenance in Mcal/d, and $\mathrm{NE_{ma}}$ is net energy value of the diet for maintenance in Mcal/kg” (NRC, 2000). To calculate $\mathrm{NE_m}$ the following equations must be done (NRC, 2000):

$$NE_m = SBW^{0.75} * \left((a_1 * BE * L * COMP) + a_2\right) \tag{2.15}$$

$$a_1 = 0.077 \tag{2.16}$$

$$a_2 = 0.0007 * (20 - T_P) \tag{2.17}$$

SBW is shrunk body weight in kg, a_1 is the thermoneutral maintenance requirement developed by the studies summarized in Garrett (1979) (Mcal/day/$SBW^{0.75}$), BE is breed effect on NE_m requirement, L is lactation effect on NE_m requirement, COMP is effect of previous plane of nutrition on NE_m requirement and a_2 is the maintenance adjustment for previous ambient temperature (Mcal/day/$SBW^{0.75}$) (NRC, 2000).

In equation 2.15 it can be seen that there is an increase in NE_m requirements of approximately one percent for every one degree Celsius decline in temperature below 20°C (Block et al. 2001). Research has identified that NE_m can increase by as much as 20% if current temperature was lower than thermoneutral zone and does not decrease in the gradual pattern that the NRC (2000) beef model indicates but when cold stress occur than it is expected to increase (Mueller, 2011). The question is the increase proposed by the NRC (2000) beef model justified or does this lead to a potential inaccuracy?

As indicated, the NRC (2000) beef model has been found to have potential issues in predicting energy requirements for beef cattle. This inaccuracy can impact the model's ability to predict DMI and gain. Research has shown that the NRC (2000) beef model under predicted intake of finishing cattle but this prediction was close to the observed average (Patterson et al. 2000). Patterson et al. (2000) identified that the model over predicted DMI on poor quality diets and the reverse was true on high quality diets. For gain, the model over predicted gain on high quality diets and under predicted gain on low quality diet (Patterson et al. 2000). The over prediction of gain and intake on high quality diets and under prediction of gain and intake on low quality diets would suggest that there is a medium quality diet that will result in accurate prediction of gain or intake and possibly both gain and intake.

McMeniman et al. (2009) evaluated commercial pens with the NRC (2000) beef model using initial body weight (iBW) and dietary NE_m concentration to predict intake. It was found that DMI was over predicted by the NRC (2000) beef model. McMeniman et al. (2009) used a second equation to predict DMI published in the NRC (2000) beef model where NE_{ma} are required. This equation was found to over predict DMI (McMeniman et al., 2009). It was reported that the reasons for the second equation in over predicting DMI was due to inaccurate conversion of TDN to NE_{ma} (McMeniman et al. 2009).

2.4.3 IMPACT OF WESTERN CANADA ENVIRONMENTAL CONDITIONS ON THE ACCURACY AND PRECISION OF THE NRC (2000) BEEF MODEL

Under western Canadian environmental conditions temperatures can range in one year from + 40°C to - 40°C. It was reported that average temperature in Lacombe Alberta was 2.4°C (Environment Canada, 2011). Cattle under such conditions will be exposed to cold stress. The NRC (2000) model as indicated above has developed equations to determine the LCT and correct for cold stress. The correction is indicated in the equations below (NRC, 2000):

$$LCT > T_C \tag{2.18}$$

$$ME_{cs} = SA * (LCT - T_C)/IN \tag{2.19}$$

$$NE_{mcs} = k_m * ME_{cs} \tag{2.20}$$

$$NE_{mtotal} = NE_m + NE_{mcs} \tag{2.21}$$

Where “LCT is the animal’s lower critical temperature in °C; T_c is current temperature in °C. ME_{cs} is metabolizable energy required due to cold stress in Mcal/day, NE_{mcs} is net energy required due to cold stress in Mcal/day, k_m is diet NE_m/diet ME, and NE_{mtotal} is net energy for maintenance required adjusted for breed, acclimatization and stress effects in Mcal/d” (NRC, 2000). This allows adjustment to cold stress and thus it allows the incorporation of actual environmental conditions in predicting DMI and gain.

Block et al. (2001) conducted two feedlot trials to assess the accuracy of the NRC (2000) beef model. The diets used were barley based (Block et al. 2001). It was found that there was an accurate prediction of DMI in one of the two trials as well as when both trials were analyzed as one data set (Block et al. 2001). In both trials there was a backgrounding and a finishing period. Both trials were conducted under western Canadian environmental conditions. The model over predicted DMI during backgrounding for both trials which was expected as the NRC (2000) beef model predicts voluntary feed intake and the cattle had been feed restricted (Block et al. 2001). The potential reason for the discrepancy in results between the two trials could be the inability of the model to accurately model actual environmental conditions

Average daily gain prediction was found to be inaccurate and less than actual ADG for most periods of the trial (Block et al. 2001). There were a number of potential reasons given for this inaccuracy. First the model may have predicted NE_m inaccurately, which ultimately impacted the predictability of gain. Second, the inaccurate prediction of gain can be attributed to the model's potential inability to model changes in carcass composition and for NE_m, the model's inability to predict energy needs under western Canadian environmental conditions. According to Block et al. (2001) when the cattle were transferred from backgrounding to finishing, they also experienced compensatory growth. These authors indicated that another potential reason for the inaccurate prediction could be due to the fact that the NRC (2000) beef model cannot totally account for compensatory growth (Block et al. 2001). The NRC (2000) beef model also inputs actual environmental conditions into its model. As such, modeling the environment may be inaccurate and thus result in inaccurate prediction of DMI and gain.

Koenig and Beauchemin (2005) used four different treatments based on varying protein supplements to a corn finishing diet and comparing it to barley based finishing diet without protein supplementation to assess the accuracy of the NRC (2000) beef model. They found that the NRC (2000) beef model under estimated gain for cattle that were fed a corn based diet without protein supplementation and also underestimated the improvement in gain when corn diets were supplemented with protein sources such as urea or canola meal. There are a number of potential reasons for this. The major one could be the inability to estimate changes in body composition and thus changes in energy requirements will be inadequately modeled. It was also found that DMI was over predicted by the NRC (2000) beef model for steers fed a barley-based diet (Koenig and Beauchemin, 2005). When comparing a corn finishing diet to a barley finishing diet it was identified that gain as predicted by the model was limited not by the level of metabolizable protein but rather by the ME availability as predicted by the NRC (2000) beef model (Koenig and Beauchemin, 2005).

A second study was conducted in western Canada to investigate the NRC (2000) beef model accuracy for beef cows (Block et al. 2010). This study found that DMI in the second and third trimester was over predicted when actual environmental data was used but not when thermoneutral conditions were assumed (Block et al. 2010). Precision was still low for both conditions. For the third trimester under thermoneutral conditions, DMI (prediction) was under predicted with low precision (Block et al. 2010). Prediction of the ADG for second trimester beef cows using actual environmental conditions was under predicted while under thermoneutral conditions it was over predicted (Block et al. 2010). For the third trimester when actual environmental conditions were used, ADG was inaccurately predicted but under thermo neutral conditions it was over predicted (Block et al. 2010). The most important findings in this study were that cows were observed to gain weight while the model predicted that they lose weight. This indicated that the model has issues in predicting NE_m and no issues observed in predicting NE_g.

The last study that will be discussed looked at 15 feedlots in the western United States and Canada (Zinn et al. 2008). The number of animals examined in this study was over three million (Zinn et al. 2008). It was found that the NRC (2000) beef model equations were able to explain a significant portion of DMI for steers and heifers but a significant over prediction was found (bias) (Zinn et al. 2008). According to Zinn et al. (2008) DMI prediction was impacted by actual ADG and a potential for the bias in predicting DMI was due to inaccurate prediction of NE_m.

2.5 ULTRASOUND AND BODY CONDITION SCORE

The beef and dairy industries use the subjective measurement referred to as body condition score (BCS) to assess an animal’s energy reserves. It has been demonstrated that the reproductive and productive performance of beef cows has been correlated to body condition (Richards et al. 1986; Houghton, 1988; Osoro and Wright, 1992). The subjective measurement of BCS makes it difficult to be consistent between different individuals. The benefits of this method of measurement are that it is low cost and very practical while ultrasound techniques require special equipment as well as appropriate training (Broring et al. 2003).

Body condition score (BCS) continually changes in dairy cows due to changes in fat reserves (Shroder and Staufenbiel, 2006); the same would be expected with the beef cow. Body condition score was affected by a number of factors including milk yield, reproduction, health status and feeding regiment (Shroder and Staufenbiel, 2006; Osoro and Wright, 1992; Gentry and Del-Vecchio, 2004). Bullock et al. (1991) indicated that a reduction in BCS will result in a reduction in conception rate and an increase in calving interval. A drop in BCS had a greater impact on total body fat content when BCS was high (5 dropping to 4) versus when BCS was lower (BCS three dropping to two) (Pedron et al. 1993). Body condition score can be used as a way to assess an animal’s plane of nutrition (Miller et al. 2004).

Fat cows that were sent to a slaughter plant can be assessed for their BCS for carcass grade assessment (Apple et al. 1999). Body condition score could be used for steers to identify when they finish and if they were too heavy or too thin when purchased. BCS can help determine price and feeding regimen.

A number of equations have been published using either BCS or an objective measurement such as real-time ultrasound to predict body composition (Bullock et al. 1991). These equations were designed to allow accurate measurement of body reserves with limited stress on the animal. For dairy cows changes in BCS can be observed throughout the lactation curve with highest being prior to calving and lowest being after calving (Bernabucci et al. 2005). Heritability of degree of change of BCS in cattle was found to be low (Dechow et al. 2002). The low heritability indicates that the change in BCS for cattle was attributed to nutrition rather than genetics.

Further studies on BCS have found that there was a curvilinear relationship between change in live weight and change in the unit of BCS (Teixeira et al. 1989). This relationship was affected by breed and age of the animal (Broring et al. 2003). This indicated that a set of equations is needed that can distinguish different weight groups. The equations used by the NRC (2000) beef model do not allow for this. This limited its use to only mature cows, as only the level of fat will change in these animals.

Unlike BCS which is assessed through palpation and visual assessment, ultrasound technology uses an imaging technology which requires trained technicians and equipment that can have a substantial cost to any operation (Smith et al. 1992). It is believed that ultrasound technology is much more accurate at determining the level of subcutaneous fat thickness or total body fat when compared to body condition score due to its less subjective nature.

Ultrasound was used to determine subcutaneous fat thickness in feedlots and breeding operations. Previous work has found that large variation in subcutaneous fat thickness was observed for medium frame cows compared to large frame cows (Broring et al. 2003). Ultrasound subcutaneous fat (USF) measurement was used to assess carcass quality prior to slaughter similar to BCS. Ultrasound subcutaneous fat thickness was accurate at measuring subcutaneous fat thickness (Brethour, 1992). Studies have indicated that a one mm change in subcutaneous fat thickness resulted in a five kilogram change in total body fat reserves (Gallo et al. 1996; Shroder and Staufenbiel, 2006).

Ultrasound can thus be used as a management tool in the feedlot and the breeding herd (Miller et al. 2004). Research has further found that ultrasound measurement between the 12th rib and 13th rib was an accurate measurement for subcutaneous fat, intramuscular fat and ribeye area (Miller et al. 2004). Further studies evaluated USF to carcass subcutaneous fat thickness and it was found that in some cows' measurements were significantly different (Perkins et al. 1992; Smith et al. 1992). Ultrasound image interpretation was found to be significantly different between individuals (Miles et al. 1972). The correlation coefficients between USF and carcass measurements of fat thickness varied from 0.42 to 0.92 (Houghton, 1988).

The accuracy of ultrasound subcutaneous fat thickness when compared to carcass subcutaneous fat thickness was found to improve in accuracy with an increase in technician's experience (Moody et al. 1965). Ultrasound measurement of both subcutaneous fat thickness and marbling can thus be used as an assessment of carcass quality (Brethour, 2000).

Few studies have assessed the accuracy of BCS and USF when compared to total body fat or to each other. Broring et al. (2003) found that BCS were positively related to ultrasound measurements but were inconsistent. Broring et al. (2003) found highest correlation when BCS was compared to USF during weaning for cows. Body condition score or USF were both found to be accurate in being able to predict total body fat, protein and ash in cows (Bullock et al. 1991).

2.6 CONCLUSIONS

The literature review has indicated that nutritional models were developed to allow researchers and producers to predict growth, DMI and potentially predict profit with current and future management practices. It has been identified from previous research that the NRC (2000) beef model was inaccurate at predicting DMI and gain but such research could not identify if the prediction of NE_m and NE_g was responsible for the observed inaccuracy.

2.7 HYPOTHESIS

The NRC (2000) beef model prediction of DMI and SWG of finishing cattle will be inaccurate due to over prediction of NE_m and under prediction of NE_g requirements of cattle fed under Western Canadian environmental conditions.

2.8 OBJECTIVE

The objectives of the research that follows include:

1. To determine the accuracy and precision of the NRC (2000) beef model under both environmental and thermoneutral conditions for predicting dry matter intake (DMI) and gain (SWG) of individually fed finishing steers.
2. To determine if improvements in the model's predictive ability can be made by evaluating different approaches in calculating equivalent shrunk body weight (EQSBW).
3. To determine the accuracy and precision of the NRC (2000) beef model for predicting net energy of maintenance (NE_m) and gain (NE_g) requirements of growing cattle under actual environmental conditions.
4. To determine if ultrasound subcutaneous fat thickness (USF) is a better predictor of total body fat than BCS.
5. To determine the accuracy of the NRC (2000) beef model equations based on BCS for mature cows for predicting body composition of growing steers.

3.0. ACCURACY AND PRECISION OF THE NRC (2000) BEEF MODEL FOR PREDICTING CATTLE PERFORMANCE UNDER WESTERN CANADIAN ENVIRONMENTAL CONDITIONS

3.1 INTRODUCTION

The NRC (2000) beef model is capable of predicting DMI and SWG for different classes of cattle under different management practices, as well as under different environmental conditions. To do so, the NRC (2000) beef model takes the average ambient temperature calculated over an extended period of time. The model does not however, define the length of time that should be used, a factor that could lead to discrepancies between studies. Based on examples in text it would appear that the time should be one month previous but it is not clearly stated. To calculate SWG, equivalent shrunk body weight (EQSBW) must be calculated by choosing one of the three values proposed by the NRC (2000) beef model for standard reference weight (SRW) and identifying the final shrunk body weight (FSBW) the producer or researcher wants the steer to reach.

The use of initial or final weight instead of average weight may be a better alternative under western Canadian environmental conditions to predict DMI. The data set used for this investigation allowed the examination of the effect of weight on prediction of DMI. Three weights were examined; initial, mid and final weight. No previous research has taken this approach.

Environmental modeling was one aspect that has been questioned by Block et al. (2001 and 2010) for potentially impacting the model's accuracy and precision. Birkelo et al. (1991) indicated that acute cold stress was more of an issue than seasonal temperature fluctuation while Young (1981) indicated that seasonal fluctuations in temperature could impact resting metabolic rate and thus change the DMI and gain requirements. Both Birkelo et al. (1991) and Young (1981) investigated current temperature. Acute environmental stress and seasonal temperature fluctuations were not modeled by the NRC (2000) beef model. The NRC (2000) beef model uses mean temperature for the feeding period to represent current temperature and uses a mean temperature prior to the feeding period to represent previous temperature. Therefore to investigate if temperature affected the model's accuracy and precision, it was necessary to modify the current and previous temperatures and to identify if such modifications had an impact on the model's predictive ability. This was the rationale for the use of minimum, maximum and average temperatures to calculate average ambient temperature in order to identify the most appropriate method for western Canadian environmental conditions.

Block et al. (2001) and Koenig and Beauchemin (2005) have indicated that the NRC (2000) beef model was inaccurate and imprecise in predicting DMI and SWG. These studies used group averages to determine actual gain over the period in question. In these studies, dry matter intake (DMI) was determined from the amount of feed provided to the pen daily and thus individual cattle may not have consumed to their maximum intake.

Block et al. (2001) conducted feedlot experiments to assess the accuracy of the NRC (2000) beef model. The diets were based on barley grain and the cattle were fed under western Canadian environmental conditions (Block et al. 2001). Two trials were conducted. In both trails there was a restricted feeding backgrounding and an ad libitum finishing stage. It was observed that DMI was over predicted during the backgrounding stage for both trials which was expected as the cattle were limit fed and the NRC (2000) beef model predicts voluntary feed intake (Block et al. 2001). Actual DMI was accurately predicted for one of the two finishing trials and when the two trials were combined (Block et al. 2001). Actual ADG was lower than predicted for all feeding periods except when predicting ADG using level one for one of the finishing periods (Block et al. 2001). It was also identified that ADG residuals were significant for all trials indicating that the model was inaccurate at predicting ADG.

Koenig and Beauchemin (2005) had four different treatments based on varying the type of protein supplement in a corn diet and comparing it to a barley-based diet to assess the accuracy of the NRC (2000) beef model. It was found that the NRC (2000) beef model underestimated gain for cattle that were fed a corn-based diet without protein supplementation and also underestimated the improvement in gain when corn diets were supplemented with protein sources such as urea or canola meal (Koenig and Beauchemin, 2005). Zinn et al. (2008) examined cattle performance at 15 feedlots involving over three million head to compare actual versus predicted DMI. They concluded that the NRC (2000) beef model explained a significant portion of the variation in observed DMI for steers as well as heifers.

Inaccurate prediction of gain can be attributed to potentially a number of reasons in the NRC (2000) beef model. The first was the original Garrett (1979) equation for prediction of NE_m

may not be accurate (Zinn et al. 2008). The second was the model's inability to predict net energy of gain (NE_g). Reasons for inaccurate prediction of gain can be attributed to the model's potential inability to accurately model changes in carcass composition and for NE_m, the model's inability to predict energy needs under western Canadian environmental conditions. Block et al. (2006) developed a net energy modifier to correct for potential errors of net energy but it was identified that these adjusters may not be valid for all herds and Block et al. (2006) indicated that adjustments to the adjusters may be needed for different herds.

The third reason was the model's inability to account for compensatory growth when changing from a backgrounding to finishing diet. The NRC (2000) model can account for compensatory growth but Block et al. (2001) indicated that compensatory growth may not be fully accounted for by the equations used by the model. Finally the NRC (2000) beef model utilizes actual environmental conditions to model the effects of the environment. The inputs used in modeling the environment may not reflect the stress on the animal and lead to inaccurate prediction of DMI and ADG.

As indicated above the NRC (2000) beef model was inaccurate in predicting DMI and ADG. No previous trial has assessed the impact of body weight used for DMI and ADG predictions on the accuracy and precision of the NRC (2000) beef model, similarly the impact of changing the standard reference weight and final shrunk body weight when calculating equivalent shrunk body weight (EQSBW) on the accuracy and precision of the model has not been modeled. Modifying the EQSBW will impact the prediction of SWG. Previous studies did not investigate if it was possible to improve the accuracy and precision of predicting SWG. Modifying EQSBW can be done by changing standard reference weight (SRW) and final shrunk body weight (FSBW).

3.2 OBJECTIVES

The objectives of this study were to determine the accuracy and precision of the NRC (2000) beef model under both environmental and thermoneutral conditions for predicting DMI and gain of individually fed finishing steers. Secondly, to identify if changing the weight of the steers used to predict DMI will impact DMI prediction. Thirdly, to identify the impact of changing temperature used in environmental modeling on predicting DMI and SWG. Finally, to identify if it is possible to improve the accuracy and precision of the NRC (2000) model by evaluating different approaches to calculating EQSBW.

3.3 MATERIALS AND METHODS

3.3.1 ANIMAL INPUTS

Data was obtained from a published study by Basarab et al. (2003). The study was conducted over two years in which 74 animals in each year composed of five beef booster strains were used. The animals were fed for 71, 99, 127,155 and 183 days. In each year, three steers from each composite strain were randomly selected for slaughter at each target slaughter date. The animals were fed a high grain barley-based diet using the GrowSafe® system. This system allows individual DMI to be obtained. All animals were cared for under the guidelines established by the Canadian Council on Animal Care (1993).

3.3.2 DATA COLLECTED

Data collected included daily dry matter intake using the Grow Safe® system and individual average daily gain. A digestibility trial using sheep was performed to determine DE which was converted to ME then NE_m and NE_g using the approach indicated in the NRC (2000) beef model. Daily environmental temperature and wind speed were recorded. Actual average daily gain was shrunk by four percent to create SWG.

3.3.3 MODEL INPUTS AND CALCULATION

The low ambient temperature that the animals were exposed to would not result in heat stress but the animals are likely to experience cold stress. Mud depth was not reported and thus it was assumed that there was no mud. No anabolic implants were used for all steers used in this feeding trial and thus ADTV (Implanted animal will be one, non-implanted animal will be 0.94). The Holstein breed was not used in the development of the beef booster breed and thus the breed correction (BI) factor was kept at one. Hide thickness and skin thickness was kept to the default proposed by the computer model. Only level one was calculated using Excel® and no level two calculations was performed. Previous temperature was obtained according to the Environmental Canada while current data was obtained from Basarab et al. (2003).

3.3.4 APPROACHES USED IN CALCULATING EQUIVALENT SHRUNK BODY WEIGHT

Several approaches to determine EQSBW were tested by changing the method of calculating SRW as well as FSBW. Two different SRW were assessed:

1. Equation adopted from the Cornell Net Carbohydrate and Protein System (CNCPS v5.01) model. The formula was as follows:

$$SRW = 399 - (1019.5 * FBF) + \left(4621.1 * (FBF^2)\right) \tag{3.1}$$

   FBF: Use actual Final body fat (kg/100kg body weight)

2. SRW equals 390

The SRW value of 390 is the value obtained when calculating SRW using the method discussed in the footnote of Table 3.2 on page 26 of the NRC (2000) beef model.

Four different final shrunk body weights (FSBW) were tested, they included:

1. Actual final shrunk body weight
2. SAS model for each beef booster strain
3. Final shrunk body weight using the model developed from SAS 9.2® using all animals.
4. FSBW using final shrunk body weight of each strain that finished at day 183

The SAS model equations were developed using the SAS 9.2® proc model approach where the variables were percent fat (independent variable) and amount of fat (dependent variable). Only largest and smallest adjusted r^2 were examined.

Table 3.1: Description of steps used in predicting dry matter intake (DMI) and shrunk weight gain (SWG)

DE to NE_m and NE_g

1. DE is converted to ME
2. ME is converted to NE_m
3. ME is converted to NE_g

Calculating shrunk weight gain (SWG)

1. Base maintenance requirements (no previous temperature impact for thermoneutral)
2. Heat production, internal and external insulation is used to determine LCT.
3. Cold stress effect is calculated if applicable to actual temperature
4. Intake for maintenance and intake remaining for gain is calculated.
5. ADG is calculated from equivalent shrunk body weight and retained energy.

Calculating Dry matter intake (DMI)

1. Calculated up to step five
2. DMI was adjusted (not temperature for thermoneutral)

3.3.5 APPROACHES USED TO CALCULATE DRY MATTER INTAKE (DMI) AND SHRUNK WEIGHT GAIN (SWG)

Dry matter intake and shrunk weight gain were calculated according to Table 3.1. Under environmental conditions average ambient temperature was calculated by taking minimum, maximum or average daily temperature for the feeding period and then averaging them. For previous temperature, average ambient temperature was calculated by taking average of minimum, maximum or average daily temperature for the five months prior to the start of the feeding period. For DMI under thermoneutral conditions three weights; initial, mid and final weights of the steers were used to determine DMI.

3.3.6 STATISTICAL ANALYSIS

Accuracy and precision of predicted DMI and SWG versus observed values were determined using a number of statistical approaches including regression, residual analysis (actual minus predicted versus predicted), concordance correlation coefficient (CCC), reliability index (RI), partitioning of mean square error into mean, slope and residual component (MC, SC, RC respectively) and means comparison. SAS 9.2® was used for all statistical analysis except for RI and partitioning of mean square error which was done using Excel®.

3.3.6.1 DESCRIPTION OF STATISTICAL METHODS

Significant regression ($P<0.05$) indicates that there was a relationship between observed and predicted values with adjusted r^2 giving an idea of how much of the variation was explained by the model. Residual analysis compares residual (observed-predicted) versus predicted. A non-significant residual with no observable pattern indicates that the data fits the model. Mean comparison compares the average of predicted versus observed for each parameter of interest. Significance ($P<0.05$) indicated that the averages were different.

Partitioning of mean square error (MSE) into its error components was only relevant if the regression was significant ($P<0.05$). The higher the MSE the poorer the agreement between the observed and predicted. Partitioning of MSE produces three numbers, the higher the number the higher the error. Bias (MC) indicates that it was either over or under predicting, while slope component (SC) indicates that the error was not consistent, sometimes it was over while other times it was under-predicting. Ideally the residual component (RC) should be close to one, indicating that the error was due to a random component.

Concordance correlation coefficient (CCC) was a statistical approach to assess the degree of agreement using accuracy and precision components. This statistical approach looks at two points and their relationship to a line with intercept of zero and a slope of one. A CCC value of one indicates perfect agreement, zero no agreement and negative one indicates perfect reverse agreement (Lin, 1992). Concordance correlation coefficient values are split into two values, accuracy and precision. Both accuracy and precision values should have a value of one. Values less than one, indicate that there is an issue with either accuracy or precision or both. The one with the lowest value indicates the area of greatest concern.

The last statistical approach performed was the reliability index (RI). Reliability index assess the model predicted value agreeing with observed value with one being perfect agreement and the further the number is from one the lower the reliability (Leggett and Williams, 1981). A value of one k indicates that the predicted and observed were the same but as the value gets further from one; the model becomes less reliable at predicting observed values.

3.4 RESULTS

3.4.1 MEAN COMPARISON

Predicted dry matter intake (DMI) and shrunk weight gain (SWG) were different ($P<0.05$) from observed with the exception that under thermoneutral conditions, observed versus predicted DMI were similar ($P=0.20$) (Table 3.2). The model under predicted SWG under actual and thermoneutral conditions and over predicted DMI under actual environmental conditions (Table 3.2). The magnitude of under prediction was 40% (1.5 versus 0.9 kg/d) for SWG under actual environmental conditions and 25% (1.5 kg/d versus 1.2 kg/d) under thermoneutral conditions. The over prediction for DMI was 10% (8.5 kg/d versus 9.4 kg/d) under actual environmental conditions and no significant difference (8.5 kg/d versus 8.3 kg/d) under thermoneutral conditions.

Table 3.3 indicates that the use of initial weight was not appropriate to predict DMI as predicted was different ($P < 0.05$) from actual DMI. Similarly predicted DMI based on final body weight was different ($P<0.05$) from observed but the difference was lower in magnitude than with initial weight. In contrast, predicted DMI using midweight was not significantly different ($P=0.20$) between observed and predicted values. For final weight and initial weight P value was the same but the difference between observed and predicted for final weight was higher than initial weight.

Shrunk weight gain was under predicted under all environmental conditions examined (Table 3.4). The magnitude difference when using minimum, average and maximum ambient average temperature was 45%, 36% and 40% respectively. Under thermoneutral conditions (20°C and no wind) the magnitude difference between observed and predicted values was 13% for SWG. The smallest difference was observed when using average ambient temperature and thus it was the most relevant for the NRC (2000) beef model in predicting gain (Table 3.4).

Dry matter intake under actual environmental conditions differed between eight and twelve percent for the different average temperatures investigated while under thermoneutral conditions there was no significant different from actual ($P=0.20$) (Table 3.4). Modeling under actual environmental had a higher deviation from actual than under thermoneutral conditions.

3.4.2 REGRESSION ANALYSIS

A significant ($P<0.05$) regression between actual and predicted DMI and SWG was noted under both environmental and thermoneutral conditions (Figure 3.1). This indicates that a relationship exists between observed and predicted values. Further, in both cases the regression line was different ($P<0.05$) from the isopleth indicating that the model was inaccurate at predicting DMI and SWG under actual environmental and the thermoneutral conditions.

The adjusted r^2 values for observed versus predicted DMI under actual environmental and thermoneutral conditions were 0.47 and 0.37, respectively. Coefficient of determination for SWG was 0.51 and 0.55, respectively. Removing the effects of the environment only changed the percent of variation that the regression model explains for DMI or SWG by 10% and 4%, respectively. The S_{y*x} under actual environmental conditions was 0.15 for SWG while for DMI it was 0.73 indicating precision was an issue.

The regression of observed versus predicted DMI was significant ($P<0.05$) when using initial, mid or final weight (Table 3.5). Adjusted r^2 was lowest for initial weight but similar adjusted r^2 existed when using midweight and final weight (Table 3.5). This indicated that precision was similar for midweight and final weight. When comparing the regression line to the isopleth all three weights modeled were found to be different ($P<0.05$) indicating that the model was inaccurate for all weights examined but had the highest precision when midweight or final weight was used with lowest precision when initial weight was used. The model had the same P-value when comparing the regression line to the isopleth indicating that accuracy of the model did not differ between the different weights examined.

The relatively low adjusted r^2 value for initial, mid and final weight indicates that regardless of weight chosen, less than 50% of the variation was explained by the model. The S_{y*x} value was the highest for initial weight at 0.90 kg/d indicating lowest precision, and lowest for midweight at 0.80 kg/d indicating better precision. Final weight S_{y*x} was close to midweight at 0.79 kg/d. The S_{y*x} was high for all weights examined indicating that precision was a concern.

A significant ($P<0.05$) regression between actual versus predicted DMI and SWG were noted under all environmental conditions modeled (i.e minimum, maximum and average ambient temperature) (Table 3.6 and Table 3.7).This indicated that a relationship exists between observed and predicted values. Further the regression line differed ($P<0.05$) from the isopleth (intercept of zero and a slope of one) indicating that the model was inaccurate at predicting DMI and SWG under each environmental condition modeled. Adjusted r^2 for DMI using minimum, average and maximum ambient temperature was 0.43, 0.47 and 0.45, respectively. Adjusted r^2 for predicting SWG using minimum, average and maximum ambient temperature was 0.44, 0.51 and 0.53 respectively. This indicates that the use of maximum ambient temperature had the highest precision under all situations examined.

Table 3.8 shows the highest and lowest adjusted r^2 when changing EQSBW by changing SRW and FSBW and thus impacting SWG prediction. The highest adjusted r^2 for predicting SWG (Table 3.8) was observed when using actual final shrunk body weight and the CNCPS equation to calculate SRW. This improved the adjusted r^2 by less than 10%. The lowest adjusted

Table 3.2: Mean comparison for predicting dry matter intake (DMI) and shrunk weight gain (SWG) using the standard reference weight (SRW) and final shrunk body weight (FSBW) values indicated in the NRC (2000) beef model.

Variable	Least Squares Means		P-value
	Observed	Predicted	
Environment			
SWG[Z]	1.5 ± 0.02	0.9 ± 0.02	<0.01
DMI[Y]	8.5 ± 0.08	9.4 ± 0.08	<0.01
Thermoneutral			
SWG	1.5 ± 0.02	1.3 ± 0.02	<0.01
DMI	8.5 ± 0.08	8.3 ± 0.08	0.20

[Y] DMI: Dry matter intake (kg/d)

[Z] SWG: Shrunk weight gain (kg/d)

Table 3.3: Mean comparison for predicting dry matter intake (DMI) using the NRC (2000) beef model and using initial, mid or final weight under thermoneutral conditions.

	Least Squares Means		
Variable	Observed	Predicted	P-value
Initial weight DMI[z]	8.5 ± 0.08	6.7 ± 0.08	<0.05
Midweight DMI	8.5 ± 0.08	8.3 ± 0.08	0.20
Final weight DMI	8.5 ± 0.08	9.4 ± 0.09	<0.05

[z] DMI=Dry matter intake (kg/d)

Table 3.4: Mean comparison for predicting dry matter intake (DMI) and shrunk weight gain (SWG) using the standard reference weight (SRW) and final shrunk body weight (FSBW) values indicated in the NRC (2000) beef model under minimum, maximum and average ambient temperature.

Variable		Least Squares Means		P-value
		Observed	Predicted	
Environmental	Minimum[Z] SWG[Y]	1.5 ± 0.02	0.8 ± 0.02	<0.01
	Maximum[X] SWG	1.5 ± 0.02	0.9 ± 0.02	<0.01
	Average[W] SWG	1.5 ± 0.02	0.9 ± 0.02	<0.01
Thermoneutral[V] SWG		1.5 ± 0.02	1.3 ± 0.02	<0.01
Environmental	Minimum DMI[U]	8.5 ± 0.08	9.5 ± 0.08	<0.01
	Maximum DMI	8.5 ± 0.08	9.2 ± 0.08	<0.01
	Average DMI	8.5 ± 0.08	9.4 ± 0.08	<0.01
Thermoneutral DMI		8.5 ± 0.08	8.3 ± 0.08	0.20

[Z] Minimum: Average temperature calculated from lowest daily temperature

[Y] SWG: Shrunk weight gain (kg/d)

[X] Maximum: Average temperature calculated from highest daily temperature

[W] Average: Average temperature calculated from average daily temperature

[V] Thermoneutral: 20°C and no wind

[U] DMI: Dry matter intake (kg/d)

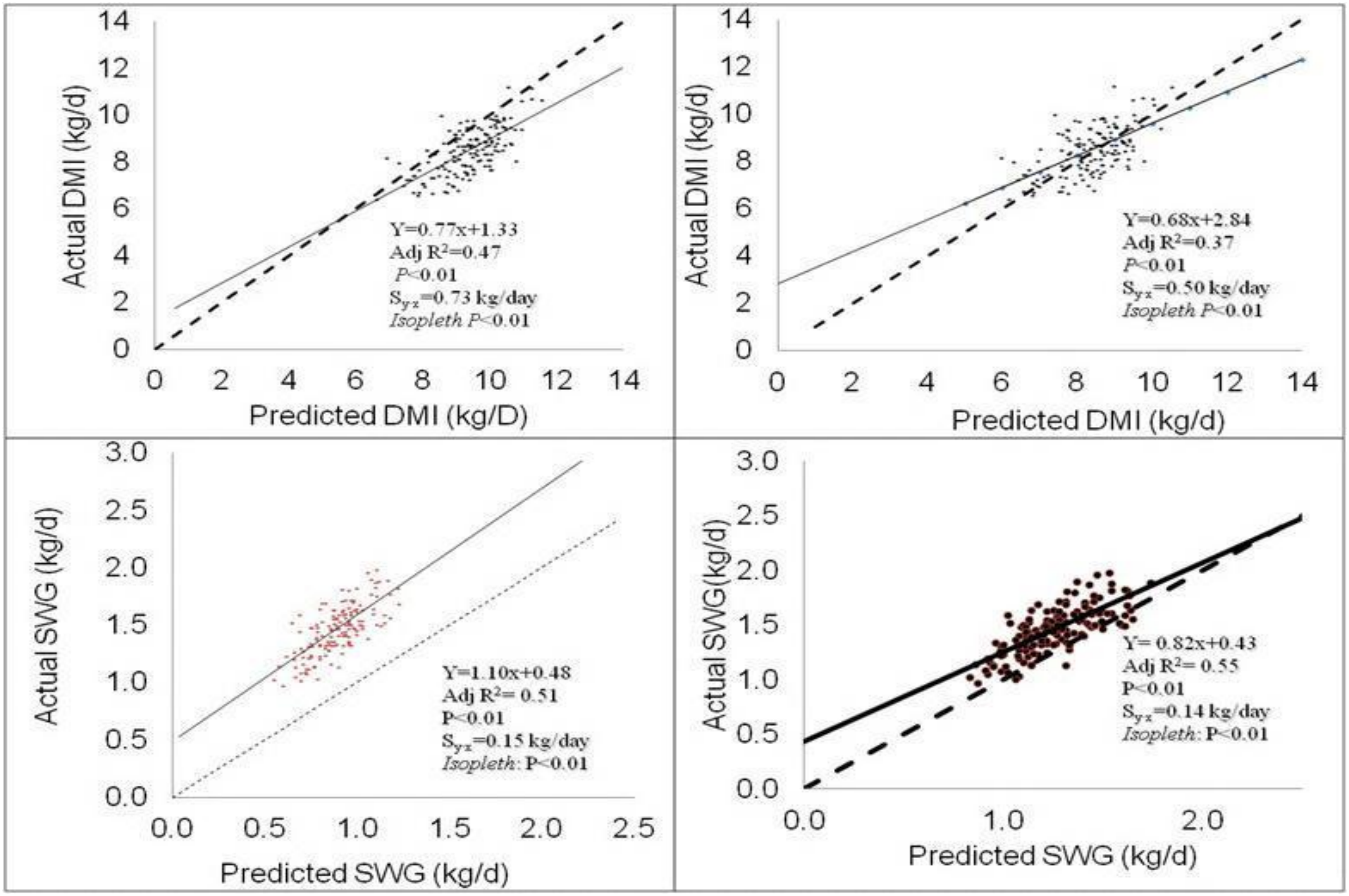

Figure 3.1: Predicted versus observed for dry matter intake (DMI) and shrunk weight gain (SWG) under actual environmental (average ambient temperature; graphs on the left) and thermoneutral (20°C and no wind; graphs on the right) conditions using the standard reference weight (SRW) and final shrunk body weight (FSBW) values indicated in the NRC (2000) beef model. S_{y*x} represents MSE.

Table 3.5: Predicted versus observed regression, residual, partitioning of mean square error, mean component, slope component and residual component, concordance correlation coefficient, and reliability index for dry matter intake (DMI) for the NRC (2000) model under thermoneutral conditions using the standard reference weight (SRW) and final shrunk body weight (FSBW) values indicated in the NRC (2000) beef model but adjusting the weight to either initial weight of the animal, midweight or final weight.

		Thermo neutral		
		Mid-weight	Initial weight	Final Weight
Regression equation	MSE[Z]	0.64	0.80	0.62
	Pr > F	<0.01	<0.01	<0.01
	RMSE[Y]	0.80	0.90	0.79
	Adjusted R^2	0.37	0.21	0.39
	Intercept ± SE[X]	2.8 ± 0.61	4.8 ± 0.59	2.9 ± 0.58
	Slope ± SE	0.7 ± 0.07	0.5 ± 0.09	0.6 ± 0.06
	Isopleth	<0.01	<0.01	<0.01
Regression residual (Predicted minus Observed)	MSE	0.64	0.80	0.62
	Pr > F	<0.01	<0.01	<0.01
	RMSE	0.80	0.90	0.79
	Adjusted R^2	0.11	0.16	0.22
	Intercept ± SE	2.8 ± 0.61	4.8 ± 0.59	2.9 ± 0.59
	Intercept ± SE	-0.3 ± 0.07	-0.5 ± 0.59	-0.4 ± 0.58
MSE partitioning	MC[W]	0.03	0.76	0.50
	SC[V]	0.12	0.04	0.11
	RC[U]	0.86	0.20	0.39
CCC analysis	CCC[T]	0.60	0.16	0.45
	Precision	0.60	0.46	0.62
	Accuracy	0.98	0.36	0.72
RI[S]		1.05	1.12	1.06

[Z] MSE: Mean square error
[Y] RMSE: Root mean square error
[X] SE: Standard error
[W] MC: Mean component (bias)
[V] SC: Slope component
[U] RC: Residual component
[T] CCC: Concordance correlation coefficient
[S] RI: Reliability index

Table 3.6: Predicted versus observed regression, residual, partitioning of mean square error, mean component, slope component and residual component, concordance correlation coefficient, and reliability index for dry matter intake (DMI) for the NRC (2000) beef model under environmental conditions using the standard reference weight (SRW) and final shrunk body weight (FSBW) values indicated in the NRC (2000) beef model.

		Environment		
		Minimum	Maximum	Average
Regression equation	MSE[Z]	0.57	0.56	0.53
	Pr > F	<0.01	<0.01	<0.01
	RMSE[Y]	0.76	0.75	0.73
	Adjusted R^2	0.43	0.45	0.47
	Intercept ± SE[X]	1.7 ± 0.64	1.5 ± 0.64	1.3 ± 0.62
	Slope ± SE	0.7 ± 0.07	0.8 ± 0.07	0.8 ± 0.07
	Isopleth	<0.01	<0.01	<0.01
Regression residual (Predicted minus Observed)	MSE	0.78	0.74	0.53
	Pr > F	<.01	0.01	<.01
	RMSE	0.88	0.86	0.73
	Adjusted R^2	0.11	0.07	0.47
	Intercept ± SE	9.1 ± 0.12	9.0 ± 0.10	1.3 ± 0.10
	Slope ± SE	-0.4 ± 0.09	-0.3 ± 0.09	0.8 ± 0.11
MSE partitioning	MC[W]	0.60	0.47	0.57
	SC[V]	0.05	0.04	0.03
	RC[U]	0.36	0.49	0.40
CCC analysis	CCC[T]	0.44	0.52	0.49
	Precision	0.66	0.67	0.69
	Accuracy	0.66	0.77	0.70
	RI[S]	1.07	1.06	1.06

[Z] MSE: Mean square error
[Y] RMSE: Root mean square error
[X] SE: Standard error
[W] MC: Mean component (bias)
[V] SC: Slope component
[U] RC: Residual component
[T] CCC: Concordance correlation coefficient
[S] RI: Reliability index

Table 3.7: Predicted versus observed regression, residual, partitioning of mean square error, mean component, slope component and residual component, concordance correlation coefficient, and reliability index for shrunk weight gain (SWG) for predicted versus observed for the NRC (2000) beef model under environmental (minimum, maximum and average ambient temperature) and thermoneutral conditions using the standard reference weight (SRW) and final shrunk body weight (FSBW) values indicated in the NRC (2000) beef model.

		Environment			Thermo neutral
		Minimum	Maximum	Average	
Regression analysis	MSE^Z	0.03	0.02	0.02	0.02
	Pr > F	<0.01	<0.01	<0.01	<0.01
	RMSE^Y	0.16	0.15	0.15	0.14
	Adjusted R^2	0.44	0.53	0.51	0.55
	Intercept ± SE^X	0.7 ± 0.07	0.4 ± 0.08	0.5 ± 0.08	0.4 ± 0.08
	Slope ± SE	0.9 ± 0.08	1.1 ± 0.09	1.1 ± 0.09	0.8 ± 0.06
	Isopleth	<0.01	<0.01	<0.01	<.01
Residual equation	MSE	0.03	0.02	0.02	0.02
	Pr > F	0.03	0.68	0.81	0.004
	RMSE	0.16	0.14	0.14	0.14
	Adjusted R^2	0.02	-0.01	-0.01	0.05
	Intercept ± SE	0.9 ± 0.05	0.9 ± 0.04	0.9 ± 0.04	-0.4 ± 0.08
	Slope ± SE	-0.2 ± 0.09	0.04 ± 0.09	0.02 ± 0.08	0.2 ± 0.06
MSE partitioning	MC^W	0.93	0.90	0.94	0.65
	SC^V	0.002	0.01	0.01	0.02
	RC^U	0.07	0.10	0.06	0.33
CCC partitioning	CCC^T	0.09	0.13	0.11	0.50
	Precision	0.67	0.73	0.72	0.75
	Accuracy	0.13	0.18	0.15	0.67
	RI^S	1.27	1.17	1.25	1.08

^{Z}MSE: Mean square error

^{Y}RMSE: Root mean square error

^{X}SE: Standard error

^{W}MC: Mean component (bias)

^{V}SC: Slope component

^{U}RC: Residual component

^{T}CCC: Concordance correlation coefficient

^{S}RI: Reliability

Table 3.8: Predicted versus observed for shrunk weight gain (SWG) for the NRC (2000) beef model under environmental and thermoneutral conditions using different standard reference weight (SRW) and final shrunk body weight (FSBW) (lowest adjusted R^2 and highest adjusted R^2)

		(Lowest adjusted R^2)[Z]		(Highest adjusted R^2)[Y]	
		Environmental	Thermoneutral	Environmental	Thermoneutral
Regression analysis	MSE[X]	0.03	0.04	0.02	0.02
	Pr > F	<0.01	<0.01	<0.01	<0.01
	RMSE[W]	0.18	0.19	0.15	0.13
	Adjusted r^2	0.33	0.24	0.51	0.61
	Equation[V]	0.89 + 0.72x	0.92 + 0.48x	0.48 + 1.08x	0.55 + 0.77x
	Isopleth	<0.01	<0.01	<0.01	<0.01

[Z] Shrunk weight gain predicted using equivalent shrunk body weight developed using SRW determined by CNCPS model and for FSBW the SAS model developed for each strain

[Y] Shrunk weight gain predicted using equivalent shrunk body weight developed using SRW determined by CNCPS model and FSBW.

[X] MSE: Mean square error

[W] RMSE: Root mean square error

[V] Equation: Regression equation.

r^2 for predicting SWG under thermoneutral conditions (20°C and no wind) was observed when the CNCPS equation was used to calculate SRW and for FSBW when the SAS model developed for each strain was used. This indicated that accuracy was an issue for all situation and only precision was affected by modifying EQSBW. The increase in complexity in calculating FSBW and SRW did not justify the increase in precision and no change in accuracy.

3.4.3 PARTITIONING OF MEAN SQUARE ERROR, CONCORDANCE CORRELATION COEFFICIENT ANALYSIS AND RELIABILITY INDEX

Table 3.5, 3.6, and 3.7 provides the reliability index (RI), the partitioning of mean square error (MSE) into mean (MC), slope (SC) and residual components (RC) and concordance correlation coefficient (CCC) analysis. These analyses allow a more descriptive analysis of the accuracy and precision of the NRC (2000) beef model. The RI values in Table 3.7 indicate that all predictions were close to actual values except for SWG under actual environmental conditions which had an RI value of 1.25 indicating that environmental modeling resulted in a higher discrepancy between predicted and observed values.

Reliability index (RI) indicated that the highest discrepancy between predicted and observed values for DMI was when initial weight was used followed by final weight and then midweight (Table 3.5). Bias (MC) was highest when initial weight was used as was expected due to the highest magnitude difference between observed and predicted values (Table 3.5). Table 3.7 indicates the partitioning of MSE for SWG. It is evident that the majority of the error was due to bias under the different environmental conditions examined. Under thermoneutral conditions (Table 3.7) for prediction of SWG error was distributed between bias (65%) and residual (33%) components and the remainder was for slope (2%) error component. This indicated that majority of the error was due to differences between the mean of observed versus predicted.

The majority of the error for DMI under actual environmental conditions using minimum, maximum or average ambient temperature was due to bias and residual components (Table 3.6). This means that the majority of the error is due to difference between the observed and predicted means. Under thermoneutral conditions (20°C and no wind) using average weight, error was due to residual component but when using initial weight, error was due to bias and when using final weight error was distributed between residual and bias (Table 3.5).

The last statistical approach was the CCC which had values that ranged from being close to 0 to values close to 0.7 indicating that either accuracy or precision or both are a concern for both DMI and SWG under all conditions modeled. When partitioning CCC, it was found that for gain under actual environmental conditions, accuracy was more of a concern than precision while for thermoneutral conditions both were of equal concern. For DMI predictions, partitioning of CCC indicated that under actual environmental or thermoneutral conditions, there were similar issues for both accuracy and precision (Table 3.9). When examining the impact of weight on predicting DMI, it was identified that CCC value varied from being close to zero (midweight) to being close to one (Final weight) (Table 3.5). Using initial weight or average weight indicated that both precision and accuracy had similar concerns while for final weight, precision was more of a concern (Table 3.5).

Results from modifying EQSBW by changing SRW and FSBW indicated that error composition and CCC values did change whether actual environmental or thermoneutral conditions were modeled but the degree of change was low and did not justify the increase in complexity in defining SRW and FSBW (Table 3.10).

Table 3.9: Partitioning of mean square error into mean component (MC), slope component (SC) and residual component (RC), reliability index (RI) and concordance correlation coefficient (CCC) for dry matter intake (DMI) and shrunk weight gain prediction (SWG) for the NRC (2000) model under thermoneutral and environmental conditions using the standard reference weight (SRW) and final shrunk body weight (FSBW) values indicated in the NRC (2000) beef model.

		DMI (Environment)	DMI (Thermoneutral)	SWG (Environment)	SWG (Thermoneutral)
MSE partitioning	MC^{W}	0.57	0.03	0.94	0.65
	SC^{V}	0.03	0.12	0.01	0.02
	RC^{U}	0.40	0.86	0.06	0.33
CCC analysis	CCC^{T}	0.49	0.16	0.11	0.50
	Precision	0.69	0.46	0.72	0.75
	Accuracy	0.70	0.36	0.15	0.67
	RI^{S}	1.06	1.05	1.25	1.08

^{W}MC: Mean component (bias)

^{V}SC: Slope component

^{U}RC: Residual component

^{T}CCC: Concordance correlation coefficient

^{S}RI: Reliability index

Table 3.10: Partitioning of mean square error into mean component (MC), slope component (SC) and residual component (RC), reliability index (RI) and concordance correlation coefficient (CCC) for shrunk weight gain (SWG) for the NRC (2000) beef model under environmental and thermoneutral conditions using different standard reference weight (SRW) and final shrunk body weight (FSBW) (lowest adjusted r^2 and highest adjusted r^2)

		(Lowest adjusted R^2)[Z]		(Highest adjusted R^2)[Y]	
		Environmental	Thermoneutral	Environmental	Thermoneutral
MSE partitioning	MC[X]	0.93	0.70	0.93	0.80
	SC[W]	0.01	0.08	0.0004	0.03
	RC[V]	0.07	0.22	0.07	0.18
	RI[U]	1.32	1.15	1.24	1.12
CCC partitioning	CCC[T]	0.08	0.03	0.12	0.01
	Precision	0.57	0.48	0.72	0.31
	Accuracy	0.15	0.69	0.16	0.04

[Z] Shrunk weight gain predicted using equivalent shrunk body weight developed using SRW determined by CNCPS model and for FSBW the SAS model developed for each strain

[Y] Shrunk weight gain predicted using equivalent shrunk body weight developed using SRW determined by CNCPS model and FSBW.

[X] MC: Mean component (bias)

[W] SC: Slope component

[V] RC: Residual component

[U] RI: Reliability index

[T] CCC: Concordance correlation coefficient

3.5 DISCUSSION

Dry matter intake was over predicted under actual environmental conditions, which disagrees somewhat with Block et al., (2001) who conducted similar trials under similar feeding practices and under western Canadian environmental conditions. These workers identified that the NRC (2000) beef model over predicted DMI during a restricted feed intake phase during backgrounding. The NRC (2000) beef model predicts voluntary feed intake and thus it was expected to over predict DMI during a restricted feeding trial. They identified that of the two trials there was accurate prediction of finishing DMI in one trial and over prediction in the second. This study concluded that under actual environmental conditions the model over predicted DMI while under thermoneutral conditions there was no significant difference between observed and predicted. The authors suggest that the model may not be able to accurately model changes in environmental conditions (Block et al., 2001).

Beauchemin and Koeing (2005) conducted a trial based on diets that were either composed of barley or corn grain. The model underestimated DMI in this investigation. These trials were conducted under western Canadian environmental conditions and most indicated that there was significant bias in predicting DMI. Similar results were observed in this study were the model over predicted DMI. These findings where contrary to the studies conducted by Rayburn and Fox (1990) and Fox et al., (1992) which found that the equations used in developing the NRC (2000) beef model were accurate at predicting DMI. The studies of Rayburn and Fox (1990) and Fox et al., (1992) did not evaluate the overall model as the model was not yet published.

The differences in results can be attributed to differences in environmental conditions. The NRC (2000) beef model was developed using data from cattle exposed to environments that have temperatures higher than those of western Canada. These cattle are not expected to be exposed to the low temperature in western Canada. Thus their energy requirements will be different to that for cattle exposed to western Canadian environmental conditions. In fact environment Canada indicated that the average temperature for western Canada was around 2°C which was much lower than what was expected in the studies of Rayburn and Fox (1990) and Fox et al., (1992).

Block et al., (2001) indicated that in the NRC (2000) beef model, for every one degree Celsius drop in temperature from 20°C there was a one percent increase in NE_m requirements. This increase in NE_m requirement may not be necessary at such a high temperature (when temperature drops below 20°C). Kleiber (1975) indicated that there was no change in the amount of heat produced within the thermoneutral zone. This indicates that the adjustment modeled by the NRC (2000) beef model for every one degree Celsius below 20°C for NE_m prediction may not be appropriate.

To test if environmental modeling affected the accuracy and precision of the NRC (2000) beef model under western Canadian environmental conditions, two tests were conducted. The first was to investigate if under thermoneutral conditions (20°C and no wind) does it have a significant impact on the model's accuracy and precision. The second is to model using minimum, maximum and average temperature to calculate average ambient temperature to determine which will be the best approach for estimating current and previous temperature. Comparing the adjusted r^2 under environmental and thermoneutral conditions it was shown that under thermoneutral conditions the model explains 10% more of the DMI variation than under actual environmental conditions indicating that precision did improve. These results could be attributed to inability of environmental modeling and thus modifications will be required to explain more of the variation and a second reason could be due to another aspect of the DMI equation which requires modification. Other aspects include the adjustments incorporated into the DMI equation and the models method used in converting DE to NE_{ma}. The results of the regression analysis were contrary to the findings of mean comparison which indicated that under thermoneutral conditions predicted versus observed was not significantly different indicating that the model was accurate under this situation. The contradictory results between regression analysis and mean comparison can be due to the fact that mean comparison was based on means while regression analysis was based on individual animals.

These results can also be explained by the weaknesses that these two statistical approaches have. Regression investigates it requires there to be a relationship between individual animals observed and predicted while mean comparison does not require this to be so. In addition to this the mean is sensitive to outliers and thus can cause bias which the regression was less likely to be sensitive to (Mann, 2007). The use of more than one statistical approach is to ensure that weakness of each statistical approach can be ignored by taking note of the results of the different statistical methods used. Residuals for DMI under both environmental and thermoneutral conditions were observed to be significant by Block et al., (2001) indicating that there is an inaccurate relationship between observed and predicted DMI, similar to the results of this study.

When modifying the temperature, it was identified that when performing the mean comparison or regression statistical analysis for all temperature investigated observed versus predicted was inaccurate. The change in accuracy could be due to the one percent increase in NE_m per one degree Celsius drop in temperature below 20°C or due to inability to model changes in cold stress. It's been suggested that acute cold stress is more of an issue than chronic cold temperature (Birkelo et al., 1991). The model does not incorporate the number of days where cold temperature resulted in acute cold stress. The model takes the average temperature over a period of time. Cattle fed under western Canadian environmental conditions may experience temperature as low as -40°C where it is expected that cold stress would occur. The average temperature will not indicate that acute cold stress. This will impact the prediction of gain.

Modeling under thermoneutral conditions and eliminating the environmental modeling did improve the model's predictive ability of SWG as indicated by regression analysis, CCC and the partitioning of the MSE; however the model was still inaccurate under all situations investigated. Another potential reason for the inaccuracy could be due to the inability to accurately calculate change in maximum feed intake. Maximum feed intake will change due to both physical and nonphysical limitations (Ketelaars and Tokamp, 1992).

When midweight was used to predict DMI as indicated previously it was identified not to be significantly different between predicted and observed. When using initial weight or final weight the predicted DMI was less than or larger than observed values respectively. This indicated that the model was most accurate when using midweight. This was potentially due to the fact that the model was developed based on average weight. Another important factor that should be considered was that when using initial weight of the animal, prediction of DMI was less than with mid weight and when using final weight of the animal, prediction of DMI was higher than with mid weight of the animal. According to this, the NRC (2000) beef model predicts total feed intake in a nonlinear pattern as body weight increased. Changing weight did impact the accuracy and precision of the NRC (2000) beef model with the use of average weight being the most appropriate.

Prediction of SWG was also found to be inaccurate and imprecise. This was similar to the findings of Block et al., (2001, 2006 and 2010) where gain prediction was found to be inaccurate for steers and cows, respectively. The precision of gain could be attributed to the adjusted r^2 which changed from 0.51 under actual environmental conditions to 0.55 under thermoneutral conditions. The moderate adjusted r^2 under both conditions indicates that the model's inability to predict SWG could be due to aspects not related to environmental modeling but due to others aspects within the model. Changing the ambient temperature changed the adjusted r^2 by no more than 15% with more than 40% of the variation not explained by environmental modeling.

The calculation of EQSBW could explain some of the variation not explained by environmental modeling. As indicated previously, EQSBW was calculated from SRW and FSBW. Changing EQSBW only increased adjusted r^2 almost by 10%. This change indicated that the increase in complexity in calculating EQSBW was not justifiable to the change in adjusted r^2. This indicates that another aspect of the model may not be precise and thus impacting the precision of DMI and SWG predictions. The study of Block et al., (2010) proposed that the model may not be accurate at predicting the net energy requirements for maintenance as well as its impacts on gain.

It has been proposed by Block et al., (2006) and McMeniman et al., (2009) that the model was inaccurate due to inability to accurately predict NE_m. Inaccurate prediction of NE_m will impact the accuracy of SWG prediction. In addition to this, the NRC (2000) beef model could inaccurately predict NE_g impacting SWG prediction. Previous studies such as those of Block et al., (2006) and McMeniman et al., (2009) did not have sufficient data to allow the investigation of the accuracy and precision of both NE_m and NE_g.

3.6 CONCLUSION

The prediction of DMI and SWG had issues with accuracy and precision when calculated under actual environmental conditions. When calculating under thermoneutral conditions, the accuracy and the precision for both did not improve in all statistical approaches used. This indicated that accuracy and precision was still an issue. When examining effects of weight on DMI calculation, mid weight or final weight had similar outcomes but only when initial weight was used did the model become less precise according to the adjusted r^2 of the regression analysis and less accurate according to the portioning of CCC into its accuracy and precision components. Method used to calculate ambient temperature did not affect the NRC (2000) beef model accuracy as indicated by regression analysis. For SWG, the effects of EQSBW were examined. It was identified that the model could be improved by using a different method in determining EQSBW, but this improvement was not sufficient to require modifications of the NRC (2000) beef model. Overall the NRC (2000) beef model predictability for DMI and SWG for finishing steers has accuracy and precision issues that are likely due to factors not examined in chapter 3. Research is required to evaluate the accuracy and precision of the model for predicting net energy of maintenance (NE_m) and gain (NE_g). Overall, previously observed issues with the NRC (2000) beef model predictions of DMI and ADG were also observed with the dataset of Basarab et al., (2003) and further investigation specifically on NE may provide additional insight on sources of inaccuracy and imprecision.

4.0. ACCURACY AND PRECISION OF THE NRC (2000) BEEF MODEL FOR PREDICTING NET ENERGY OF MAINTENANCE (NE_M) AND GAIN (NE_G) REQUIREMENTS OF CATTLE

4.1 INTRODUCTION

The NRC (2000) beef model uses a description of cattle and feed to predict feed intake and gain by estimating the net energy required for maintenance (NE_m) and that left over for gain (NE_g). Previous studies (Block et al., 2001 and 2010) have indicated that under western Canadian environmental conditions, the NRC (2000) beef model lacks accuracy and precision in predicting dry matter intake (DMI) and average daily gain (ADG). Potential reasons for this inaccuracy is the inability of the model to accurately predict NE_m and NE_g. Zinn et al., (2008) and Block et al., (2006) developed modifications for the net energy equations within the NRC (2000) beef model to improve the model's accuracy but neither assessed the accuracy and precision of the new equations to cattle under western Canadian environmental conditions.

Previous studies have lacked the details required for determining if the inaccuracy in prediction of DMI and ADG was due to error in predicting NE_m or NE_g. This was due to the fact that it was not possible to estimate the actual amount of net energy used for gain by an individual animal and thus what was left over for maintenance. Actual NE_m and NE_g utilized can be determined through techniques such as the respiratory chamber and the comparative slaughter technique. The comparative slaughter technique uses groups of animals that are fed at two or more levels of feed intake and determines retained energy (RE) in each individual animal at slaughter (Lofgreen and Otagaki, 1962). Retained energy is equivalent to the net energy of gain consumed by the animal. This allows extrapolation to obtain NE_m. Net energy of gain is calculated as the difference between the initial slaughter group and the group in question in terms of whole body energy content. No study to this point has had sufficient data to determine individual animal feed intake, metabolizable energy intake and retained energy and environment data to determine actual NE_m and NE_g requirements to test the accuracy of the NRC (2000) beef model predictions of net energy.

4.2 OBJECTIVE

The objectives of this trial were to determine the accuracy and precision of the NRC (2000) beef model in determining NE_m and NE_g requirements of growing beef steers fed under western Canadian environmental conditions.

4.3 MATERIALS AND METHODS

Data was obtained from Basarab et al., (2003). The study was conducted over two years. In each year of the study, 88 animals composed of five composite breeds were used. Beef steers were fed for 1, 71, 99, 127, 155 and 183 days. In each year, three steers from each composite strain were randomly selected for slaughter at each target date. All animals were fed a barley based finishing diet. All animals were cared for under the guidelines established by the Canadian Council on Animal Care (1993).

Data collected by Basarab et al., (2003) were based on individual animals. Daily DMI was collected using the GrowSafe® system. Start and end of test live animal weights, ultrasound subcutaneous fat thickness (USF), marbling score (UMAR), rib eye area (UREA) and hip height (HH) were also collected. Carcass and non-carcass body parts were ground and analyzed for chemical composition. Total body fat was determined by petroleum ether extract, total body protein by nitrogen analysis using Leco analyzer and total body water was determined by drying at 105°C, for 24 hour. Ash was calculated by difference.

4.4 METHODS

4.4.1 DETERMINING IF INITIAL GROUP CAN BE USED TO REPRESENT THE INITIAL COMPOSITION OF ALL ANIMALS.

To calculate NE_m and NE_g the following three steps were carried out. The first was to determine the energy content of the animal's body at the start and end of the trial. The second step was to calculate retained energy by difference. This was done by subtracting initial body energy content from final body energy content. The third step was to calculate net energy of maintenance used (Mcal/d). This was done by taking the energy content of the diet consumed (in ME, Mcal/d) and subtracting the retained energy (in ME Mcal/d) to obtain maintenance requirements in ME (Mcal/d) which was then converted to NE_m (Mcal/d). A challenge to this approach was that measurement of body energy content is a destructive process; an individual can only be measured once, typically at slaughter. Initial body composition values must be estimated using a contemporary group that was either assumed to have the same composition, or on which measurements were collected that can allow for estimation of body energy content for live animals.

The approach used by Basarab et al., (2003) was to slaughter a random group (N=3 per strain) of cattle on day one of the trial to determine initial total percent protein, fat and ash. In order to determine if this initial slaughter group represented subsequent slaughter groups a means comparison using the *Bonferroni* method was run for each of the following measurements; start of test hip height (HH), body condition score (BCS), ultrasound subcutaneous fat thickness (USF), and ultrasound rib eye area (UREA).After performing this mean comparison it was found that there was significant difference ($P<0.05$) noted between some of the variables measured on day one for the initial slaughter groups and subsequent slaughter groups (Appendix Table A.3). This indicates that the initial slaughter group was not representative in body composition for all subsequent slaughter groups. Therefore it was necessary to develop equations to predict percent protein and fat at the start of the feeding period for each group of animals.

These equations were developed using live animal ultrasound subcutaneous fat thickness (USF), ultrasound rib eye area (UREA), ultrasound marbling (UMAR), hip height (HH), and total body fat and protein for animals slaughtered from day one to 183. Both linear and nonlinear regression was used as well as transforming the variables using cos, sin, tan, log, square root, and exponential functions. The final equations removed the issue of collinearity by ensuring USF and UMAR were not regressed together as they both measured fat levels. The final equation chosen to predict body composition was based on the highest r^2 and lowest MSE. These equations were then used to estimate each individual animal's initial level of body fat and protein.

4.4.2 DETERMINATION OF NET ENERGY OF MAINTENANCE (NE_M) AND GAIN (NE_G)

Retained energy or net energy of gain (NE_g; Mcal/day) accumulated was calculated using initial body composition as determined from the equations developed in section 4.5. For each animal, final body energy content was subtracted from the energy content of the initial slaughter group. Actual NE_m utilized was calculated in four steps. Net energy of gain was converted to metabolizable energy used for gain (ME_g) by dividing by the efficiency of metabolizable energy used for gain (k_g). Efficiency of metabolizable energy used for gain was calculated according to equation 4.1 where ME was the metabolizable energy content of the feed and NE_{ga} was the net energy for gain content of the feed.

$$k_g = \frac{NE_{ga}}{ME} \tag{4.1}$$

The NE and ME values in equation 4.1 and 4.2 were based on DE from a sheep trial published in Basarab et al., (2003). Metabolizable energy used for gain was subtracted from total metabolizable energy consumed to give metabolizable energy used for maintenance (ME_m). Metabolizable energy used for maintenance was multiplied by the efficiency of metabolizable energy used for maintenance (k_m) to obtain NE_m utilized (Mcal/day). Efficiency of metabolizable energy used for maintenance was calculated according to equation 4.2 where ME was metabolizable energy content of the feed and NE_{ma} was the net energy of maintenance content of the feed.

$$k_m = \frac{NE_{ma}}{ME} \tag{4.2}$$

4.4.3 CALCULATING PREDICTED NET ENERGY OF MAINTENANCE (NE_M) AND GAIN (NE_G) REQUIREMENTS

Predicted NE_g (Mcal/day) was calculated according to NRC (2000) beef model using two methods. The intake method used actual DMI. The gain method used actual SWG. The intake method (Equation 4.3) used intake needed for maintenance (I_m) calculated under both environmental and thermoneutral conditions (20°C and no wind) according to the NRC (2000) beef model. The gain method is illustrated in equation 4.4 where equivalent shrunk body weight (EQSBW) was determined according to the method proposed in the NRC (2000) beef model.

- Intake method

$$NE_g (Mcal\ d^{-1}) = (DMI - I_m) * NE_{ga} \tag{4.3}$$

- Gain method

$$NE_g\ (Mcal\ d^{-1}) = ((SWG)/(13.91 * (EQSBW^{-0.6837}))^{\frac{1}{0.9116}} \tag{4.4}$$

Predicted NE_m (Mcal/day) was calculated according to NRC (2000) beef model. The equation can be referred to in section D.1.3.

4.4.4 STATISTICAL ASSESSMENT

Actual versus predicted NE_m and NE_g requirements were statistically compared using a regression, residual and mean comparison ($P<0.05$).

4.5 RESULTS

Regression equations developed to predict initial body composition are given in Table 4.1. Protein and fat prediction were both significant with an adjusted r^2 higher for predicting fat than protein. To calculate actual NE_m (Mcal/day) and NE_g (Mcal/day) it was necessary to calculate the efficiency of ME use for maintenance (k_m) and for gain (k_g), for each year that the digestibility trial was conducted (Table 4.2).

Table 4.1: Regression equations used to determine initial body composition for each of the 148 steers investigated

Variable	Equation	Adjusted R^2	MSE^Z
Total body fat (%)	$0.08382+0.01082+USF^Y+0.00107*UREA^X$	0.60	0.001
Total body protein (%)	$0.1233 + 0.00034045 * HH^W - 0.00221 * USF + 0.10196 * \frac{UREA}{WEIGHT}$	0.32	0.0001

^{Z}MSE=Mean square error

^{Y}USF= Ultrasound subcutaneous fat thickness

^{X}UREA= Ultrasound rib eye area

^{W}HH= Hip height

Table 4.2: Efficiency of metabolizable energy (ME) used for gain (k_g) and maintenance (k_m) for each of the two years.

Variable	Year 1	Year 2
k_g[Z]	0.44	0.42
k_m[Y]	0.67	0.66

[Z] k_g = Efficiency of metabolizable energy used for gain

[Y] k_m = Efficiency of metabolizable energy used for maintenance

Regression of actual versus predicted NE_m requirements under environmental and thermoneutral conditions (Mcal/d) was not significant ($P=0.29$ and $P=0.63$, respectively) indicating no relationship exist between these variables. Regression analysis of predicted versus residual (actual minus predicted) NE_m requirements was significant ($P<0.05$) indicating the model is inaccurate. The CCC and RI values are given in Appendix B (Table B.2-B.3**)**. Mean comparisons for NE_m (mean ± standard deviation) for all 148 animals are given in Table 4.3. Values by kill data are given in Appendix B (Table B.1**)**. Means comparison (Table 4.3) shows that NE_m utilized in Mcal/d was over predicted ($P<0.05$) relative to actual values regardless of whether environmental or thermoneutral conditions were modeled. Under actual conditions, the magnitude of the over prediction of NE_m was 49% while under thermoneutral conditions it was 28%. Thermoneutral modeling improved the accuracy of the model by 21% but did not remove all of the inaccuracy.

Regression of actual versus predicted NE_g requirements under both sets of environmental conditions modeled and the gain method was not significant ($P=0.18$, $P=0.87$, $P=0.07$; Figure 4.2). Regression of predicted NE_g requirements versus residual (actual NE_g requirements minus predicted NE_g requirements; Figure 4.3) for all methods investigated was significant indicating the model was inaccurate. Concordance correlation coefficient and RI are given in the Appendix B (Table B.3). Mean comparisons for NE_g (mean ± standard deviation) for all 148 animals are given in Table 4.3. Values by kill data are given in the Appendix B (Table B.3). There were two methods used to calculate NE_g. Using the gain method, it was identified that the degree of difference between observed NE_g and predicted was 8% (Table 4.3). With the intake method under actual environmental conditions the magnitude of the difference was 32% (Table 4.3). When using the intake method under thermoneutral conditions, observed versus predicted was not significantly different ($P=0.24$) (Table 4.3).

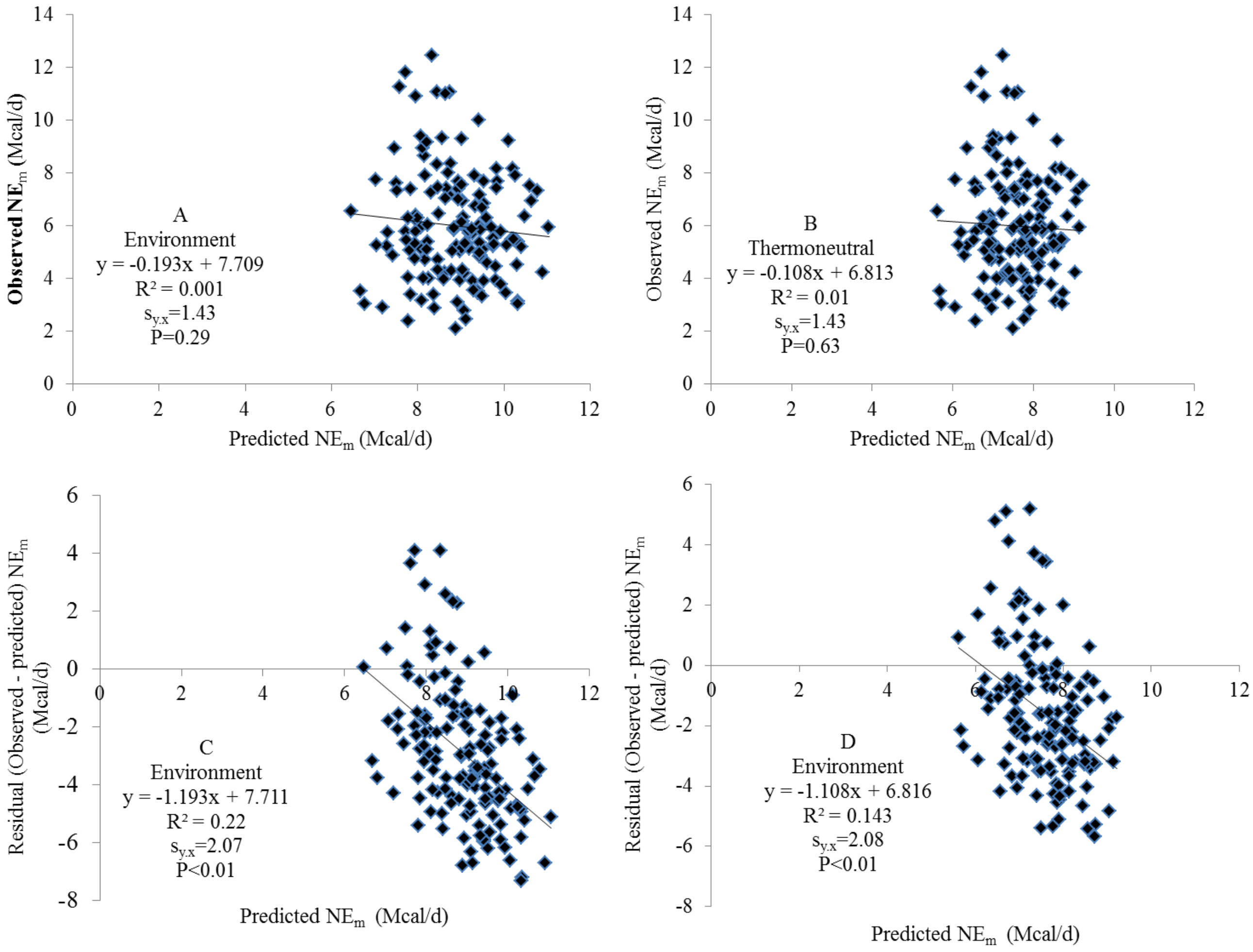

Figure 4.1: Actual net energy of maintenance ($\mathrm{NE_m}$) versus predicted $\mathrm{NE_m}$ under actual environmental (A) and thermoneutral B) conditions for all 148 animals. Residual (actual minus predicted) versus predicted for all 148 under actual environmental (C) and thermoneutral (D) conditions. A solid line represents the regression line for all 148 animals. $S_{y.x}$ represents MSE.

Table 4.3: Mean comparison of net energy of maintenance (NE_m ± SD) and gain (NE_g ± SD) requirements (Mcal/day) for all 148 animals with respective standard deviation.

	Observed	Predicted	P-value
Net energy of maintenance (NE_m^Z)			
Environmental	6.0 ± 0.10	8.9 ± 0.10	<0.05
Thermoneutral	6.0 ± 0.10	7.6 ± 0.10	<0.05
Net energy of gain (NE_g^Y)			
Gain method	6.1 ± 0.10	5.6 ± 0.10	<0.05
Intake method (Actual environmental condition)	6.1 ± 0.10	4.2 ± 0.10	<0.05
Intake method (Thermoneutral)	6.1 ± 0.10	6.3 ± 0.10	0.24

NE_m^Z Net energy needed for maintenance

NE_g^Y Net energy needed for gain

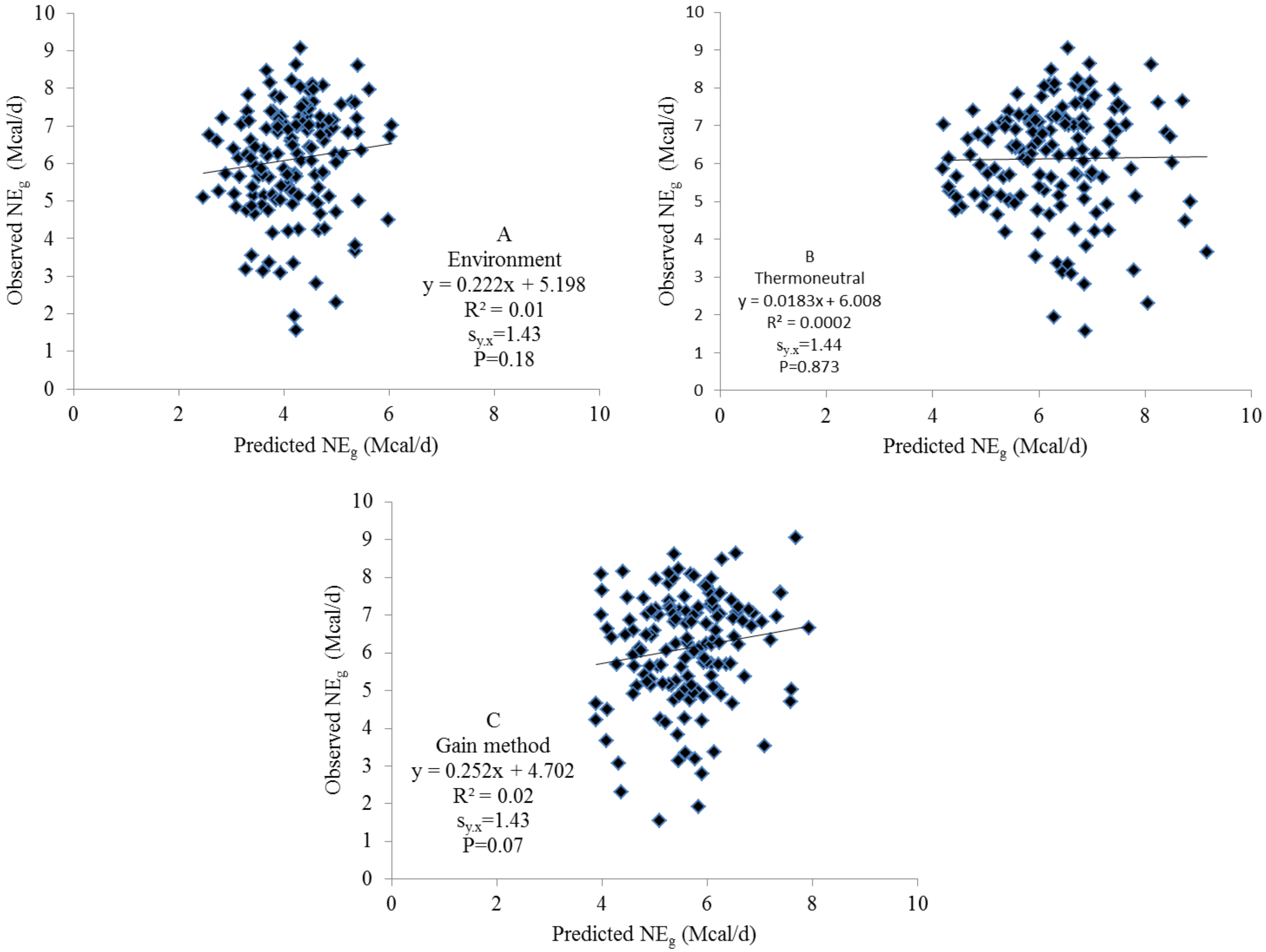

Figure 4.2: Actual net energy of gain (NE$_g$) versus predicted NE$_g$ under actual environmental conditions (A; intake method), thermoneutral (B; intake method) and gain method (C) for all 148 animals. A solid line represents the regression line for all 148 animals. S$_{y*x}$ represents MSE.

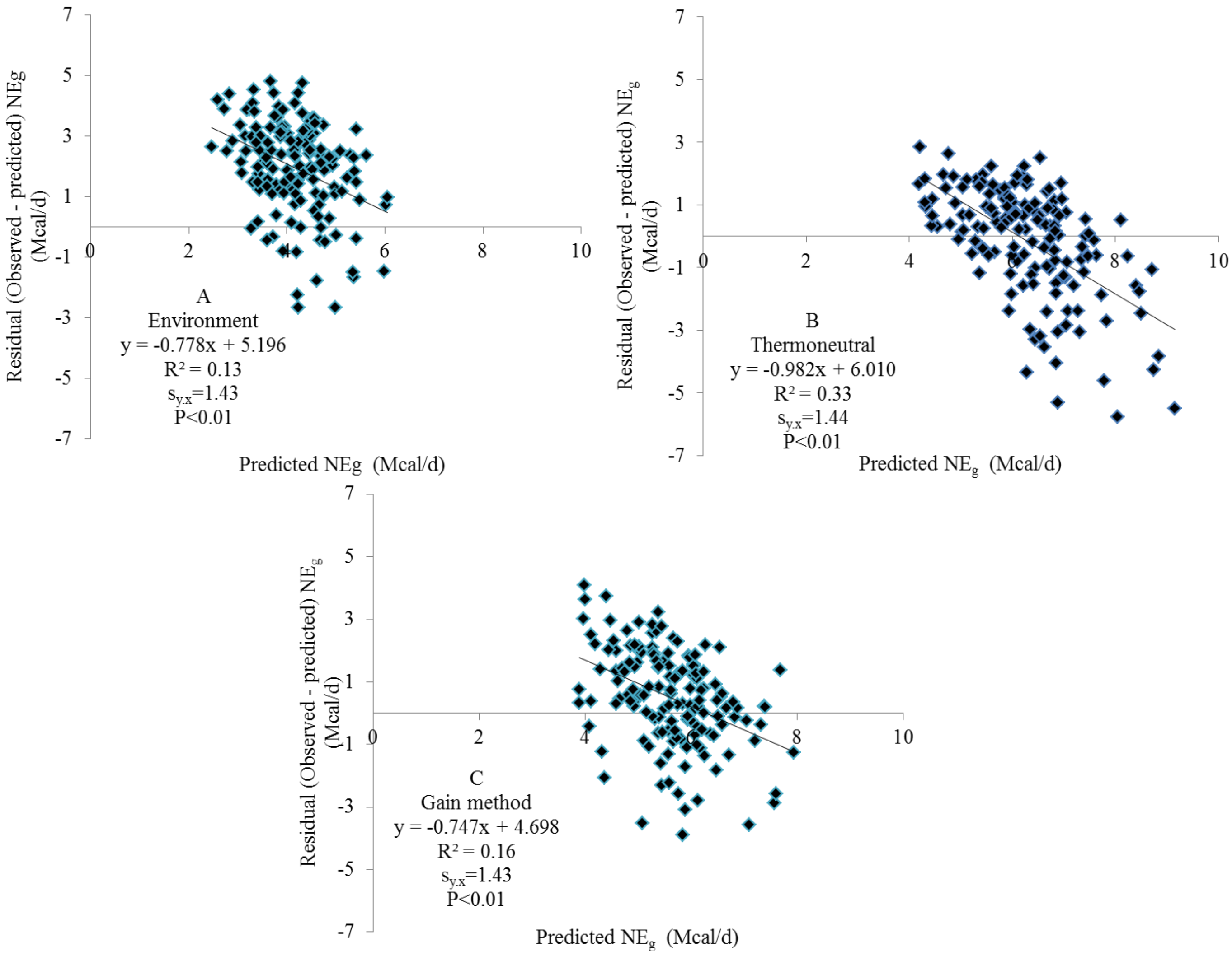

Figure 4.3: Residual (actual minus predicted) net energy of gain (NE_g) versus predicted NE_g using gain method (A), under thermoneutral conditions (B; intake method) and under actual environmental conditions (C; intake method), thermoneutral (B; intake method) for all 148 animals. A solid line represents the residual line versus predicted line for all 148 animals. S_{y*x} represents MSE.

4.6 DISCUSSION

With regard to prediction of initial body composition prediction of fat had a higher precision than that of protein (Table 4.1). This is likely due to the use of ultrasound as one of the parameters in measuring fat and protein. Research has found that ultrasound measurement between the 12th rib and 13th rib is an accurate measurement for subcutaneous fat, intramuscular fat and rib eye area (Miller et al., 2004, Turner et al., 1990 and Brethour. 1992). A review of the literature found that the correlation coefficient between USF and carcass measurements of fat thickness varied from 0.42 to 0.92 (Houghton, 1988). This indicates that there is medium to strong correlation between these parameters and it is further found that a one mm change in subcutaneous fat thickness (which has a strong correlation to USF) resulted in a five kg change in total body fat reserves (Gallo et al., 1996; Shroder and Staufenbiel, 2006). **A**nother potential reason is that there is higher variation in fat content compared to protein and thus it is either to create a regression equation. Never the less, these equations that were developed indicate that error is likely higher in predicting protein than fat.

When examining lean yield, regression equations developed using USF with UREA had an r^2 of 0.73 (Bergen et al., 1996) and those that used the USF and live weight had an r^2 of 0.67 (Faulkner et al., 1990). When using USF as a sole predictor of lean yield it was found that a strong correlation exists (Bergen et al., 1996). The relationship was negative in nature (as the level of fat increases the level of lean declines). It must be indicated that USF becomes significantly less accurate at predicting subcutaneous fat in very thin or very fat animals (Bergen et al., 1996). This can explain the relatively weak regression equations in Table 4.1 as these equations were developed to predict initial body composition where fat levels are expected to be very low. In addition as discussed previously, a higher range in fat content exists making it easier to predict.

Regression of actual versus predicted NE_m and NE_g was not significant for all methods investigated ($P>0.05$) (Figure 4.1 and Figure 4.2). The non-significant regression indicated that there was no relationship between observed and predicted NE_m or NE_g requirements (Mcal/d). The regression graphs Figure 4.1 and Figure 4.2 indicated that observed had higher variation (degree of difference between lowest and largest net energy) than predicted. This could be due to two reasons. The first is that the NRC (2000) beef model reduced the differences in NE_m and

NE_g between animals. This could be due to the inability of the model to account for differences in feed efficiency between animals. Basarab et al., (2003) demonstrated that within a group of animals feed efficiency can vary significantly. There is no method to adjust for this significant variation in the NRC (2000) beef model. The second reason is that the method used to calculate actual NE_m and NE_g used a regression equation to determine initial body composition. This regression equation may have led to an increase in the differences between animals. This method did not correct for potential outliers or define maximum boundaries of predicted values. Both of these can result in variation in predicted values (Gordon, 1968). The regression equations were developed on the premise to remove all subjective values (BCS) and reduce the potential for collinearity. Steps were taken to reduce the potential for collinearity by ensuring that USF and UMAR were not tested together when developing the regression equation to predict initial body composition for fat and protein.

Net energy of maintenance (Table 4.3) was over predicted under actual environmental conditions. Under thermoneutral conditions the model had a significant improvement in its ability to predict NE_m. This indicates that environmental modeling (i.e accounting for cold stress and acclimatization) reduced the accuracy and precision of the NRC (2000) beef model for NE_m. Block et al., (2001) proposed that the reason why NE_m was inaccurately predicted was due to the acclimatization adjustment; that for every one degree Celsius change in temperature below 20°C there is an increase in NE_m requirements by approximately one percent. This adjustment may not be necessary at the temperature observed at this data set.

Net energy of maintenance does increase by as much as 20% if the current temperature is lower than thermoneutral zone. However NE_m does not increase in the gradual pattern modeled by the NRC (2000) beef model (Mueller, 2011). The NRC (2000) beef model indicated that energy requirements change when temperature deviated from 20ºC. For cattle living under western Canadian environmental condition it is expected to be much lower than the 20ºC due to the physiological changes that these animal would have gone through (Young, 1975). This explains why modeling under actual environmental conditions increased the over prediction of NE_m compared to thermoneutral conditions (Table 4.3). A second potential reason is that the base equation used to predict NE_m may itself be inappropriate for cattle under western Canadian environmental conditions. This equation is based primarily on cattle that are of British breeds and medium framed (Garrett, 1979). Beef booster cattle are composed of both medium and large frame genetics from British and continental breeds. This may have changed energy requirements as well as growth characteristics. There are a number of factors that affect the energy requirements of cattle. These include weight, stage of growth, and breed type (Fox et al., 1988). All these have changed (higher weight at finish, different frame size and different growth characteristics) compared to the cattle used in the development of the base equation.

An over prediction of NE_m will theoretically result in an under prediction of NE_g. This is because energy left from NE_m requirements will be used for gain. The accuracy and precision of NE_g will directly influence SWG. Table 4.3 indicates that NE_g was under predicted. Under prediction of NE_g (Table 4.3) explains the under prediction of SWG observed in chapter 3. Net energy of gain is a variable that is used to predict SWG. The under prediction of SWG agrees with the studies of Block et al., (2001), Beauchemin and Koenig (2005) and Koenig and Beauchemin, (2005) who identified that ADG was under predicted under barley based finishing programs in western Canada. In all these studies, under prediction of gain would be due to the under prediction of NE_g as observed in this study. This is because NE_g and EQSBW are the only two variables used in calculating gain. These studies would have used similar EQSBW and only predicted NE_g would have changed. Prediction of NE_g would change between studies due to different DMI, NE_m, NE_{ma} and NE_{ga} values. Reasons for the inaccurate prediction of NE_g could also be due to the model's inability to accurately estimate changes in body composition as an animal grows.

The magnitude of the difference between observed and predicted NE_g was similar to SWG (32% and 40%, respectively) indicating that majority of the error is due to NE_g prediction. This is because only two variables are used when predicting SWG; NE_g and EQSBW. Chapter three indicated that adjusting EQSBW did not result in significant improvement in SWG prediction. This indicates that improving the accuracy of the NE_g prediction will have a significant effect on the accuracy of SWG prediction. Net energy of gain is also impacted by the prediction of NE_m. In theory the degree of over prediction of NE_m will result in an equivalent under prediction of NE_g. According to Table 4.3 NE_m was over predicted at a higher level than NE_g was under predicted. This indicates that NE_m did reduce the accuracy of NE_g but because of a significant difference between NE_m and NE_g another factor also played a role in the accuracy of NE_g. Block et al., (2001) proposed that the prediction of NE_g does not accurately portray changes in body composition as an animal grows. No study has yet assessed the model's ability to predict NE_g changes as days on feed increase for growing cattle.

Determining the ME content of the feed and then converting it to NE_{ma} and NE_{ga} using the proposed NRC (2000) beef model equations can also impact the accuracy of determining actual NE_m and NE_g. Both ME and NE_{ma} are required to calculate the k_m and k_g values**.** It is presumed that the NRC (2000) beef model accurately and precisely converts DE to ME and then to NE_{ma} and NE_{ga}**.** McMeniman et al., (2009) indicated that conversion of TDN to NE_{ma} may not be precise or accurate, therefore impacting the accuracy and precision of k_m and k_g value. In this experiment it was necessary to convert ME to NE_{ma} and NE_{ga}. The NE_{ma} is needed when predicting DMI and NE_{ga} is needed when predicting NE_g and thus inaccuracies in either will impact the prediction of DMI and SWG. The NRC (2000) beef model was used to do these conversions. These equations were not evaluated in this study and thus they themselves could be inaccurate and thus reducing the accuracy of determining actual NE_m and NE_g.

4.7 CONCLUSION

Regression of actual versus predicted NE_m and NE_g under both actual and thermoneutral conditions was not significant indicating there was no relationship between observed and predicted. Mean comparison indicated that NE_m was over predicted and NE_g was under predicted. Possible reasons for this include the inability to accurately model environmental impact on NE_m or for NE_g, inability to estimate changes in body composition. Net energy of gain is also under predicted when the gain method was used indicating issues with composition of gain.

5.0. EVALUATING BODY CONDITION SCORE (BCS) AND ULTRASOUND SUBCUTANEOUS FAT THICKNESS (USF) AS A MEASURE OF TOTAL BODY FAT FOR USE IN THE NRC (2000) BEEF MODEL

5.1 INTRODUCTION

Determination of body composition without slaughtering the animal has been an important research objective. This is because slaughtering an animal is a destructive and costly process and thus one must continually purchase new animals to test new feeding methods, genetics as well as management practices. Body condition score (BCS) measured by palpation is a subjective measurement of total body fat in cattle while ultrasound subcutaneous fat thickness (USF) is an objective measurement of subcutaneous fat thickness (Broring et al., 2003). These two methods can be used to assess body fat reserves in cattle and provide an estimate of stored energy that can be used for maintenance or productive functions. Body condition scoring is used due to its low cost while the objective ultrasound technique requires both training and specialized equipment and thus is more costly (Broring et al., 2003).

The NRC (2000) beef model uses BCS as an adjuster of previous plane of nutrition (COMP) for the predicting NE_m requirements. Other adjustments include internal and external tissue insulation value (TI, °C/Mcal/m^2/day). For mature cows, a set of four equations were developed to calculate energy and protein reserves at a given BCS. No such equations have been published to assess body composition for growing cattle using BCS or USF.

If the set of four equations used to calculate body reserves in mature cows are accurate and precise for growing steers then these equations could be incorporated into the calculation for dry matter intake (DMI) and gain (SWG) of the NRC (2000) beef model. The NRC (2000) beef model assumes that BCS has a strong relationship to total body fat. In addition, if it was identified that if both BCS and USF are accurate at predicting body composition than it can be used to improve the NRC (2000) beef model or incorporate both into the model and as well as a tool in collecting appropriate data.

The development and testing of ultrasound technology in the livestock industry has been done since the 1950's (Houghton and Turlington, 1992). Ultrasound subcutaneous fat thickness was identified as a good measurement of carcass subcutaneous fat thickness (Greiner et al., 2003). The correlation between the USF measurement between the 11th and 12th ribs and carcass subcutaneous fat thickness was high (r = 0.89) (Greiner et al., 2003). Houghton and Turlington (1992) indicated that for beef cattle, fat measurements using ultrasound had a correlation from 0.45 to 0.96. Such a large range in correlation indicated that accuracy and precision of the measurement can be related to aspects such as the operator, animal and the equipment. The drawbacks of ultrasound can include its high cost and its potential imprecision due to factors stated above. Ultrasound has however been reported to be acceptable in the use of finishing programs to ensure that the animal reaches a constant body fat (Houghton and Turlington, 1992). The use of ultrasound in predicting retail yield has been found promising but more work is needed to become viable option under commercial settings (Greiner et al., 2003).

Variation in BCS measurement has been documented between trained individuals (Houghton and Turlington, 1992). Ultrasound measurement of subcutaneous fat thickness was less subjective and it was hypothesized to be more accurate in predicting total body fat. The use of BCS to relate to carcass characteristics has been found to be significant for cows that have high BCS but not for those that have low BCS (Apple et al., 1999).

Broring et al., (2003) using cull cows indicated a positive but inconsistent relationship between BCS and USF. The coefficient of determination when BCS was regressed against USF ranged from as low as 0.14 to as high as 0.41 for beef cows under different stages of pregnancy (Broring et al., 2003). Ultrasound subcutaneous fat thickness was found to have a larger variation within a given BCS (Broring et al., 2003). To date no study has evaluated BCS versus USF as a predictor of total body fat for growing steers. For cows, equations have been developed to predict different body composition using mainly BCS and on rare occasions using USF (Bullock et al., 1991).

The objective of the current study were to compare body condition score (BCS) and ultrasound subcutaneous fat thickness (USF) as predictions of total body fat and to determine if the NRC (2000) beef model equations to predict body composition for mature cows based on BCS were applicable to steers.

5.2 MATERIALS AND METHODS

Data used for this investigation was published by Basarab et al., (2003). A total of 176 animals composed of five composite strains were fed a high grain barley finishing diet and then slaughtered after BCS and USF were measured. Three animals per year from each composite breed were randomly selected for slaughter after being on feed for a period of 1, 71, 99, 127, 155 and 183 days.

Following slaughter, body fat was determined by petroleum ether extraction of the ground carcass and the non-carcass body parts. Body protein was determined by total N-content using the Leco apparatus. Body water was determined by drying at 105°C for a period of 24 hour. Body ash was determined by difference.

Individual steers were measured for BCS using the one to five scoring system as described by Lowman et al., (1976). Ultrasound measurements were taken using Aloka 500V diagnostic real time ultrasound with a 17 cm 3.5 MHz linear array transducer using the procedure described by Brethour (1992). Body condition score was also used to calculate body composition using the NRC (2000) beef model equations for cows. Body condition score was converted to the one to nine system and then body composition was calculated using the equations 5.1 to 5.4.

$$Proportion\ of empty\ body\ fat\ =\ 0.037683\ *BCS \tag{5.1}$$

$$Proportion\ of empty\ body\ protein\ =\ 0.200886 - 0.0066762\ *BCS \tag{5.2}$$

$$Proportion\ of empty\ body\ water\ =\ 0.766637 - 0.034506\ *BCS \tag{5.3}$$

$$Proportion\ of empty\ body\ ash\ =\ 0.078982 - 0.00438\ *BCS \tag{5.4}$$

5.2.1 STATISTICAL ANALYSIS

Body condition score (1-5) was compared to USF (units in mm) in relation to total percent body fat based on empty body weight using the regression procedure of SAS 9.2©. The independent variable was either USF or BCS while the dependent variable was percent total body fat based on empty body weight.

The statistical approach used in chapter three was performed to compare predicted body composition using the NRC (2000) beef model to the actual values. The statistical analysis performed included, regression, comparing the regression line to the isopleth (Intercept of 0, slope of 1), residual analysis, mean comparison partitioning of mean square error (MSE) into mean (MC), slope (SC) and residual components (RC), concordance correlation coefficient (CCC) and the reliability index (RI).

5.3 RESULTS AND DISCUSSION

5.3.1 COMPARISON OF BODY CONDITION SCORE (BCS) TO ULTRASOUND SUBCUTANEOUS FAT THICKNESS (USF) FOR PREDICTING TOTAL BODY FAT

Animals were serially slaughtered over a range of 0 to 183 days. This resulted in a range of carcass fat levels at slaughter. The level of percent total body fat increased from 17% at day zero and plateaus at 30% at day 155 (Appendix B: Table A.1). In contrast, total body protein content goes from 18% at day 0 to 16% at day 183 (Appendix B: Table A.1). These values are based on empty body weight (EBW) and represents values with moisture in. Owens et al., (1993) and Batt (1980) described changes in the deposition of fat and protein according to the sigmoidal growth curve where fat deposition increased as observed between day one and 71 and then plateaus. Based on the increase in total body fat over the feeding period, it would be expected that BCS and USF would increase as days on feed increased. Both BCS and USF increased as the days of feed increased prior to slaughter (Table A.3). A significant linear relationship ($P<0.01$) was observed for both BCS and USF in relation to percent total body fat (Figure 5.1 Table A.1, and Table A.2). The S_{y*x} was 0.04 for both BCS and USF indicating that precision was similar between the two measurements. The adjusted r^2 was similar for the regression of BCS and USF (0.57 and 0.56, respectively) to percent total body fat. The similarity indicates that both variables explain a similar degree of variation in total body fat. Broring et al. (2003) found that fat reserves were positively related to ultrasound measurements which were similar to the findings in this study.

From the regression analysis it can be concluded that both USF and BCS were equal in strength in predicting percent body fat and both can be used by the NRC (2000) beef model. Reasons why both had a moderate adjusted r^2 can include that the correlation of ultrasound and BCS to total body fat is impacted by factors not related to total body fat. Factors can include breed composition (dairy versus beef breeds) and age of an animal (older animals generally will gain fat but no skeletal growth while growing animals will gain both protein and fat at different degree).

It's been reported that low BCS (<3 out of 5) can impact the relationship of BCS to total body fat. Decreases in internal body fat deposition can for example result in an overestimation of total body fat when using BCS (Miller et al., 2004). The same will be expected when using USF as an estimator of total body fat. Perkins et al., (1992) indicates that USF accuracy declines on extreme subcutaneous fat thickness which would be observed in animals that have been fed for a period of 155 and 183 days. The reason why this happens was because both BCS and USF measure external body fat. If the relation between internal and external body fat changes then either over or under estimation of total body fat will occur and if the detector (USF) becomes incapable of estimating accurately the region it is measuring, it will reduce overall accuracy when attempting to predict total body fat. The steers used for this study (Figure 5. 1) had a BCS that were as low as 1.5 to as high as 4.5 and thus issues with low BCS could result in the observed adjusted r^2.

However, Herring et al., (1994) stated that a potential reason why a moderate correlation was observed between USF and carcass subcutaneous fat thickness was due to removal of hide and some of the subcutaneous fat at slaughter. It can also be due to differences in fat deposition between animals. Wright and Russell (1984) indicated that differences in animal breed composition resulted in differences in rate of fat deposition. Bergen et al., (1997) mentioned that there was high repeatability in USF within breeds with r^2 similar to those identified in this study.

Other potential reasons can be due to bias related to the technicians involved in assessing the animals. Studies with sheep have identified a relationship between technicians in measuring BCS where repeatability within technicians was 90% while between technicians was 80% (Teixera et al., 1989). Correlation coefficients for technician repeatability ranged from 0.69-0.90 while those for accuracy of technician and machine were similar (Herring et al., 1994). Overall both BCS and USF have similar ability in predicting total body fat.

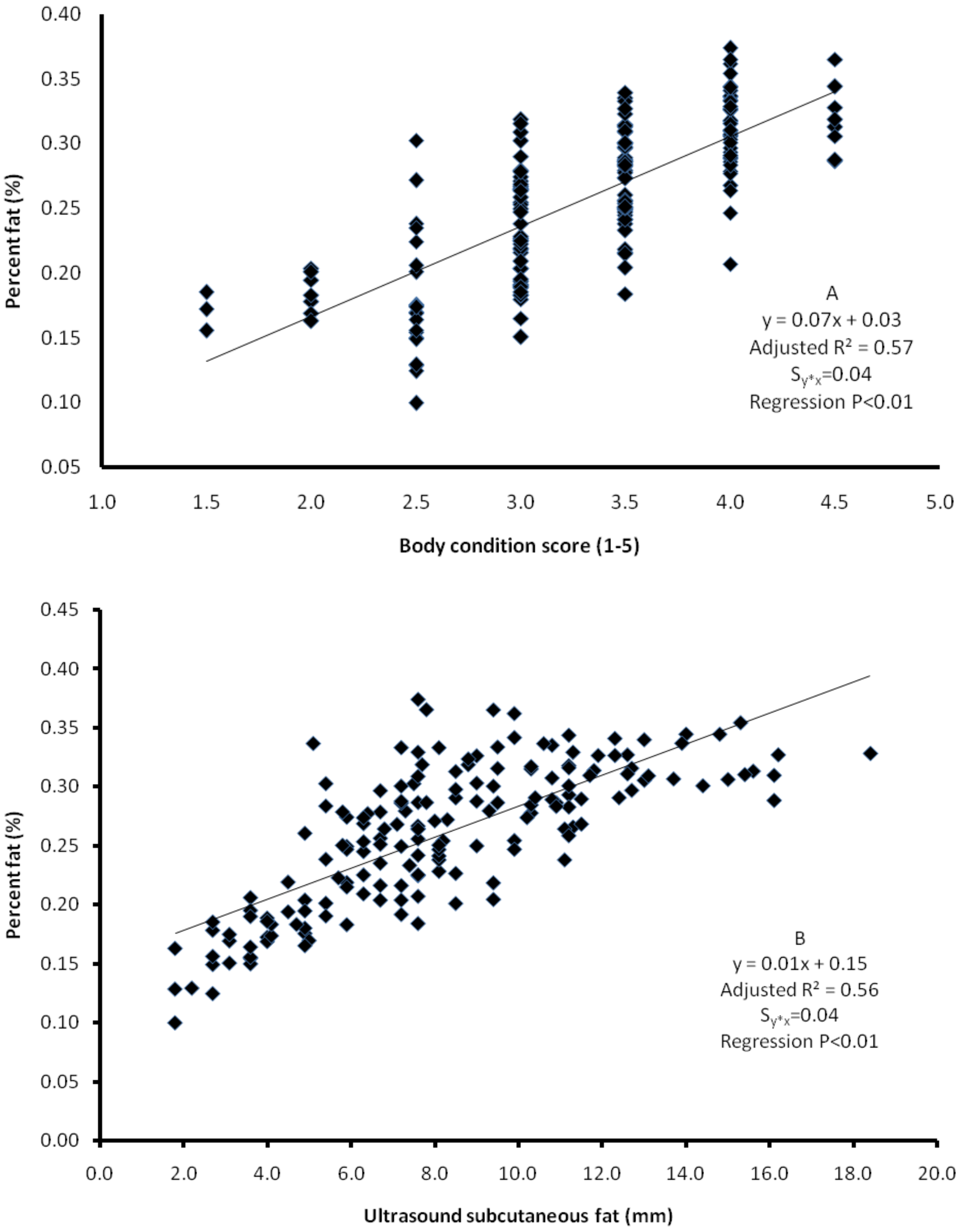

Figure 5.1: Regression of body condition score (1-5; A) and ultrasound subcutaneous fat thickness (mm; B) versus percent total body fat. Total percent fat was represented on the y-axis while body condition score (A) or ultrasound subcutaneous fat thickness (B) was represented on the x-axis. Regression line represents the solid line. S_{y*x} represents MSE.

5.3.2 DETERMINING THE ACCURACY OF THE NRC (2000) BEEF MODEL EQUATIONS IN PREDICTING BODY COMPOSITION.

For mature cows, BCS and total body fat was influenced by animal productivity, health as well as reproduction (Gentry and Del-Vecchio, 2004). For steers only health and productivity are indicative of BCS. The equations used to determine body composition for mature cows using BCS were found to be moderately applicable for steers in predicting percent body fat and water but less when predicting ash and protein. It was identified that there was a significant ($P<0.05$) difference between observed and predicted values for total body fat, protein, ash and water (Table 5.1). Total body fat, (26% versus 21%) and protein (17% versus 16%) were under predicted while ash (4% versus 5%) and water (53% versus 57%) were over predicted. Regression for predicted versus observed (Figure 5.2) for total body water, ash, protein and fat were significant ($P<0.05$). Total body water and fat were predicted with an adjusted r^2 of 0.57. Respective values for ash and protein were 0.28 or 0.15.

Previous studies have indicated that there was a linear relationship between actual muscles to bone ratio to BCS (Apple et al., 1999). Such findings indicate that the use of BCS can be used to predict muscle or ash but the results of the current work show that in growing steers, BCS is not a precise predictor of ash due to the low adjusted r^2 (Figure 5.1).

Concordance correlation coefficient analysis varied from as low as 0.19 for percent ash to as high as 0.57 for percent fat (Table 5.2). The CCC identified that overall agreement was at best only moderate. Partitioning of CCC identified that accuracy and precision was moderate to strong for both water and fat while for ash it was identified to be moderate to weak for both precision and accuracy. Prediction of protein had a strong accuracy but poor precision. The poor precision observed for predicting percent protein could be due to a larger diversity between animals for percent protein for every given BCS than what the NRC (2000) beef model predicted. The poor precision observed for predicting percent protein could be due to a larger diversity between animals for percent protein for every given BCS than what the NRC (2000) beef model predicted and due to the observed low overall range in percent protein (only 14 to 20%).

Partitioning of mean square error into its distinctive error components found that majority of the error was due to bias and thus the model was either over or under predicting (Table 5.3).

The exception to this was for prediction of percent protein in which error was distributed between bias and slope component.

The data in Figure 5.2, Table 5.1 and Table 5.2 indicate that BCS can be used to predict body composition of growing steers but these predictions have accuracy and precision concerns. Previous studies conducted on cows identified that BCS was not affected by changes in skeletal size or protein level (Apple et al., 1999).

This finding was contrary to the current study which showed that BCS had a low adjusted r^2 for protein and ash predictions indicating that it was potentially affected by changes in muscle and skeletal growth. This difference can only be explained by differences in growth characteristics between steers and mature cows. Mature cows do not have a change in their overall skeletal size (i.e ash mass was expected to stay the same according to the NRC (2000) beef model) but percent fat will change (NRC, 2000). This was unlike steers where all components parts will change as the animal grows (NRC, 2000). Such studies indicate why BCS can be used for cows to predict body composition but cannot be for steers. In order to predict body composition of growing steers new equations are needed to be developed to take into account animal growth.

For mature cows, total protein does change but energy retained within the carcass will change as the weight of the animal changes (Schake and Riggs, 1973). A cow’s weight will change according to changes in productivity (lactation, stage of pregnancy, environment) as well as the type and amount of feed provided (Schake and Riggs, 1972). The four equations used by the NRC (2000) beef model to predict body composition of mature cows do not take into consideration growth characteristics of steers and thus future modification of these equations will have to ensure that changes in bone, protein and fat mass were accounted for as the animal grows.

It should also be recognized that these equations were developed for cows and not for steers. Studies on steers have shown that carcass composition changes throughout the age of an animal (Barber et al., 1981 and Kock et al., 1982). These changes in body composition were unlikely to be explained accurately and precisely using a linear based equation if we are predicting growth over time but it could be not true if we are merely predicting composition in relation to factors such as USF and thus a non linear based equation may have to be developed. The last potential reason that can explain the accuracy and precision issues was that this system does not take into account the weight of the animal, frame size, hip height and diet characteristics. Body condition score is a subjective measurement and studies on mature cows have identified that the use of BCS and the use of objective measurements such as body weight are useful tools in predicting body composition (Houghton et al., 1990). Incorporating BCS with an objective measurement may improve the ability to predict body composition for the growing steers.

Table 5.1: Predicted versus observed values for percent body water, fat, protein and ash based on the NRC (2000) beef model cow equations for body composition for all 176 steers.

Variable	Observed	Predicted	P-value
Water (Percent/100)	53 ± 0.3	57 ± 0.3	<0.01
Fat (Percent/100)	26 ± 0.4	21 ± 0.4	<0.01
Protein (Percent/100)	17 ± 0.1	16 ± 0.1	<0.01
Ash (Percent/100)	4 ± <0.1	5 ± <0.1	<0.01

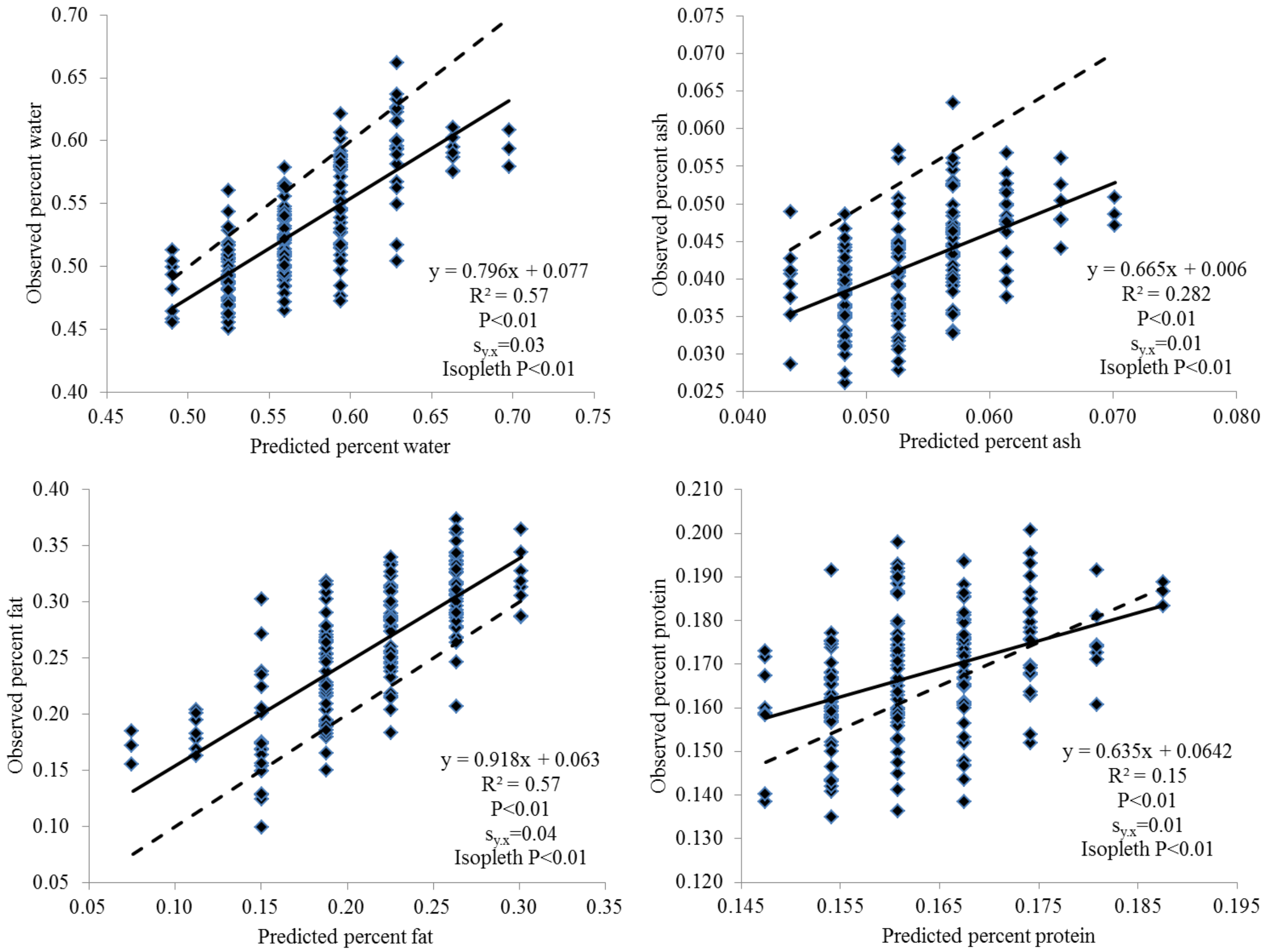

Figure 5.2: Predicted body composition using the NRC (2000) beef model equations versus actual percent body water (A), Ash (B), Fat (C) and protein (D). Dashed line represents the isopleth (Intercept of zero and slope of 1) while the solid line represents the regression line. S_{y*x} represents MSE.

Table 5.2: Concordance correlation coefficient, partitioning of mean square error (MSE) and reliability index (RI) for body composition of growing steers (Actual versus Predicted) using NRC (2000) mature cow equations

		Percent water	Percent fat	Percent protein	Percent ash
CCC analysis	CCC[Z]	0.55	0.57	0.33	0.19
	Precision	0.76	0.76	0.40	0.54
	Accuracy	0.73	0.73	0.84	0.36
MSE partitioning	MC[Y]	0.61	0.57	0.11	0.78
	SC[X]	0.03	0.004	0.05	0.02
	RC [W]	0.36	0.42	0.84	0.20
	RI[V]	1.04	1.12	1.03	1.12

[Z] CCC=Concordance correlation coefficient

[Y] MC=Mean component (bias)

[X] SC=Slope component

[W] RC=Residual component

[V] RI=Reliability index

5.4 CONCLUSION

When comparing BCS or USF to total body fat using regression analysis, a similar adjusted r^2 value was observed. This indicates comparable ability for predicting total body fat. The non-subjective nature of USF will be a better choice when more than one operator is expected to take measurements as it reduces bias between individuals. The use of BCS to predict body composition using NRC (2000) beef model equations had a moderate to low accuracy and precision for predicting body composition but there was a significant regression indicating that these equations can be used with appropriate adjustment to become applicable for steers. Incorporation of parameters such as weight, breed, hip height and feeding conditions could improve the overall equation accuracy and precision. Any parameter incorporated into these equations should be non-subjective and easily obtainable. It can be observed that because BCS is easily obtainable and is just as accurate as USF and thus can be used to determine total body fat without the needs to do slaughter animals.

6.0. GENERAL DISCUSSION

It was hypothesized that the NRC (2000) beef model prediction of DMI and SWG of finishing cattle will be inaccurate due to over prediction of NE_m and under prediction of NE_g requirements of cattle fed under western Canada environmental conditions. All predictions were conducted under actual environmental and thermoneutral (20ºC and no wind) conditions to determine if the adjustments for the impact of the environment used by the NRC (2000) beef model are suitable for western Canadian environmental conditions.

To investigate these hypothesis four major objectives were established for the research undertaken in this study. The first was to determine the accuracy and precision of the NRC (2000) beef model under actual environmental and thermoneutral conditions for predicting dry matter intake (DMI) and gain (SWG) of individually fed steers. The second was to evaluate the accuracy and precision of the NRC (2000) beef model for predicting net energy of maintenance (NE_m) and gain (NE_g) requirements of growing cattle under actual environmental conditions. The third was to determine if ultrasound subcutaneous fat thickness (USF) is a better predictor of total body fat than BCS and the fourth objective was to determine the accuracy of the NRC (2000) beef model equations based on BCS for mature cows for predicting body composition of growing steers.

As was observed in chapter three and chapter four, modeling under actual environmental and then thermoneutral conditions with some improvement observed, but not enough to make predictions accurate and precise meaning more needs to be done. This indicates that adjustments related to actual environmental conditions were not the only factors responsible for the observed inaccuracy and imprecision. In addition, it was identified that both BCS and USF explain a similar amount of variation (i.e: 56% versus 57%) in total body fat and that BCS and USF can be used to determine body composition of growing steers. The regression equations that used BCS to determine body composition in mature cows were found to have a significant regression ($P<0.05$) that differed from the isopleth ($P<0.05$) indicating they were inaccurate for growing steers and had a CCC value that were either close to zero or close to 0.5 indicating that the predictions are either imprecise, inaccurate or both. Thus modification of such equations will be required. The establishment of such equations for growing steers will allow the examination of changes in body composition of an animal throughout its growth period without the need to do comparative slaughter trials.

According to the results of chapter 5, BCS can be used to calculate body composition and thus can be used to calculate previous plane of nutrition as both are related. The findings in chapter five indicate that BCS is as strongly correlated to body fat as USF and thus the NRC (2000) beef model use of BCS, is acceptable. The adjustment for previous plane of nutrition in the NRC (2000) beef model is calculated using a regression equation that contains BCS as a variable. The calculation of previous plane of nutrition is used as an adjustment for NE_m. This could impact the accuracy of NE_m prediction. The calculation of previous plane of nutrition is necessary to determine if an animal was either feed restricted or over fed, as both will impact NE_m and NE_g (Patterson et al., 1995). It must be indicated that animals with higher mature weight are likely to require more NE_m (Owens et al., 1993) due to factors such as larger organ size, thinner hide, and larger surface area. The larger the animal the higher the NE_m required but less per kg of body weight. The surface area is used in the NRC (2000) beef model when calculating LCT, but there are no adjustments for different beef breeds only adjustments for dairy or dual purpose breeds.

As indicated, the prediction of NE_m, NE_g, and DMI were inaccurate and imprecise. Net energy of maintenance was over predicted under both actual environmental and thermoneutral conditions. Thermoneutral modeling reduced the magnitude of over prediction by 21% but did not remove all of the error. This indicates that in addition to adjustments for actual environmental conditions another aspect of the model such as the base equation ($0.077*\text{body weight}^{0.75}$) is likely impacting its ability to predict NE_m. This base equation may be leading to the inaccurate prediction of NE_m under western Canadian environmental conditions. This equation was developed based on the comparative slaughter technique using medium framed British cattle (Garrett, 1979). Today's cattle are composed of both medium and large framed cattle of British and Continental breeding and thus their size and the rate of protein and fat deposition will impact NE_m and NE_g, respectively.

For NE_g prediction, when comparing the intake method under actual environmental conditions to that observed with the gain method, the model under predicted NE_g requirements with both methods. This explains why SWG was under predicted (chapter 3). Modeling the intake method under thermoneutral conditions removed a major portion of the error as mean comparison indicated that observed versus predicted NE_g requirements were not significantly different (P>0.05). This indicates that using actual environmental conditions reduced the accuracy of the model. This was because under thermoneutral conditions there was a reduction in NE_m requirements and thus more energy available for gain. Another reason for the inaccuracy in NE_g prediction could be the inability of the NRC (2000) beef model to accurately reflect changes in body composition thus impacting NE_g retained.

For NE_g it has been shown that after a period prior to entering the finishing phase there is an initial increase in protein gain while later on there is an increase in the level of fat gain (Fox et al., 1972). Oltjen et al., (2000) indicated that protein production has a theoretical maximum. The issue is does the NRC (2000) beef model accurately portray this. When examining the results of chapter 4, it was identified that NE_g prediction was both inaccurate and imprecise and when looking at regression it was identified that the relationship between predicted and observed was not significant indicating that the equation requires modification as it does not portray changes in NE_g for the data set investigated.

Another potential reason why the model inaccurately predicted NE_g was that the adjustments proposed by the NRC (2000) beef model for mature size by calculating EQSBW is not applicable to current cattle. The findings in chapter three indicate otherwise. It was identified that changing the method of calculating SRW or FSBW did not have a profound impact on the model's ability to predict gain.

When removing actual environmental conditions and applying thermoneutral conditions, adjusted r^2 changes were minor for DMI and SWG while the regression between actual and predicted was not significant for NE_m and NE_g. There are two conclusions that can be drawn from these results. The first was that changes are needed in the equations that model the effects of cold stress and for acclimatization to improve the model's ability to predict. The second is that adjustment for the effect of environment is not the only culprit in affecting model accuracy and precision, as all statistical tests with or without such adjustments indicated that the model is inaccurate and imprecise.

It must be indicated that there was under prediction of NE_g as well as SWG. The magnitude difference between observed and predicted values for NE_g and SWG (32% and 40%, respectively) was similar. This is expected as NE_g in the regression equation was related directly to SWG. As indicated previously, the NRC (2000) beef model uses NE_m to predict NE_g. In theory an over prediction of NE_m will result in the same percentage of under prediction for NE_g. According to Table 4.3, this was not the case. This indicates that NE_m was not the only factor impacting the predictability of NE_g. There are a few factors not examined that could impact the accuracy of NE_g predictability. McMeniman et al., (2009) indicated that converting ME to NE_{ma} and NE_{ga} may not be accurate. Future work is required to assess this premise. Another reason why the NRC (2000) beef model was inaccurate and imprecise can be its inability to accurately account for changes in body composition as an animal grows under western Canadian environmental conditions, thus impacting NE_g prediction and SWG prediction. Shrunk weight gain was also affected by NE_m prediction.

According to the studies discussed above the NRC (2000) beef model inaccurately predicted SWG and DMI of growing cattle under western Canadian environmental conditions. It was further identified that modeling under actual environmental conditions reduced the models ability to predict both parameters. Prediction of SWG was also affected by the observed inaccurate prediction of NE_m and NE_g. The inaccuracy and imprecision was found to be higher under environmental than thermoneutral conditions. This indicates that under western Canadian environmental conditions the model inaccurately determined net energy requirements for both maintenance and gain.

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A.0APPENDIX: DATA FOR BODY COMPOSITION

Table A.1: Averages (± SE) for initial weight, final weight, percent fat, percent protein, percent ash and percent water for each group of animals and for all the animals.

Days on feed	Weight (kg)		Empty body weight composition			
	Initial weight	Final weight	Percent			
			H_2O	FAT	PROTEIN	ASH
1	320 ± 8.4	320 ± 8.4	60.27 ± 0.004	16.52 ± 0.005	18.23 ± 0.002	4.98 ± 0.001
71	345 ± 8.1	450 ± 9.8	56.71 ± 0.005	22.41 ± 0.006	16.58 ± 0.003	4.29 ± 0.001
99	345 ± 7.4	501 ± 10.5	52.11 ± 0.005	26.28 ± 0.007	17.38 ± 0.002	4.24 ± 0.001
127	335 ± 8.2	529 ± 11.5	51.16 ± 0.005	28.37 ± 0.007	16.39 ± 0.002	4.08 ± 0.002
155	330 ± 5.7	563 ± 9.4	49.51 ± 0.004	30.75 ± 0.005	15.97 ± 0.002	3.77 ± 0.001
183	326 ± 11.3	585 ± 17.5	49.18 ± 0.006	30.28 ± 0.008	16.33 ± 0.002	4.21 ± 0.001
Overall[Z]	338 ± 3.2	492 ± 7.7	53.09 ± 0.004	25.93 ± 0.005	16.77 ± 0.001	4.22 ± 0.001

[Z] Overall=176 animals

Table A.2: Average (± SE) for initial body condition score, initial hip height, initial ultrasound subcutaneous fat thickness, and initial ultrasound rib eye area and initial ultrasound marbling.

Days on feed	BCS[Z]	HH[Y]	USF[X]	UREA[W]	UMAR[V]
1	2.38 ± 0.084	115.91 ± 1.039	3.69 ± 0.261	58.16 ± 1.392	4.34 ± 0.108
71	2.48 ± 0.080	118.43 ± 0.903	4.01 ± 0.224	64.82 ± 1.251	4.16 ± 0.090
99	2.40 ± 0.076	117.91 ± 0.860	4.00 ± 0.211	60.71 ± 1.301	4.42 ± 0.095
127	2.45 ± 0.094	117.55 ± 0.882	4.05 ± 0.246	60.09 ± 1.270	4.30 ± 0.096
155	2.51 ± 0.056	117.92 ± 0.649	3.73 ± 0.173	59.56 ± 1.670	4.42 ± 0.070
183	2.23 ± 0.118	116.57 ± 1.646	4.10 ± 0.418	57.38 ± 1.632	4.06 ± 0.116
Overall[U]	2.43 ± 0.032	117.51 ± 0.373	3.90 ± 0.096	60.27 ± 0.641	4.31 ± 0.039

BCS[Z] = Body condition score

HH[Y] = Hip Height

USF[X]= Ultrasound subcutaneous fat thickness

UREA[W] = Ultrasound rib eye area

UMAR[V] = Ultrasound marbling

Overall[U] = 176 animals

Table A.3: Average (± SE) for final body condition score, initial hip height, initial ultrasound subcutaneous fat thickness, and initial ultrasound rib eye area and initial ultrasound marbling

Days on feed	BCS^{Z}	HH^{Y} (cm)	USF^{X} (mm)	UREA^{W} (cm^{2})	UMAR^{V}
1	2.38 ± 0.083	115.91 ± 1.039	3.69 ± 0.261	58.15 ± 1.393	4.34 ± 0.108
71	2.99 ± 0.068	124.81 ± 0.960	6.68 ± 0.359	80.43 ± 1.611	4.83 ± 0.089
99	3.21 ± 0.068	126.19 ± 1.028	7.75 ± 0.343	84.25 ± 1.164	5.06 ± 0.120
127	3.57 ± 0.071	126.60 ± 0.981	8.53+0.399	86.01 ± 1.048	4.94 ± 0.114
155	3.86 ± 0.047	130.08 ± 0.763	10.63+0.437	86.08 ± 1.216	5.39 ± 0.086
183	4.07 ± 0.083	116.57 ± 1.701	12.14+0.788	94.96 ± 2.606	6.08 ± 0.187
Overall^{U}	3.34 ± 0.049	125.58 ± 0.532	8.17 ± 0.257	81.15 ± 0.983	5.06 ± 0.056

BCS^{Z} = Body condition score

HH^{Y} = Hip Height

USF^{X}= Ultrasound subcutaneous fat thickness

UREA^{W} = Ultrasound rib eye area

UMAR^{V} = Ultrasound marbling

Overall^{U} = 176 animals

B.0 APPENDIX: AVERAGE AND STANDARD DEVIATION FOR NET ENERGY (NE) AND STATISTICAL ANALYSIS.

Table B.1: Actual versus predicted means (±SD) for net energy of maintenance (NE_m; Mcal/day) and net energy of gain (NE_g ; Mcal/day) for finishing steers.

Days on feed	Actual (Mcal/day)		Predicted (Mcal/day)				
	NE_m[Z]	NE_g[Y]	Thermoneutral		Environmental		Predicted NE_g using gain method
			NE_m	NE_g	NE_m	NE_g	
71	8.27+0.47	6.62+0.22.	6.91+0.12	5.99+0.19	8.08+0.14	4.10+0.14	6.23+0.15
99	5.59+0.34	6.17+0.19	7.40+0.14	6.46+0.17	8.76+0.17	4.30+0.12	6.05+0.14
127	5.33+0.25	6.00+0.25	7.62+0.14	6.21+0.18	8.90+0.17	4.15+0.12	5.53+0.13
155	5.11+0.21	5.61+0.24	7.96+0.10	6.49+0.17	9.39+0.13	4.16+0.11	5.29+0.11
183	6.33+0.39	6.87+0.28	8.09+0.19	6.17+0.24	9.31+0.22	4.19+0.21	4.89+0.14
Overall[Z]	5.99+0.17	6.12+0.12	7.59+0.06	6.30+0.09	8.90+0.08	4.18+0.06	5.63+0.07

[Z] NE_m=Net energy of maintenance

[Y] NE_g=Net energy of gain

Table B.2: Comparing actual versus predicted net energy of maintenance (NE_m) using concordance correlation coefficient (CCC) and reliability index (RI) used by growing steers under thermoneutral and environmental conditions over the entire feeding period (all cattle included)

		Environmental (NE_m^Z)	Thermoneutral (NE_m)
CCC partitioning	CCC[V]	-0.03	-0.02
	Precision	-0.09	-0.04
	Accuracy	0.28	0.43
Reliability index		1.29	1.26

[V] CCC: Concordance correlation coefficient

Table B.3: Comparing actual versus predicted net energy of gain (NE_g; intake method) used by growing steers under thermoneutral and environmental conditions over the entire feeding period (all cattle included) and comparing actual versus predicted NE_g using the gain method.

		Environmental (NE_g[Z])	Thermoneutral (NE_g)	NE_g (Gain)
CCC partitioning	CCC[Y]	0.07	0.03	0.12
	Precision	0.69	0.85	0.15
	Accuracy	0.11	0.04	0.81
	RI[X]	1.16	1.23	1.14

[Z] NE_g: Net energy of gain

[Y] CCC: Concordance correlation coefficient

[X] RI: Reliability index

C.0APPENDIX: ENVIRONMENT

Table C.1: Ambient temperatures identified for minimum, maximum and average for both current and previous temperature by year of study and days on feed.

Days on feed	Year	Current temperature ^{Y}			Previous temperature^{Z}		
		Minimum	Maximum	Average	Minimum^{V}	Maximum^{W}	Average^{X}
71	Year 1 ^{U}	-16.0	-2.9	-9.5	-3.3	9.9	3.4
71	Year 2 ^{T}	-12.5	0.3	-6.1	-6.2	7.1	0.4
99	Year 1	-12.9	-0.2	-6.6	-7.1	5.9	-0.6
99	Year 2	-10.4	2.9	-3.8	-6.2	7.1	0.4
127	Year 1	-9.9	3.1	-3.4	-3.3	9.9	3.4
127	Year 2	-8.0	6.1	-1.0	-6.2	7.1	-0.4
155	Year 1	-7.4	5.5	-0.9	-3.2	10.0	3.4
155	Year 2	-5.3	8.5	1.6	-6.2	7.1	0.4
155	Year 2	-1.4	12.6	5.7	-9.5	3.6	-2.9
183	Year 1	-5.1	7.9	1.4	-3.2	10.0	3.4

Previous temperature ^{Z}: Average temperature prior to feeding for a period of five months.

Current temperature ^{Y}: Average temperature for the feeding period

Average^{X}: Average temperature used for calculating ambient average temperature

Maximum^{W}: Maximum temperature used to calculate ambient average temperature

Minimum^{V}: Minimum temperature used to calculate ambient minimum temperature

Year 1^{U}: First year of study

Year 2^{T}: Second year of study

D.0APPENDIX: METHOD

D. 1: NRC (2000) BEEF MODEL CALCULATIONS

D. 1.1: FEED EVALUATION

Feed digestibility was evaluated using six Suffolk sheep in a metabolic trial. The DE values obtained from the sheep digestibility trial were converted to ME and then NE_m available from feed and NE_g according to the following steps:

$$ME = DE \times 0.82 \tag{D.1}$$

$$NE_{ma} = 1.37\,ME - 0.138\,ME^2 + 0.0105\,ME^3 - 1.12 \tag{D.2}$$

$$NE_{ga} = 1.42ME - 0.174ME^2 + 0.0122ME^3 - 1.65 \tag{D.3}$$

In equation D.1 ME represent metabolizable energy, while DE represents digestible energy. In equation D.2 NE_{ma} represents the net energy of maintenance provided by the diet. In equation D.3 NE_{ga} represents the net energy of gain provided by the diet.

D.1.2: PREDICTED DMI

Predicted DMI was calculated using the NRC (2000) model under actual environmental and thermoneutral conditions (20°C and no wind). Thermoneutral conditions were modeled in order to evaluate the accuracy of environmental modeling. Thermoneutral conditions were modeled in order to remove the environmental affect. The equation used by the NRC (2000) beef model in calculating DMI is as follow:

$$DMI = \left(\frac{(SBW^{0.75} \times (0.2435NE_{ma} - 0.0466NE_{ma}{}^{2} - 0.0869))}{NE_{ma}} \right) \times ((BFAF) \times (B1) \times (ADTV) \times (TEMP1) \times (MUD1)) \tag{D.4}$$

In equation D.4 “DMI stands for dry matter intake in kg/d, SBW is shrunk body weight in kg, NE_{ma} is net energy value of diet for maintenance in Mcal/kg, BI is breed adjustment factor for

DMI according to Table D.1. The body fat adjustment factor (BFAF) is given in Table D.1, ADTV is the feed additive adjustment factor for DMI according to Table D.1.The temperature adjustment factor (TEMP1) for DMI is given in Table D.1 and the model uses average temperature to define this parameter. The adjustment factor for mud depth (MUD1) on DMI is indicated in Table D.1”.

Table D.1: Adjustment factor values that are incorporated into the equation to predict dry matter intake (DMI) in the NRC (2000) beef model.

Adjustment factor	Multiplier	Adjustment factor	Multiplier
Breed (BI[Z])		Empty body fat effect (BFAF[W])	
Beef	1.00	21.3 (up to 350 kg EQW[V])	1.00
Holstein X Beef	1.04	23.8 (400 kg EQW)	0.97
Holstein	1.08	26.5 (450 kg EQW)	0.9
Implant (ADTV[Y])		29.0 (500 kg EQW)	0.82
Anabolic implant	1.00	31.5 (550 kg EQW)	0.73
No anabolic stimulant	0.94	Mud (MUD1[U])	
Temperature, °C (TEMPI[X])		None	1.00
>35, no night cooling	0.65	Mild (10-20 cm)	0.85
>35, with night cooling	0.90	Severe (30-60 cm)	0.70
25 to 35	0.90		
15 to 25	1.00		
5 to 15	1.03		
- 5 to 5	1.05		
- 1 5 to - 5	1.07		
< - 1 5	1.16		

[Z] BI: Breed adjustment factor

[Y] ADTV: Implant adjustment factor

[X] TEMP1: Temperature adjustment factor

[W] BFAF: Adjustment for final body fat

[V] EQW: Equivalent weight (kg)

[V] MUD1: Adjustment factor for mud depth

When predicting DMI under thermoneutral conditions, three different weights were examined, including initial, mid and final weight. The NRC (2000) beef model uses mid body weight for predicting DMI. This study examined initial as well as final weight impact to predict DMI. These weights were used to evaluate the impact on the accuracy and precision of predicting DMI.

D.1.3: PREDICTED SHRUNK WEIGHT GAIN (SWG).

Predicted SWG was calculated using the NRC (2000) beef model under actual environmental and thermoneutral conditions (20°C and no wind). In equation D.5, body weight (BW) of each animal was converted to shrunk body weight (SBW) using the following equation:

$$SBW = BW \times 0.96 \qquad \text{D.5}$$

The net energy of maintenance (NE_m) requirements was calculated using equation D.6:

$$\mathrm{NE_m} = (0.077 + \mathrm{a2})\ \mathrm{SBW}^{0.75}\ (\mathrm{Comp})(\mathrm{BE}) \qquad \text{D.6}$$

$$a2 = 0.0007\ (20 - Previoustemperature) \qquad \text{D.7}$$

$$Comp = 0.8 + 0.05\ (Body\ condition\ score - 1) \qquad \text{D.8}$$

Previous temperature was calculated by using the minimum, maximum or average temperature of the five month, and prior to the start of the feeding trial and used to calculate average ambient temperature. These will be compared to each other to identify which temperature provides the best accuracy and precision for predicting body weight gain. Feed required for maintenance (I_m) is then calculated by the following equations:

$$\mathrm{I_m} = \frac{\mathrm{NE_m}\,required}{\mathrm{NE_{ma}}} \qquad \text{D.9}$$

Retained energy (NE_g) was calculated according to the formula:

$$\mathrm{NE_g} = (DMI - I_m) \times \mathrm{NE_{ga}} \tag{D.10}$$

Equivalent Shrunk Body weight (EQSBW; kg) was calculated according to the formula:

$$EQSBW = \frac{(Shrunk\ body\ weight\ x\ Standard\ reference\ weight\ )}{Final\ shrunk\ body\ weight} \tag{D.11}$$

Shrunk weight gain (SWG) was than calculated according to the NRC (2000) beef model formula:

$$SWG\ =\ 13.91\ \times NE_g{}^{0.9116} \times EQSBW^{-0.6837} \tag{D.12}$$

D.1.4: ENVIRONMENTAL CALCULATION TO PREDICT NE$_M$ NEEDS UNDER ACTUAL ENVIRONMENTAL CONDITIONS.

Lower critical temperature (LCT) of an animal is calculated according to the following formula:

$$LCT = 39 – (IN * HE *\ 0.85) \tag{D.13}$$

$$IN = TI\ +\ EI \tag{D.14}$$

$$EI = (7.36 - 0.296 \times WIND + 2.25 \times HAIR) \times MUD2 \times HIDE \tag{D.15}$$

$$If EI < 0\ then EI = 0 \tag{D.16}$$

$$SA = 0.09 * Bodyweight^{-0.67} \tag{D.17}$$

$$HE = \frac{(MEI - NE_g)}{SA} \tag{D.18}$$

$$If LCT > T_c, then ME_{cs} = SA * \frac{LCT – T_c}{IN} otherwise, ME_{cs} = 0 \tag{D.19}$$

In equation D.13 to D.19 IN stands for total insulation in °C/Mcal/m^2/day, HE stands for heat production in Mcal/day, EI stands for external insulation value in °C/Mcal/m^2/day, Wind stands for wind speed in kilometers per hour (kph), HAIR stands for effective hair depth in centimeter (cm), MUD2 stands for mud adjustment factor for external insulation and its values are indicated in Table D.2. HIDE stands for hide adjustment factor for external insulation and its values are indicated in Table D.2. SA stands for surface area in m^2. ME_{cs} stands for metabolizable energy required for cold stress in Mcal/day. T_c stands for current temperature in °C TI stands for tissue internal insulation value in $°C/Mcal/m^2/day$ and it was calculated based on age of the animal, thus the formula will change depending on the age of the animal and the equations are as follow:

$$If\, t \leq 30 \; then\, TI = 2.5 \qquad \text{D.20}$$

$$If\, t > 30 \; and \leq 183 \; then \; TI = 6.5 \qquad \text{D.21}$$

$$If\, t > 183 \; and \leq 363 \; then\, TI = 5.1875 + (0.3125 \times CS) \qquad \text{D.22}$$

$$If\, t > 363 \; then \; TI = 5.25 + (0.75 \times CS) \qquad \text{D.23}$$

The amount of energy needed with the LCT adjustments will be calculated as indicated below:

$$NE_{mcs} \; = \; k_m * ME_{cs} \qquad \text{D.24}$$

$$NE_m total \; = \; NE_m \;\; + NE_{mcs} \; + NE_m NEmact \qquad \text{D.25}$$

$$k_m = \frac{NE_{ma}}{dietME} \qquad \text{D.26}$$

In equation D.24 to D.26 NE_{mcs} stands for as the net energy needed for maintenance under cold stress in Mcal/day, k_m is calculated according to equation D.24 to D.26. The NE_m total calculated in equation D.24 to D.26 was used when modeling under actual environmental conditions.

Table D.2: Categories and their description.

	Adjuster	Description
MUD2	Mud adjustment factor for external insulation;	
	1	Dry and clean
	2	Some mud on lower body
	3	Wet and matted
	4	Covered with wet snow or mud
HIDE	Hide adjustment factor for external insulation	
	1	Thin
	2	Average
	3	Thick