Spring 4-21-2014

Model development for the prediction of intake and carcass measures to be used as economic marketing determinants for calf-fed steers

Mallorie F. Wilken
University of Nebraska-Lincoln, mfwilken@gmail.com

Follow this and additional works at: http://digitalcommons.unl.edu/animalscidiss

Part of the Animal Sciences Commons

Wilken, Mallorie F., "Model development for the prediction of intake and carcass measures to be used as economic marketing determinants for calf-fed steers" (2014). Theses and Dissertations in Animal Science. 83.
http://digitalcommons.unl.edu/animalscidiss/83

This Article is brought to you for free and open access by the Animal Science Department at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Theses and Dissertations in Animal Science by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.
MODEL DEVELOPMENT FOR THE PREDICTION OF
INTAKE AND CARCASS MEASURES TO BE USED AS
ECONOMIC MARKETING DETERMINANTS
FOR CALF-FED STEERS

By

Mallorie F. Wilken

A DISSERTATION

Presented to the Faculty of
The Graduate College of the University of Nebraska
In Partial Fulfillment of Requirements
For the Degree of Doctorate of Philosophy

Major: Animal Science

Under the Supervision of Professors Larry L. Berger and Galen E. Erickson

Lincoln, Nebraska

May, 2014
MODEL DEVELOPMENT FOR THE PREDICTION OF
INTAKE AND CARCASS MEASURES TO BE USED AS
ECONOMIC MARKETING DETERMINANTS
FOR CALF-FED STEERS

Mallorie Faith Wilken, Ph.D.
University of Nebraska, 2014

Advisors: Larry L. Berger and Galen E. Erickson

Accurate prediction of intake and carcass characteristics can assist in projecting input costs and potential premiums when cattle are sold at optimum finishing so net profit/loss can be anticipated. Currently published DMI prediction equations and dietary NE values are based off of data collected over 50 years ago and have been shown to inaccurately predict intake compared to a prediction equation based off performance data. Calculating dietary NE values from performance data increased precision and accuracy of prediction. Additionally, prediction accuracy was increased for diets containing ethanol byproducts. Since ethanol byproducts have been shown to have 110 to 140% the feeding value of corn, the improvement in predicting intake illustrated the need for research to more accurately defining feedstuff energy values via performance data and using that information to derive new intake prediction equations. Even so, predicting optimum endpoint for the producer can be the most economically beneficial prediction since carcasses are awarded premiums for high cutability and high quality grades. It has been found that predicting marbling score by measuring backfat and BW over the feeding period seems to be the most viable and accurate compared to other model combinations of backfat, BW and DMI. However, backfat and BW are not
synonymous with marbling score and therefore, bias increases at the end of the feeding period. Still, the economic advantage may be given to feeding the animal longer as a greater return was found for projections of animals fed past the 1.2 cm optimum backfat. Since carcass gain can be up to 90% of total gain at the end of the feeding period, it is beneficial for the producer to feed cattle longer as the cost of gain is spread over more carcass weight. The resulting paradigm shift to feeding cattle what is deemed past industry optimum will lead to greater carcass weights, higher quality grades, and ultimately greater premiums for the producer.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>II. REVIEW OF LITERATURE</td>
<td></td>
</tr>
<tr>
<td>a. Energy Intake: Past, Present, and Future</td>
<td>3</td>
</tr>
<tr>
<td>b. Energy Intake as Related to Growth, Protein Accretion, and Fat Deposition</td>
<td>9</td>
</tr>
<tr>
<td>c. Growth Rate Over Time</td>
<td>13</td>
</tr>
<tr>
<td>d. Alterations in Growth and Efficiency by Technology</td>
<td>16</td>
</tr>
<tr>
<td>e. Impact of Residual Feed Intake on Energy Utilization</td>
<td>22</td>
</tr>
<tr>
<td>f. Economic Viability of Ultrasonic Carcass Evaluation</td>
<td>25</td>
</tr>
<tr>
<td>g. Evaluation of Statistical Procedures for Model Development</td>
<td></td>
</tr>
<tr>
<td>i. Background Statistics</td>
<td>27</td>
</tr>
<tr>
<td>ii. Analysis of Past and Currently Published Models</td>
<td>33</td>
</tr>
<tr>
<td>iii. Model Development and Validation</td>
<td>44</td>
</tr>
<tr>
<td>h. Research Objectives</td>
<td>50</td>
</tr>
<tr>
<td>i. Literature Cited</td>
<td>52</td>
</tr>
<tr>
<td>III. EVALUATION OF DIET NET ENERGY CALCULATIONS WITHIN INTAKE PREDICTION EQUATIONS FOR NRC (1996) FEEDSTUFF ENERGY VALUE INACCURACIES</td>
<td></td>
</tr>
<tr>
<td>a. Abstract</td>
<td>60</td>
</tr>
<tr>
<td>b. Introduction</td>
<td>61</td>
</tr>
<tr>
<td>c. Materials and Methods</td>
<td></td>
</tr>
<tr>
<td>i. Data Collection</td>
<td>62</td>
</tr>
<tr>
<td>ii. Prediction Equation Analysis</td>
<td>64</td>
</tr>
<tr>
<td>iii. Dataset-Specific Prediction Equation Development</td>
<td>66</td>
</tr>
<tr>
<td>d. Results</td>
<td></td>
</tr>
<tr>
<td>i. Prediction Equation Comparison</td>
<td>67</td>
</tr>
</tbody>
</table>
ii. Developed Prediction Equation Analysis ............................................. 69

e. Discussion ......................................................................................... 71

f. Implications ....................................................................................... 75

g. Literature cited .................................................................................. 76

IV. FACTORS INFLUENCING INTRAMUSCULAR FAT DEPOSITION OVER THE FEEDING PERIOD DETERMINED BY INTERIM ULTRASONIC CARCASS MEASUREMENTS AND MODEL DEVELOPMENT FROM REPEATED MEASURES

a. Abstract ............................................................................................. 91

b. Introduction ........................................................................................ 92

c. Materials and Methods
   i. Data Collection .................................................................................. 93
   ii. Prediction Equation Development ...................................................... 95

d. Results .................................................................................................. 97

e. Discussion .......................................................................................... 102

f. Literature Cited .................................................................................. 106

V. MARKETING STRATEGY INFLUENCES OPTIMUM MARKETING DATE OF STEERS IN RELATION TO CORN PRICE AND DAYS ON FEED

a. Abstract ............................................................................................. 118

b. Introduction ........................................................................................ 119

c. Materials and Methods
   i. Data Collection .................................................................................. 120
   ii. Economic Analysis .......................................................................... 122
   iii. Statistical Analysis .......................................................................... 124

d. Results and Discussion ...................................................................... 124

e. Implications ........................................................................................ 133

f. Literature Cited .................................................................................. 134
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1. Diet composition fed from 4 yr of data collected at the University of Illinois-Urbana</td>
<td>78</td>
</tr>
<tr>
<td>2. 1996 NRC feedstuff energy values</td>
<td>79</td>
</tr>
<tr>
<td>3. Diet energy values as calculated from 1996 NRC feedstuff energy</td>
<td>80</td>
</tr>
<tr>
<td>4. Mean absolute bias of prediction equation with diet energy calculated one of two ways</td>
<td>81</td>
</tr>
<tr>
<td>5. R-squared values for prediction equation with diet energy calculated on of two ways</td>
<td>82</td>
</tr>
<tr>
<td>6. Correlation matrix for parameters to predict dry matter intake</td>
<td>83</td>
</tr>
<tr>
<td>7. Dry matter intake prediction models developed with parameters from 1,794 animals with daily intake measurements</td>
<td>84</td>
</tr>
<tr>
<td>8. Mean absolute bias of prediction equation tested against animal intakes of diets fed during yr 4</td>
<td>85</td>
</tr>
<tr>
<td>9. R-squared values of prediction equation tested against animal intakes of diets fed during yr 4</td>
<td>86</td>
</tr>
<tr>
<td>Table 1. Diet composition fed from 4 yr of data collected at the University of Illinois-Urbana</td>
<td>108</td>
</tr>
<tr>
<td>2. Correlation matrix for parameters to predict marbling score</td>
<td>109</td>
</tr>
</tbody>
</table>
3. Marbling prediction models developed from 1,761 animals with serial ultrasound carcass measurement .................................................................110

4. Average marbling score compared to predicted marbling scored from model derived from animals fed during yr 1, 2, and 3 and tested against animals fed during yr 4 ....................................................................................111

5. Prediction equation within day absolute mean bias of ultrasonic-measured marbling versus predicted marbling calculated from yr 4 data ..................112

6. R-squared values for ultrasonic-measured marbling versus predicted marbling calculated from yr 4 data .........................................................................113

Chapter V.

1. Performance parameter averages by trial. ..................................................138

2. Predicted average performance of steers marketed at 75, 100, and 125% of expected days on feed ........................................................................139

3. Predicted profit/loss and cost of gain of steers fed corn priced at $5.26/25.4 kg and marketed at 75, 100, and 125% of expected days on feed .................................................................140

4. Predicted profit/loss and cost of gain of steers fed corn priced at $3.50/25.4 kg and marketed at 75, 100, and 125% of expected days on feed ................................................................................141

5. Predicted profit/loss and cost of gain of steers fed corn priced at $5.50/25.4 kg and marketed at 75, 100, and 125% of expected days on feed ................................................................................142
6. Predicted profit/loss and cost of gain of steers fed corn priced at $7.50/25.4 kg and marketed at 75, 100, and 125% of expected days on feed.
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chapter III.</strong></td>
<td></td>
</tr>
<tr>
<td>1. Bias of observed dry matter intake versus predicted dry matter intake from prediction model for diet 1 of yr 4.</td>
<td>87</td>
</tr>
<tr>
<td>2. Bias of observed dry matter intake versus predicted dry matter intake from prediction model for diet 4 of yr 4.</td>
<td>88</td>
</tr>
<tr>
<td>3. Bias of observed dry matter intake versus predicted dry matter intake from prediction model for diet 7 of yr 4.</td>
<td>89</td>
</tr>
<tr>
<td>4. Bias of observed dry matter intake versus predicted dry matter intake from prediction model for diet 13 of yr 4.</td>
<td>90</td>
</tr>
<tr>
<td><strong>Chapter IV.</strong></td>
<td></td>
</tr>
<tr>
<td>1. Bias of ultrasonic measured marbling score versus prediction marbling score from prediction model on Day 0 of Year 4.</td>
<td>114</td>
</tr>
<tr>
<td>2. Bias of ultrasonic measured marbling score versus prediction marbling score from prediction model on Day 42 of Year 4.</td>
<td>115</td>
</tr>
<tr>
<td>3. Bias of ultrasonic measured marbling score versus prediction marbling score from prediction model on Day 84 of Year 4.</td>
<td>116</td>
</tr>
<tr>
<td>4. Bias of ultrasonic measured marbling score versus prediction marbling score from prediction model on Day 120 of Year 4.</td>
<td>117</td>
</tr>
<tr>
<td><strong>Chapter V.</strong></td>
<td></td>
</tr>
<tr>
<td>1. Five-year average feeder calf, live slaughter and corn prices per month.</td>
<td>144</td>
</tr>
</tbody>
</table>
2. Change in BW on a live weight and carcass weight basis throughout the feeding period. .................................................................145

3. Change in ADG on a live weight and carcass weight basis throughout the feeding period. .................................................................146

4. Change in feed efficiency on a live weight and carcass weight basis throughout the feeding period. .................................................................147

5. Dry matter intake throughout the feeding period. .................................................................148

6. Percentage of live weight gain transferred to carcass weight gain throughout the feeding period. .................................................................149

7. Change live weight cost of gain at three different corn prices throughout the feeding period. .................................................................150

8. Change in carcass weight cost of gain at three different corn prices throughout the feeding period. .................................................................151
INTRODUCTION

The concept of energy utilization from initial intake, to digestion and fermentation, to heat expulsion and excretion has long been measured, analyzed, and modeled. Lavoisier and La Place posed the idea of metabolic combustion in 1780 and later developed the laws of thermodynamics (Rappaport, 1963). Berthelot theorized calorimetry to measure energy values in feeds, foods, and other organic compounds like feces to later define carbohydrates, proteins, fats, minerals, and vitamins based on digestibility and energy composition (Ferrell and Oltjen, 2008). Garrett et al. (1959) analyzed the metabolic systematic proportional changes of an animal over the finishing period through serial slaughter techniques. But with recent increases in input costs (Hoffman et al., 2010), serial slaughter methods, though valid in nature, are not cost effective. Therefore, ultrasonic measurements in place of serial slaughter has been widely studied and found to be valid (Brethour, 1992; Hassen et al., 1998; Brethour, 2000; Crews et al. 2002; Brethour 2004; Bruns et al., 2004).

The use of ultrasonic measures has increased the accuracy of growth model development (Owens et al. 1995; Brethour, 2000). Modeling required a large amount of diverse input data in order to correct for variation in breed, size, season, location, diet, and other potential feeding factors (Owens et al, 1995; St-Pierre, 2001). The most benefit is found by measuring the same animal multiple times over the feeding period (Owens et al., 1995). Often, meta-analysis and repeated measures analysis have been the most widely used strategies for statistical verification of currently published models and development of new growth and intake models. Covariance structure analysis allows for
effective determination of model fit (Brown and Prescott, 2006; Littell et al., 2006) along with Akaike’s and Schwarz information criterion (MacNeil, 1983; Littell et al., 2006).

Overall, currently published models require constant research to diversify and expand datasets in order to improve accuracy or to prove development of new models is required (Owens et al., 1995; Ferrell and Oltjen, 2008). As new feedstuffs are fed like that of ethanol byproducts (Stock et al., 2000; Klopfenstein et al., 2008), accurate energy value determination of these feeds is important in order to accurately predict intake and input costs. Additionally, genetic selection and improvement in feeding diet with higher energy content has increased animal efficiency (Eggert and Nielsen, 2006; Ferrell and Jenkins, 2008) which has improved animal performance and carcass quality. Understanding the components to improve production efficiency through intake and growth parameters is important to maximizing returns by utilizing the lowest input costs and taking advantage of changing market conditions through accurate prediction of carcass value at the end of the feeding period thereby increasing profit potential for producers (Lawrence et al., 2001; Ibarburu-Blanc et al., 2009; Hoffman et al., 2010).
REVIEW OF LITERATURE

Energy Intake: Past, Present, and Future

As expressed in an ASAS centennial paper, Ferrell and Oltjen (2008) stated “the current Net Energy system remains useful but is empirical and static in nature and thus fails to capture the dynamics of energy utilization by diverse animals as they respond to changing environmental conditions.” However, to understand the concept of energy intake and utilization, credit needs to be given to Lavoisier and La Place who in 1780 established the relationship between O₂ use, CO₂ production, and heat production and developed the concept of metabolism and combustion into the equation: C₆H₁₂O₆ + 6O₂ → 6CO₂ + 6H₂O + heat (Rappaport, 1963). Afterwards, the first two laws of thermodynamics were developed with the first law that energy can neither be created nor destroyed but can be transferred from one form to another and the second law that all forms of energy can be quantitatively converted to heat. These theories lead to bomb calorimetry by Berthelot to determine the gross energy available in feeds, feces, urine and other organic compounds allowing for the later definition of carbohydrates, proteins, fats, minerals, and vitamins (Ferrell and Oltjen, 2008). By use of direct calorimetry, measurement of animal energy consumption and heat production was analyzed for several years by Eggert and Nielsen (2006). Mice were used to measure heat loss of genetically selected groups of high heat loss, low heat loss, and nonselected controls to estimate feed energy costs of maintenance and gain. Selection was determined to have changed the requirement for maintenance per unit body size with low heat loss mice having decreased cost of maintenance and thus decreased energy cost per unit of gain.
Doubly labeled water experiments have been used to illustrate flux to measure H$_2$O consumption and CO$_2$ production. When measuring flux rates, five assumptions need to be met. First, body composition must be held constant where the animal is at maintenance, not gaining or losing weight or energy. Second, water inputs and outputs must remain constant. Third, carbon dioxide and water must be the only routes for $^2$H and $^{18}$O to be lost. Ruminants complicate this with the potential production of methane, biohydrogenation, hydrogen sulfide, and urea that can all take carbon and hydrogen atoms from water production. Additionally, specific gravity of the water leaving the body is the same as that entering the body. Since $^2$H is heavier than the hydrogen atom, the labeled pool must be measured against the cold pool, requiring fractionization. And finally, no CO$_2$ or H$_2$O enters via inspired air or via the skin. This method of estimating ME intake was compared to indirect calorimetry and a nutrient-balance study to determine rates of CO$_2$ production, energy expenditure, and water intake on preterm infants (Wong et al., 1987). The results of the experiment verified that the doubly labeled water method provided accurate measurements when compared to the other studied methods but was noted that individual estimates of ME intake was subject to far more than 19% variation among samples analyzed.

Over the course of 100 years, the definition of nutritional energetics along with model development defining energy utilization have been consistently adopted and then disseminated only to be reevaluated and corrected as is appropriate in research. As assessed by Ferrell and Oltjen (2008), the Physiological Fuel Value (PFV) system for measuring caloric intake values developed by Atwater and Bryant (1900) assigns energy values to food for human and laboratory animals and is still in use today. But for beef
cattle purposes, the PFV values are essentially ME values calculated from the total digestible nutrients (TDN) system. The energy values calculated from the TDN system were derived from the digestible chemical components of the feed by accounting for crude protein, crude fiber, nitrogen free extract, and ether extract. While the TDN system was advancement in the understanding of energy utilization, the TDN system was not without its flaws due to its inability to measure forage and concentrate combinations in mixed diets.

Though not the first researchers to employ comparative slaughter techniques, Garrett et al. (1959) analyzed the partitioning of body water, body fat, body protein, body minerals, and the metabolic systematic proportions of an animal over the finishing period. This group determined through direct and indirect calorimetry that energy requirements for both sheep and cattle were similar in nature when considering TDN, DE, or ME to measure feed energy, though differences were created based on plane of nutrition. Subsequently, Lofgreen and Garrett (1968) developed a system to express net energy requirements and feed values for growing and finishing cattle that has since been incorporated and altered through various updates of the NRC Nutrient Requirements for Beef Cattle (1976, 1984, 1996, and 2000).

The basic terms of gross energy (GE), DE, ME, and NE became standard measures for energy intake and energy retention. Later ME and NE values were partitioned into heat increment of production to designate energy costs from digestion and metabolic processes for maintenance. And thus, NE_m for maintenance and NE_g for gain were created for all animals, along with NE_l for lactating animals (NRC, 2000). Additionally, the concept of metabolic body weight was determined to be $BW^{0.75}$ kg and
the requirement for both steers and heifers was approximately 0.077 Mcal per kg of metabolic body weight or $0.077 \times BW^{0.75}$ kg. Energy intake was defined in Mcal/kg and shown:

$$IE = a \times W^{0.75} + b \times W^{0.75} \times ADG$$

where $W =$ shrunk BW (SBW = BW * 0.96; NRC, 1996) and ADG = daily shrunk BW gain. The growth coefficient $b$ is based on sex, body composition, frame size, and mature BW of the animal (NRC, 1996). Fox and Black (1984) conceptualized equivalent BW with cattle at similar body composition and differing frame sizes, while Tylutki et al. (1994) took it a step further and included age and sex influences and thus, set equivalent shrunk body weight (EQSW) equal to SBW times shrunk reference weight divided by mature final weight (MFW). Shrunk reference weight (SRW) was assigned and arbitrary value of 467 kg (Tylutki et al., 1994) or 478 kg (NRC, 1996) for animals finishing at 28% fat body composition which is considered MFW, replacement heifers, and breeding bulls. These concepts allowed retained energy (RE, Mcal/d) to be calculated from equivalent shrunk $BW^{0.75}$ (EQSBW$^{0.75}$) and ADG (NRC, 1996) as:

$$RE = 0.0557 \times EQSBW^{0.75} \times ADG^{1.097},$$

and later was altered to:

$$RE = 0.0635 \times EBW^{0.75} \times EBG^{1.097},$$

with $EBW^{0.75} =$ empty metabolic BW (empty BW = 0.891 * SBW) and $EBG =$ empty body gain (kg/d; NRC, 2000).

Traditionally, TDN had been the most accurate estimate for energy content in a feed but it was uncorrected for metabolic loss and thus, Owens et al. (2010) conducted analysis to compare the accuracy of energy values calculated from TDN to that of
feedstuff values from acid detergent fiber (ADF; Morrison, 1961), neutral detergent fiber (NDF), and acid detergent insoluble nitrogen (ADIN; NRC, 2000). Equations that calculated feed energy value from ADF tended to underestimate TDN relative to concentrate and wet roughages but overestimated that of dry roughages and silages, as classified by Morrison (1961). Even so, ADF values offered greater correlation than equations based on NDF values.

Current NRC (2000) equations imply forage ADIN is unavailable and indigestible from a non-bound nitrogen standpoint. Byproducts have Maillard reactive components, which are considered as ADIN within the NRC calculated energy values. However, byproducts with high fiber content may actually be more digestible than originally anticipated (Owens et al., 2010). Some byproduct feeds from the dry milling process also contain a high proportion of fat which could contribute added energy values from these lipid structures. During the dry milling process, corn starch is extracted and the resulting feed byproduct is concentrated 3 times the normal value so protein increases to 30%, fat increases to 12%, and NDF to 36% (Stock et al., 2000). With ethanol by-products being fed at levels up to 40% of the diet DM (Klopfenstein et al. 2008), understanding the energy value of these byproducts is important in accurately predicting intake and gain for cattle.

Energy consumed as food was determined to be lost as fecal energy, urinary energy, gaseous energy, or HE, or recovered as product and was reported in the NRC (1984). Heat energy was further broken down into that used for basal metabolism, voluntary activity such as grazing, productive processes like that of fat and protein accretion, digestion and absorption of nutrients, thermal regulation, heat of fermentation
from metabolic processes like that of digestion, and waste formation and excretion like urinary and fecal output. This breakdown has been the most controversial dynamic of the NE system due to the difficulty of measurement. It is well understood these processes take place continuously throughout the body but rate and flux of nutrient and energy utilization varies from organ to organ and tissue to tissue when considering forage versus concentrate feeds.

The microbial environment of the rumen within cattle allows the animal to obtain the majority of their ME from VFA production due to microbial degradation of feedstuffs. Acetate, propionate, and butyrate are the primary VFAs produced with acetate serving as the predominant energy substrate for peripheral tissue and minimally metabolized by gut or hepatic tissues, propionate highly utilized by gut tissues and hepatic tissues almost exclusively as an energy source, and butyrate extensively metabolized by gut and hepatic tissues as well (Harmon et al., 1991). While butyrate was shown to decrease activation of acetate and propionate in ruminal epithelial tissues, it did not demonstrate limitation to propionate metabolism in hepatic tissues allowing for further utilization of both propionate and butyrate when dietary forage and energy intake influence was measured on total body metabolism by Harmon et al. (1991). As steers are fed higher concentrate diets, ruminal pH is decreased through rapid starch and carbohydrate digestion. The decrease in pH decreases the activity of acetate producing microbes thus, increasing the proportion of propionate and butyrate to acetate and increasing the rate of absorption of propionic acid and butyric acid as energy for metabolic tissues. Additionally, high concentrate diets have been shown to increase deposition of intramuscular fat, or marbling, compared to subcutaneous fat accretion
which is primarily believed to be the result of greater availability of glucose, from propionate (Pethick et al., 2004; Rhoades et al., 2007). Glucose is most simply formed from propionate because glucose is composed of a 6-carbon chain which can be made from two 3-carbon chain propionate molecules. While no differences were noted in performance when various energy sources were utilized, carcass characteristics observed alterations in adipose tissue partitioning when hay-based energy sources were compared to concentrate-based energy diets (Rhoades et al., 2007). Rhoades et al. (2007) found higher concentrations of propionic acid, a glucogenic substrate, in concentrate diets leading to greater marbling scores and increased metabolic efficiency. When calculated on a caloric basis, fat deposition is approximately 1.6 times more efficient than protein accretion and these results reiterate the observation made by Owens et al. (1995) that fat deposition carries a higher relationship with energy intake compared to protein which is more so affected by mature body size and age. Additionally, fractional growth rate for carcass protein, carcass fat, and marbling of the LM has been seen to decrease as carcass weight and skeletal maturity increases (Bruns et al., 2004).

Energy Intake as Related to Growth, Protein Accretion, and Fat Deposition

While flux varies from tissue to tissue within an animal, the animal itself maintains efficiency levels over the course of its life. All animals are born with a predisposed efficiency level through their DNA. It is the variation between animals within breeds and across breeds that created the largest impact felt in inefficiency across the industry. In 2008, Ferrell and Jenkins analyzed the influence of steer genotype on feed intake, growth rate and efficiency, mature size, and body composition during the
growing and finishing phase of production. When limit feeding five different breeds of cattle, ME intake was similar for Angus-, Braham-, Boran-, Tuli-, and Hereford-sired steers while ADG differed (Ferrell and Jenkins, 2008). However, when feeding those same five breeds ad libitum, Boran- and Tuli-sired steers ate less and grew slower than Angus-, Braham-, and Hereford-sired steers resulting in no difference in feed efficiency among breeds. These results agreed with Taylor et al. (1986) who concluded animals with the genetic potential for high productivity are at a disadvantage in a nutritionally restricted environment and have a reduced ability to adapt to lower maintenance requirements. Additionally, maintenance differences can be the result of variation in body size, temperament, voluntary activity, body composition, visceral organ size in proportion to body size, and even protein turnover, accretion, and degradation (Johnson et al, 2003). Bos indicus breeds are tropically adapted allowing animals to thrive in more stressful and restrictive environments both temperately and nutritionally. This was evident with the lack of variation in production parameters during limit-feeding analysis (Ferrell and Jenkins, 2008). Even so, genetic potential was reached at ad libitum intake like that of research conducted by Old and Garrett (1987). Hereford and Charolais steers were compared at ad libitum intakes and Charolais steers were noted to have made leaner, less energy efficient yet higher gains compared to Hereford steers whose gains consisted of a higher percentage of fat at the end of the feeding period. Additionally, steers fed at lower energy intake levels contained a higher percentage of protein and a lower percentage of fat than those consuming higher levels of energy. Understanding that synthesis and deposition of fat and protein are not synonymous, it was determined that
there was a much greater affinity of ME to be used for fat deposition than protein turnover.

Because breed can affect growth rate via protein and fat deposition, the NRC (1984) created an adjustment factor for maintenance to be incorporated into the intake equations as well as the growth rate predictions. As stated, Angus and most British influenced cattle received an adjustment of 1. Simmentals and milk producing breeds are corrected by 1.2 due to higher maintenance requirements for lactation and protein accretion. Because Bos Indicus influenced cattle have lower maintenance requirements (Ferrell and Jenkins, 2008), these breeds were assigned an adjustment value of .9. The appropriate adjustment for breed is instrumental when developing models for growth and composition as an increase in frame size can greatly alter and increase maintenance requirements and thus, decrease expected fat deposition (Oltjen et al., 1986a).

Even so, in an isocaloric diet, daily empty body weight gain, protein, fat, and energy increased with increased dietary MP when fed at five levels to Angus-Hereford crossbred steers (Tritschler II et al. 1984). These researchers found that urea-N can substitute for plant protein resulting in increased tissue protein deposition. The maintenance protein requirement for growing animals is a balance of N available for tissue synthesis and maintenance (Ames et al., 1980).

Maintenance energy requirements have been seen to decline progressively during limit feeding while basal metabolic rate can vary with quality of previous nutrition (Drouillard et al., 1991). Drouillard et al. (1991) challenged lambs to energy restricted and protein restricted states of production and found energy restricted lambs, when provided sufficient protein, were able to maintain body protein while body fat and dietary
protein were utilized as energy substrates for metabolic processes. Even though protein restricted animals were supplied adequate energy, lambs were unable to deposit fat. Internal weights of liver, stomach, and intestines were reduced in lambs that were energy or protein restricted compared to the lambs not restricted in any dietary requirement during the initial growing phase. Once animals were fed with no dietary restrictions no performance alterations were observed at the end of the feeding period. Wilson and Osburn (1960) noted that gastrointestinal tract development is not affected by nutrient deprivation. During realimentation of the Drouillard study, however, protein restricted lambs gained faster than their energy restricted counterparts by depositing more protein and fat as a percent of empty body early in the finishing period. In the end, protein and energy restricted animals were not different for ADG or composition of gain concluding compensatory growth can effectively relieve restriction states if duration is minimal on both a metabolic functionality and finish performance basis.

While limiting energy and protein intake may inhibit genetic potential for growth, animals are capable of metabolic adaptation to starvation as was evident to Labussiere et al. (2011). Fasting heat production to determine animal requirements is measured after two days of feed deprivation but prolonged duration of feed deprivation may cause changes in behavior along with metabolic adaptation. While requirements for cattle and pigs are separate to that needed for maintenance and that needed for gain, Labussiere et al. (2011) noted that the ability to measure fasting heat production can offer the opportunity to improve accuracy when estimating energy requirements and therefore potentially decrease feed costs when selection is utilized. Owens et al. (1995) concluded from previous research that digestive tract fill decreases over the feeding period.
However, when fed high forage diets, tract size and weight may not decrease in order to maintain the surface of exposure for optimum absorption of available nutrients to reach animal maturity. Even so, synergistic interactions between intake, absorbable nutrients available to the small intestine, and digestive tract status can determine small intestine proportion of empty BW (Hersom et al., 2004b).

**Growth Rate Over Time**

With growth generally defined by an animal’s rate of protein and fat accretion relating to the change in weight or mass over time, Owens et al (1995) reviewed the aspects of growth and the potential influence energy intake can have on gain. The authors examined growth rate, body weight, and energy retention for cattle given ad libitum access to high concentrate diets, and results depicted fat accretion to increase quadratically while protein responded linearly as mature weight was reached. This group noted that protein accretion “paralleled” body weight while fat deposition varied but was related most closely to initial body fat content. Additional analysis determined that limiting feed intake creates energetic efficiency and has the potential to increase mature size as protein accretion will exceed that of fat deposition. Still, when energy availability is restored, fat deposition will increase at an increasing rate while protein accretion may be maintained or even decelerates. Since energy retention is the combination of fat and protein accretion, the two rates are strongly correlated and have been shown to be difficult to quantify separately, mainly because maintenance and accretion requirements cannot be separated. Ultimately, Owens et al. (1995) concluded that protein accretion rate is dependent on mature size and age while fat deposition is more highly related to energy
intake levels. Even so, it is generally assumed that feed efficiency decreases when gain is mainly comprise of fat and not as much lean tissue, but Brethour (2004) found feed efficiency remained constant as a proportion of empty body weight by using regression analysis of repeated ultrasonic carcass measures.

Sainz et al. (1995) coordinated a comprehensive compensatory growth analysis with steers fed either a low energy diet ad libitum, a high energy diet ad libitum, or limit-fed a high energy diet during the growing phase and then reallocated and fed a concentrate diet ad libitum or limit-fed at 70% of the ad libitum group during the finishing period. Increased intake for those steers in low energy state during the growing phase was influential in compensatory gain to meet the final weights of those steers receiving diets that met or exceeded energy requirements over the growing and finishing phase combined. However, maintenance requirements were increased for steers consuming the low energy diet ad libitum during the growing phase followed by concentrate fed ad libitum but was reduced for steers consuming the concentrate diet on a limited basis during the growing phase followed by concentrate fed ad libitum. Overall, it was concluded that limiting concentrate consumption at any point in the feeding phase can alter and/or impair carcass quality and opportunity for compensatory gain. The result of limiting intake as a whole inhibits the animal to develop appropriately if energy or protein requirements are not met. Animals’ bodies are forced to metabolize fat, protein and then finally digestive tract tissue structures to meet metabolic energy requirements. Even when adequate energy and protein are available, genetic potential for growth and carcass performance may not be able to be attained. Bruns et al. (2004) determined the rate and extent of marbling deposition in steers via serial slaughter is not necessarily
deposited at the later stages of the feeding period, but instead has the potential for early development with proper nutritional supplementation typically found in high-energy concentrate diets. Similarly, Pethick et al. (2004) found increased NE<sub>g</sub> leads to increased intramuscular fat deposition which can be achieved by increasing energy intake through feeding cereal grains, processing of the grains to increase starch availability, and adding a lipid source to the diet. Additionally, intramuscular fat deposition has been found to be separate and occurring at a different rate than that of subcutaneous fat from low correlations through repeated ultrasound measurements over the feeding period (Brethour, 2000).

The previous discussion of Drouillard et al. (1991) and Sainz et al. (1995) introduced the idea that previous nutritional status can impact subsequent feedlot performance and Hersom et al. (2004a, 2004b) conducted a two-part analysis observing the effects of backgrounding on two types of forage and with or without supplementation to determine body composition and metabolic effects of each treatment that further explained the previous research. After the initial growing phase, steers allowed high levels of gain on winter wheat had the heaviest empty BW, total offal mass and body fat along with the highest ADG, followed by low-gaining steers on winter wheat, and then those grazing native range. However, after conclusion of the finishing period where all groups consumed the same high-concentrate diet to reach a common backfat, gastrointestinal tract proportion of empty BW become smaller for steers previously restricted but only to be replaced by mesenteric fat. This helps to illustrate the lack of difference noted for total weight gain during the entire period for all treatments as
compensatory gain and marbling score was inhibited by restriction as seen before (Sainz et al., 1995; Bruns et al., 2004).

Still, the protein to fat ratio can be increased through increasing mature size with the use of hormonal implants (Owens et al., 1995), limiting energy intake during the growing and finishing period (Sainz et al., 1995), or slaughtering finished cattle at an earlier stage of maturity like that of calf-feds compared to yearlings (Owens et al., 1995). Normally cattle are slaughtered before they reach mature size, where protein accretion rate plateaus and body fat content can reach up to 36% of the total body mass. Bruns et al. (2005) studied the influence of implant administration on growth, performance, and carcass characteristics in steers. Mature size was increased by implanting steers with estradiol-trenbolone acetate since 28 percent body fat was not reached until 579 and 597 kg for early implanted and delayed implanted steers compared to 546 kg final BW for non-implanted control steers which is still well below the 36% body fat content level assumed to be met at maturity. Since the greatest impact of implants are noted directly after administration (Montgomery et al., 2001), the result of delayed-implant steers observing the greatest final BW is expected since they were implanted closer to slaughter and were heavier at implant time compared to steers receiving the early implant treatment.

**Alterations in Growth and Efficiency by Technology**

Growth enhancing technologies like that of implants have been administered to cattle as early as the 1950s (Montgomery et al., 2001). While implants have been proven to not only increase mature size requiring more time on feed to reach 28% body fat
feed efficiency and protein deposition have also been increased for implanted animals (Duckett et al., 1997). Use of implants has repeatedly proven to increase carcass weight, LM area, and carcass muscle yield (Roeber et al., 2000; Smith et al., 2007). While marbling is recognized as an important aspect of value-based marketing of beef quality to consumers (Montgomery et al., 2001), Smith et al. (2007) observed an increased population of subcutaneous adipocytes at larger diameters for implanted animals compared to intramuscular adipocyte populations being higher at small and middle diameters for non-implanted animals. This result means that implanted animals measured more backfat and less marbling than non-implanted steers. Still, body lipid content did not differ between implanted and non-implanted animals. Ultimately, results translated into energy was used for hypertrophy of intramuscular fat cells being diverted to protein accretion and subcutaneous adipose tissue development for animals administered hormonal implants. Upon shear force analysis, Roeber et al. (2000) acknowledged a decrease in muscle tenderness with implant use, regardless of single implant or reimplant program protocol, which was determined to be the result of decreased marbling score. It should be noted that in this study cattle were not necessarily fed to a common backfat but instead to a similar ending BW. However, Hutcheson et al. (1997) did feed cattle to a final BW of 28% empty body fat and found implanted steers were 40 to 85 kg heavier than non-implanted steers. And while not as dramatic, Bruns et al. (2005) found implanted steers to be 25 to 45 kg heavier at similar backfat compared to the non-implanted animals.

Due to the extent of use and repeatability of growth response when cattle are administered anabolic implants, NRC (1996) added an adjustment variable to improve
accuracy when calculating expected intake, gain, or maintenance requirements. However, additional anabolic growth technologies have been developed over the past 20 years that have not been researched and repeated enough for adjustment factors to be calculated and incorporated within the prediction equations of the NRC but are widely accepted in academia. Beta-adrenergic agonists have displayed similar growth responses to that of anabolic implants with fed to finishing cattle the last 20 to 42 days of the feeding period but have very different modes of action (Bryant et al., 2010). While steroidal implants are known to bind to cytosolic receptors to increase gene expression and therefore growth-hormone release (Trenkle, 1997), beta-adrenergic agonists bind to cell-surface receptors to initiate skeletal muscle protein transcription (Mills, 2002). Two beta-adrenergic agonists are available to be fed for commercial use with the first being ractopamine, or Optaflexx® marketed by Elanco Animal Health (Greenfield, IN), approved in 2003 and fed for 28 to 42 days with no withdrawal; and the second of zilpaterol hydrochloride, or Zilmax® marketed by Merck Animal Health (Summit, NJ), approved in 2006 and fed for 20 to 40 days with a withdrawal of 3 days (Johnson et al., 2013). While both are beta-adrenergic agonists, ractopamine has a greater affinity for the $\beta_1$ receptor while zilpaterol hydrochloride has a greater affinity for $\beta_2$ receptor of binding proteins (Mersmann, 1998).

While Bryant et al. (2010) observed the interactive effect of ractopamine and estradiol implants on cattle, Kellermeier et al. (2009) measured similar performance parameters with the feeding of zilpaterol hydrochloride to cattle administered an estrogen-trenbolone acetate implant or not. In both studies, there were no significant interactions for beta-adrenergic agonist fed and implant administered on growth and
carcass characteristics. Animal response in both studies from implantation agreed with previously discussed research with final BW, HCW, ADG and G:F improved when compared to non-implanted animals. Additionally, beta-adrenergic agonist feeding increased HCW and LM area compared to steers not given the agonist, but response intensity varied with type as ractopamine (Bryant et al., 2010) fed steers gained 6 kg and 2.3 cm$^2$, respectively, and zilpaterol hydrochloride (Kellermeier et al., 2009) supplemented steers averaged 15 kg and 12 cm$^2$, respectively, more than steers not receiving the growth-promoting feed additive. Still, the most impactful response observed from an economic standpoint is HCW until corn prices exceed $6.00 per 25 kg where marbling score has more influence (Wilken et al., 2012). Though Kellermeier et al. (2009) noted no differences in backfat measures, steers marbling score was decreased by administration of implants and/or zilpaterol hydrochloride. However, an advantage in yield grade was gained in steers given one or both growth-promoting technologies over those receiving neither. This group also observed an increase in mature size for steers receiving growth-promotants since onset of bone maturity was delayed compared to those steers not implanted nor supplemented. This is where a difference is designated between growth-promoting feed additives as Bryant et al. (2010) saw no decrease in marbling score but noted the decrease resulted from the administration of implants to steers while backfat measurements were not different for steers receiving any treatment. Because each beta-adrenergic agonist responds differently, primarily due to receptors, the potential to calculate an appropriate adjustment factor for prediction equations within the NRC will prove to be difficult.
Consumers are the benefactors from the utilization of growth-enhancing technologies through reduced prices because production costs are lower. With consumers demanding leaner, more sustainably produced beef, the use of growth-enhancing technologies create increased feed efficiency of the animals, make beef leaner, and decreases land utilization for production (Johnson et al., 2013; Neumeier and Mitloehner, 2013). If growth-enhancing technologies were no longer available for use in the beef industry, it would take 385 thousand more animals to produce 454 million kg of beef to meet current demand (Capper and Hayes, 2012). Beef prices in the United States would increase due to increased costs of production and longer time on feed. Not only will land and feedstuff use increase but 20 billion more liters of water would be required to maintain the current state of production (Capper and Hayes, 2012), not including the projected 70 to 100% projected food requirement for 2050 (FAO et al., 2010). And while these technologies of implants or beta-adrenergic agonists are beneficial to the industry, environment, consumers, and producer profitability, they have inadvertently created a diminishing cash market (Lawrence et al., 2001). The negotiated cash market is the driver of live cattle prices and used as the market price determinant. Since the introduction of beta-adrenergic agonists and their limited feeding durations, especially the 3-day withdrawal period for zilpaterol hydrochloride, producers are more likely to contract cattle outside of the 14-day cash market window to ensure sale and cattle quality.

While not completely a growth technology, carboxylic polyether ionophores, like that of monensin, have been utilized widely throughout the industry to increase feed efficiency during the growing and finishing phases of cattle production. As summarized by Bergen and Bates (1984), the observed increase in efficiency when feeding an
ionophore is only the secondary result caused by the alterations in rumen microbial
digestion due to the inhibition of gram positive bacteria, reduced acetate and increased propionate. Since concentrate diets already cause a lower ruminal pH and increase the propionate to acetate ratio compare to high forage diets (Bergen and Bates, 1984), monensin has been shown to be more effective in increasing efficiency, decreasing intake and increasing daily BW weight gain when fed in corn silage or high forage diets than traditional concentrate diets for growing and finishing cattle (Duffield et al., 2012). In a meta-analysis of over 64 feeding trials, feed efficiency and ADG were increased 6.4% and 2.5%, respectively while DMI was decreased 3% (Duffield et al., 2012). When testing and comparing dynamic model simulations, Oltjen et al. (1986a) observed an improved NEm concentration of 9.3% when monensin was fed. Duffield et al. (2012) also noted a linear effect of monensin dose for the G:F, DMI, and ADG improvement. These researchers also noted a greater increase in ADG for those calves on high forage diets compared to those fed grains diets, with greater doses of monensin having lesser impact. Feeding high forage diets result in greater ruminal pH than diets containing grain diets where pH can average 5.3-5.6. At lower pH values like this, gram positive bacteria like S. bovis can thrive and create lactate, a strong VFA, which decreases pH even more. Even though, M. elsdenii utilizes lactate, the bacteria are inhibited in low pH levels and thus cannot keep up with production. Monensin decreases lactate production by inhibiting S. bovis ion gradient (Russell and Strobel, 1989). Additionally, the disruption in the potassium ([K⁺]), sodium gradient of S. bovis allows for increased passage of amino acids as they require high [K⁺] for protein synthesis. Muntifering et al. (1980) observed an 18% increase in nitrogen (N) intake and 12% increase of absorbed N through a 27% increase
of retained N in beef steers supplemented with monensin. Even so, Benchaar et al. (2006) observed no increase in ADG or efficiency. The additional gain proposed by feeding carboxylic polyether ionophores has been added to the growth and intake models within the NRC (2000) to better predict performance over the feeding period with an adjustment of 1.12 for those fed ionophores when calculating $NE_m$ and $NE_g$ compared to 1.0 for those not fed an ionophore. Ultimately, monensin increases feed efficiency in both grain and forage based diets though mode of improvement differs. Animals fed feedlot grain based diets with monensin response with improvement in G:F by decreasing intake and maintaining ADG compared to animals not fed monensin (Raun et al., 1976). Inversely, animals fed forage based diets with monensin observe improved feed efficiency via increased gain with similar intakes of those animals not supplemented with monensin (Potter et al., 1976).

**Impact of Residual Feed Intake on Energy Utilization**

A concept that has been highly discussed, analyzed, and questioned is that of residual feed intake and the influence physiology, genetic variation, and quality of energy intake have on the growth and production of the animal being studied. The potential advantage for selection of animals based off of residual feed intake is the ability to reduce input costs which is “dire for the agricultural industry as a whole” (Gilbert et al., 2007; Lancaster et al., 2009). Residual feed intake, or RFI, is defined as the difference between actual feed intake and that of expected feed intake based on maintenance and growth potential from metabolic body weight separate from gain. Foster et al. (1983) also found selection for low RFI can reduce DMI and improve efficiency without affecting ADG.
Barea et al. (2010) and Gilbert et al. (2007) both found low RFI pigs consume less feed and had fewer meals per day compared to their high RFI counterparts. The aforementioned group wanted to determine the effects of selection using RFI on digestive and metabolic energy utilization. Through the use of respiration chambers, digestibility of energy and nutrients, heat production, and energy and N retention were measured and it was found that low RFI pigs were 8% more efficient in feed intake than those expected to have high RFI even though no differences in digestibility or N retention were noted. High RFI line pigs also measured higher heat production compared to the low RFI line with no difference in energy retention between the two. This result translates to the high RFI pigs consuming more, retaining the same, and wasting more energy than the low RFI pigs. Even so, lack of differences in energy retained was transcribed into the lack of difference found in fat and protein partitioning between the low and high RFI lines. Considering that both groups received the same dietary energy, this study effectively determined efficiency on a metabolic level by measuring energy wasted. This paradigm is consistent with Nguyen et al. (2005) who determined that the differences in digestive processes and metabolic efficiency of feed reflect the positive correlation with RFI and heat production.

It is important to understand that cattle inherently will eat to an energy intake level primarily with grain based diets, even though gut fill may be a regulator with forage based diets (Miller et al., 1991). It was recognized that as plant maturity increased, intake decreased and thus, ADG decreased; even though, Miller et al. (1991) saw no differences in carcass characteristics at slaughter among cattle fed ground, pelleted, or chopped alfalfa while Nkrumah et al. (2006) noted an association between RFI and
apparent digestibilities of dietary DM and CP when comparing low-, medium-, and high-RFI steers. And while protein accretion may be connected to mature size (Owens et al., 1995), fractional degradation rate and fractional synthesis rate for protein were reported as not different when considering low- and high-RFI class steers (Castro Bulle et al., 2007) even though DM and ME intakes were associated with RFI. Castro Bulle et al. (2007) also noted the fat to protein ratio was lower for low-RFI steers compared to high-RFI steers, while carcass trait measurements were not different. While low-RFI steers in this study ate 12% less, animals with the lower RFI used less energy for maintenance allowing for tissue accretion advantages compared to their high-RFI counterparts.

Digestion of nutrients and energy can alter RFI in ruminant animals and variations can indicate differences in metabolic efficiency, basal metabolic rate and energy expenditure which can be major contributing factors affecting RFI. Seventy-three percent of RFI variation is explained by heat production from metabolic processes, body composition, and physical activity as found by Herd and Arthur (2009). Additionally, protein turnover, tissue metabolism, and stress explain 37% of the variation for RFI, with digestibility (10%), heat increment and fermentation (9%), physical activity (9%), body composition (5%), and feeding patterns (2%) following suit (Herd and Arthur, 2009). While the inefficiency of energy utilization from consumption and genetic variation is understood, genetic progress for selection is limited due to the costs of labor and equipment for effective measurement of intake compared to performance characteristics on a large scale (Lancaster et al., 2009). Still, improvement in increasing feed efficiency in beef production systems past nutrition is dependent on increased genetic variation and economically influential traits such as growth, carcass quality and fertility. Since RFI can
be phenotypically independent of carcass traits, selection programs will be less affected by differences in ADG and composition of growth if RFI is the standard selection parameter (Lancaster et al., 2009). Even so, increased feed efficiency in production systems is advantageous from an environmental and feed efficiency standpoint since methane production has been observed to be measurably less for low-RFI than high- or medium-RFI steers (28 and 24%, respectively; Nkrumah et al. 2006).

**Economic Viability of Ultrasonic Carcass Evaluation**

Prediction of performance parameters like that of intake and gain has creative beginnings that have become analytical science over the past century. Serial slaughter was one of the first methods to allow for visual measurement to calculate energetic use and animal growth over the feeding period (Lofgreen and Garrett, 1968). However, recent buying and selling price fluctuations, which are determinants of profit potential for cattle (Hoffman et al., 2010), have proven serial slaughter to be an expensive measurement method of protein and fat deposition over the feeding period. Ultrasonic measurements have been more recently used in place of serial slaughter because repeated measurements of the same animal may more accurately determine actual tissue accretion compared to postharvest collection (Owens et al., 1995). Thus, Brethour (1992) conducted a study to analyze the accuracy and precision of using ultrasound data collection of backfat in order to validate measurements would be equivalent to actual carcass measures. While backfat measures were noted to fluctuate with fatter cattle when comparing ultrasound to actual measurements, regression analysis determined that ultrasound measurements of backfat on a live animal may have been more accurate and
precise than carcass backfat due to the potential bloom of backfat after cooler storage. Additionally, repeatability between ultrasound measurements of the same animal was 97.5% allowing the author to conclude ultrasonic backfat measurement would be a sufficient replacement for serial slaughter research.

Brethour further analyzed this carcass measurement technique in 2000 by developing and evaluating the method’s accuracy for predicting future carcass merit. Even though visual judgment of cattle proved to be as sensitive as ultrasonic backfat projection in sorting finishing groups, accuracy was improved with shorter interval length of ultrasound measurements from evaluation to slaughter. Still, bias was noted to be a concern with ultrasound estimation of marbling due to environmental and animal variations like that of hair coat and moisture. Due to this limitation in accurate marbling score estimates, it had been suggested that when measuring for expected progeny differences for herd sires, seedstock and sibling carcass data should both be used to increase prediction acceptability (Hassen et al., 1999). Ultimately, Brethour (2000) concluded that while backfat measurement accuracy remains high, marbling estimation is more difficult until closer to slaughter. Furthermore, use of ultrasonic measurements can allow a producer to decrease the rate of Yield Grade 4 and 5, reducing the potential for discount carcasses. Crews et al. (2002) agreed with Brethour that preharvest ultrasound measurements are highly correlated with carcass measures. Final LM area was accurately predicted when ultrasound measures were taken at weaning but fat thickness correlations were not as strong which also matches that of Brethour (2000). In this analysis, coefficients of variation indicated that at all measurement ages (weaning, yearling, and
harvest) for all sexes (bulls, steers, and heifers), fat thickness was more variable than muscle area measures (Crews et al., 2002).

Because taking repeated measures of the same animal has been shown to increase accuracy for predicting muscle and to some degree fat (Brethour, 1992; Brethour, 2000; Crews et al., 2002), utilizing ultrasound measures is a valid method of data collection to develop prediction equations for the cutability of rib-based beef carcasses (Shackelford et al., 1995). Because complete collection of cutability data from a carcass is not only labor intensive but expensive, finding that ultrasounds of the wholesale rib portion for muscle, short ribs, and marbling can effectively predict value and carcass composition can decrease input costs of fabrication which can benefit the industry greatly (Shackelford et al., 1995).

**Evaluation of Statistical Procedures for Model Development**

**Background Statistics**

Model development can be derived from several different types of analysis. Understanding that repeatability of a model is the most important aspect of accurate model creation, multiple sources of data with diverse input variables increase the potential accuracy of the model itself (MacNeil, 1983). Additionally, independent datasets from which a model was derived are appropriate for the validation of a model. Simple regression analysis has been well documented in the determination and creation of models created from data collected over several different studies and years. This traditional approach may have been deemed accurate for the time, but further review has provided researchers with biased estimates of regression coefficients and their standard
errors (St-Pierre, 2001). Experiments can have large differences in experimental design, measurement methods, laboratory technicians, and physiological status of the experimental units impacted by age, breed, diet, and environment. Bias can occur when the experiment effect is ignored as slope and intercept can be altered. Utilizing the mixed model approach incorporates the experiment effect into the random components of the analysis and allows for a more accurate estimate of the fixed effects with less chance of committing a type II error (St-Pierre, 2001). And unlike pooled data analysis, meta-analysis summarizes the results over the studies and not the experimental unit results within the studies (Berman and Parker, 2002).

While meta-analysis is beneficial to verify results across studies, trial selection and exclusion is just as important and homogeneity among studies is desired for independent variables being included in the model or comparison (St-Pierre, 2001; Berman and Parker, 2002). Additionally, multiple measurements of the same animal are beneficial for observing changes during the growth period (Owens et al., 1995). Therefore, repeated measures which is the analysis of multiple responses taken over the testing time frame on the experimental unit, has been used for the development of growth models (Owens et al., 1995; Littell et al., 1998; St-Pierre, 2001).

Several methods have been used to analyze repeated measures data. Even though model development primarily requires minimal correlation, repeated measures data is bound by correlation due to the same animal being measured on a time scale (Littell et al., 1998; López et al., 2000). The data can be analyzed as separate data points with no specific method required but the element of time is not addressed (Littell et al., 1998)
making treatment effects the sole result which is not ideal for model development but
aids in preliminary findings of treatment application.

The second method of univariate analysis is the most commonly used method
since experimental design is set for equal time frame between measurements for
minimum variance (Littell et al., 1998). A univariate analysis can be employed to observe
the effects of time but the covariance structure of the repeated measures is ignored and
results in invalid analysis (Littell et al., 1998).

The third type of results are based on univariate and multivariate analysis where
the covariance structure is bypassed and therefore, if one data point is missing for an
animal the animal is ignored within the analysis (Littell et al., 1998; St-Pierre, 2001).

Finally, mixed model methodology is the most inclusive type of analysis as the
covariance structure is not only addressed but can be selected for the most appropriate fit
for the data, and all data can be included even if not all data points are present for the
experimental unit (Littell et al., 1998; St-Pierre, 2001). Compound symmetry requires all
measures at all times have the same variance and the same correlation of measures on the
same animal at each time point (Brown and Prescott, 2006). Unstructured covariance
makes no assumptions in reference to variance or correlation (Brown and Prescott, 2006)
but it does require estimation of variance and covariance parameters and can lead to bias
problems in unbalanced data (Littell et al., 1998). The autoregressive method assumes the
variances are considered equal and the covariances are expected to decrease
exponentially which is appropriate for evenly spaced time point measures (Brown and
Prescott, 2006). The final covariance structure is Toeplitz which assumes a separate
covariance at each time period between measurements which is similar to the
autoregressive structure but by time period instead of over the whole experiment (Brown and Prescott, 2006).

The most challenging aspect of model development is identifying the prediction equation with the “best fit,” which is generally defined by minimized squared errors of prediction and unbiased errors of prediction (MacNeil, 1983; Littell et al., 1998). But adequate power test for experimental design is additionally important as it determines the experimental units needed for appropriate and accurate prediction equation development, considering accuracy is more important than precision (MacNeil, 1983). The end goal of prediction equation development is to maximize coefficients of determination ($R^2$) values indicating closeness of fit.

$$R^2 = \frac{\text{sum of squares due to regression (SS_r)}}{\text{corrected total sum of squares (SS_y)}}$$

While $R^2$ generally identifies the largest sum of squares due to regression within a dataset, MacNeil (1983) determined that it does not necessarily guarantee the best fit equation for prediction as it can have larger error variance than other equations that may be derived from the same data. MacNeil (1983) also noted that $C_p$ and $\sigma_{y|x}^2$ statistics can offer more important information than $R^2$ values when comparing equations that were derived from the data within the same study. However, when analyzing prediction equations that were created from different datasets, accurate validation of the equations prior to implementation is required.

The basic linear regression equation,

$$Y = \beta_0 + \beta_i X_i + \epsilon_i$$

where $Y$ is the dependent variable that will be defined by the independent variables of $X_i$ and their coefficients of variation ($\beta_0$) with a slope $\beta_i$ and residual errors of the estimates
The $\epsilon_i$ can easily be estimated as the difference of the predicted $Y (\hat{Y}_i)$ from the observed $Y (Y_i)$ for each observation $n$ (Draper and Smith, 1998). The residual variance ($\sigma^2_{y\cdot x}$) is known as the difference between the observed values and the corresponding predicted values and minimum residual variance has been shown to be more desirable as a selection criterion when using a specific dataset than maximum $R^2$. Residual variance is estimated as

$$\hat{\sigma}^2_{y\cdot x} = (SS_y - SS_r)/(n - p).$$

Statistic $C_p$ is highly related to both $R^2$ and $\hat{\sigma}^2_{y\cdot x}$ and can easily assist in calculating squared true error and squared lack of fit as the relationship is shown,

$$C_p = [(SS_y - SS_r)/\sigma^2] - (n - 2p).$$

Even more so related is the adjusted $R^2$ which adjusts the residual sums of squares and corrected total sums of squares by use of the corresponding degrees of freedom, and can be used to compare equations that have been derived from multiple datasets and not just from a single specific set (Draper and Smith, 1998). Even though an equation obtained a high $R^2$ value, the regression of $\hat{Y}_l$ on $Y_l$ should have an intercept not significantly different from zero and a slope not significantly difference from one otherwise bias exists in the relationship of predictors ($X_i$) to the dependent variable (MacNeil, 1983).

Additional selection criteria are Akaike Information Criterion (AIC) and Schwarz Bayesian Criterion (SBIC). Akaike’s balances precision of fit against the number of parameters used and smaller AIC values are preferred.

$$AIC_{(p+1)} = n \ln(SS(Res)_p/n) + 2(p + 1)$$
Schwarz’s offers a larger penalty for increasing the parameters (p) than AIC even though AIC is widely used and tends to select larger subset sizes than the true model needs (Draper and Smith, 1998).

\[
SBIC_{(p+1)} = n \ln(\text{SS(Res)}_p/n) + (p + 1) \ln(n)
\]

When analyzing the residuals, problematic or beneficial assumptions can arise creating modifications in the model with respect to the independent variables (MacNeil, 1983). Residuals that are found to be outside of the range designated by the normal distribution parameters would be considered outliers and the corresponding observation value would need to be inspected and deemed as an anomaly in the data or an error which occurred in the data collection process. Still, plotting the residuals of the predicted dependent and independent variables would best illustrate the potential correlation between the two considering no correlation or collinearity is required for effective model development.

The line that is best fitted for the model makes the sums of squares for all predicted variables as small as possible (Draper and Smith, 1998). During the plotting process, there should be no evidence of pattern for the residuals in variance or trend but instead points should remain within the predetermined confidence intervals about zero (MacNeil, 1983). However, some serial correlation is expected with growth data as autocorrelation is likely at shorter time intervals with size at time \( t-1 \) and size at time \( t \) (López et al., 2000).

In order to determine the validity of a prediction equation or model, independent datasets are generally used to show the potential bias by not meeting the previously discussed criterion of \( \beta_0 = 0 \) and \( \beta_i = 1 \) (MacNeil, 1983). The range of independent variables must be diverse in nature and not correlated to the independent variable. If
sufficient numbers of $X_i$ variables are not collected to define the relationship between $X$ and $Y$, bias is likely to occur and a quadratic response compared to a linear response may be observed. However, quadratic responses have been shown in growth data as cattle reach mature body size (Lofgreen and Garrett, 1968; Owens et al, 1995; Brethour, 2004). As suggested by MacNeil (1983), researchers should routinely apply published prediction equations to independent datasets since it is important to validate model accuracy for use in industry or academia, or to question the model’s future use and influence.

Analysis of Past and Currently Published Models

Oltjen et al. (1985) developed a dynamic model to predict composition of growth over the feeding period and compared this model to other growth prediction models to determine accuracy and influence of model parameters. The model developed was originally derived from the hypothesis that factors involved in regulating growth could be identified through model development from relationships at the cellular level, like that of hyperplasia and hypertrophy. It was anticipated that by applying the model to the cellular biological response on protein and fat accretion, greater accuracy of model development would be attained compared to previous highly published models widely used in the NRC (1984) which applied growth to whole animal response.

However, the difficulty of adapting a model to account for energy intake to define protein retention potential in growing steers was evident from the interdependence observed for synthesis and degradation when estimating net protein accretion like that observed by Harmon et al. (1991), Owens et al. (1995), and Rhoades et al. (1997). Generally, Oltjen et al. (1986b) noted the over-prediction of protein retention at low
energy intakes while under-prediction was likely with high energy intakes for this protein accretion model. This model was the subset for the more in-depth dynamic model that determines the manner in which parameters included in the model interact to define the pattern of growth of beef cattle. It was thought to ultimately be an explanation as to how growth is adjusted through the resulting body compositional changes and quality of nutrition supplied.

Oltjen et al. (1986b), through the creation of their dynamic model based on protein accretion, verified that metabolic body weight is SBW raised to the 3/4 power for medium-frame sized steers like that of the NRC (1984) and included the effects of frame size in the model with three assumptions. By initially assuming animals to have a similar degree of maturity, the second assumption is that rate of functional production for an animal is proportional to mature SBW to the 3/4 power, and the third is that beef animals have equivalent body composition. The influence of increasing frame size and thus mature body size through management like implanting (Owens et al., 1995), feeding beta-adrenergic agonists (Kellermeier et al., 2009; Bryant et al., 2010), or diet energy supply (Owens et al., 1995), is important to be accounted for and considered in modeling growth over the feeding period (Oltjen et al., 1986b).

To properly validate the dynamic model, Oltjen et al. (1986a) compiled data from 77 different growth studies that accounted for nutrition, initial condition, frame size and type, and the use of growth promotants and feed additives. These researchers observed limitations of the dynamic model as it does not account for incorrect energy values for feedstuffs utilized and fed to animals being tested, offers no correction for heifers or bulls compared to steer expectations, environmental influences or disease state of the animal,
or errors in feed intake prediction (Oltjen et al., 1986a). However, the benefit of this model is the potential to provide management information for a producer to more appropriately make economic projections for increased profit potential for a similar set of steer calves due to the high rate of composition projection from the dataset analyzed (Oltjen et al., 1986b).

In a more appropriate method of evaluation, Oltjen and Garrett (1988) compared the dynamic model (MODEL; Oltjen et al., 1986b) against NRC from 1976 and 1984 growth prediction equations. To evaluate the model differences, data from 46 pens of medium-frame steers used in serial slaughter studies was used to predict energy gain (EG). Because steers were implanted, 5% increase in EG was applied to NRC systems and 4.2% increase for protein synthesis for the MODEL, after linear regression was applied to determine the relationship between the predicted and the observed values for the corresponding parameters. Additionally, the correlation coefficients for residual EG were evaluated for systematic errors to predict bias (Oltjen and Garrett, 1988) which is the appropriate method of analysis considering the outside dataset usage (MacNeil, 1983).

Through updates in model determination, NRC model of 1976 did not specify frame size or age so the resulting predictions were moderate compared to the more recent NRC (1984) model for medium-frame calves and large-frames yearlings. When looking at EG predicted values against observed EG, the 1976 NRC and 1984 NRC calculated correlations of .71 and .38, respectively. The MODEL, developed to explain body composition, was more highly correlated (0.85) for predicted compared to observed values. These researchers observed both NRC models to over-predict EG for steers that
were fatter at trial initiation while EG was underestimated for steers with the potential for compensatory gain. This was not surprising to Oltjen and Garrett (1988) after finding the negative correlation of residual error with rate of gain. Additionally, EG was under-predicted at high dietary energy concentrations from the NRC equations because cattle gain faster at higher energy intakes and the NRC models were shown to be insensitive to ADG parameters. Energy gain was over-predicted as days increased (Oltjen and Garrett, 1988) since relative weight gain has been shown to plateau (Owens et al., 1995) and the quadratic effect was not accounted for in the model due to the lack of information available at prediction equation development (MacNeil, 1983). Still in the currently discussed paper (Oltjen and Garrett, 1988), implanted steers had over-predicted EG values from 1976 NRC calculations while non-implanted steer EG was under-predicted through the 1984 NRC models, but MODEL results observed no bias when implants were used. It was concluded that all models effectively controlled animal to animal variation by analysis with pen as the experimental unit and that MODEL calculations offer great benefit due to lack of bias and additional precision of predicting EG if used in strategic marketing system where daily or weekly information is needed.

McMenimen et al. (2009) compared DMI prediction equations with the NRC (1996) based on initial BW or NE\textsubscript{m}, with (4\% decrease in DMI) or without ionophore adjustments. Pen data from over 3,363 pens were used in the analysis with equations based on initial BW:

$$DMI, kg/d = 4.45 + 0.0125IWT$$

Or on metabolic shrunk BW and finishing diet \text{NE}_{m}:

$$DMI, kg/d = [SBW^{0.75} \times (0.2435NE_{m} - 0.0466NE_{m}^{2} - 0.1128)]/NE_{m}.$$
For model evaluation, DMI was predicted using previous equations and observed DMI was regressed on the predicted values with $R^2$ used to determine the strength of the relationship between the two. Model precision was observed through mean absolute error (MAE), mean square predicted error (MSPE), and root mean square error (RMSE). The mean bias of the prediction was squared to determine the variation. Systematic and mean proportional biases were also calculated with mean and linear biases calculated from regression of residuals on mean-centered predicted DMI. The data were chosen to be mean-centered so the intercept would be the mean value of the independent variable to allow for t-test for both mean and linear biases assessment. Overall, equations had significant mean and linear bias with DMI being overpredicted and resulting in negative mean biases. Even though the INWT-based equation had lower mean, mean proportional, and MSPE compared to the $\text{NE}_m$-based equations, RMSE was exceeded by maximum bias from both equations which led to the conclusion that there is a potential for improved accuracy for predicting DMI for finishing cattle.

Mixed model regression for ADG and G:F was first developed with all variables in the model with a fixed slope and intercept along with a random slope and intercept cluster for year x feedlot x season with the COVTEST option in Proc Mixed to determine the significance of random slope, intercept and slope-intercept covariance effects (McMenimen et al., 2009). By analysis of linear and quadratic functions of the independent variables, stepwise regression was used to decrease insignificant terms until an appropriate $R^2$ resulted. Noticing a large amount of variation in initial and final BW and thus $\text{NE}_m$ requirements, the authors decided to run $\text{NE}_g$ intake and multiples of maintenance consumption as covariates with DMI and metabolizable energy intake, both
as a percent of BW. While NE$_g$ intake explained up to 70% of the variation in ADG, there was no effect of increasing NE$_g$ intake on G:F observed. Even so, low overall $R^2$ values led McMenimen et al. (2009) to determine variation in breed, compensatory growth, body composition, and even pen environment could alter the influence of energy intake or utilization on a set of animals. Therefore, the relationship between intake and performance was deemed as an important association to consider for further research.

A more abstract analysis of growth compared various models to that of the “simple rational function” of a generalized Michaelis-Menten equation (López et al., 2000). Since growth curves are generally used to predict daily feed requirements, estimates regularly predict the upper limit of intake with ad libitum feeding of high-quality diets as to not inhibit potential performance. As growth functions are defined as the rate of gain as related to the state of the animal, the ability to accurately characterize physiological or biochemical mechanisms or constraints is often the goal, resulting in an equation that can interpret biological response unlike those of empirical nature. Three models were evaluated in relation to the measurable growth, as growth is irreversible, over time and proportional to the energy available to the animal on a nonlinear and linear basis. The first equation was a generalized Michaelis-Menten model (GMM):

$$ W = (W_0K^c + W_f t^c)/(C^c + t^c) $$

where $W_0$ and $W_f$ were the zero- and infinite-time values of biomass ($W$, kg), respectively with time $t$ and week $K$. The other two were well-known functions of the time by Gompertz and Richards as described by France and Thornley (1984) and used by López et al. (2000).

Gompertz

$$ W = W_0 \exp[\mu_0(1 - e^{-Dt})/D] $$
Richards

\[ W = \frac{w_0 w_f}{[w_0^n + (w_f^n - w_0^n)e^{-kt}]^{1/n}} \]

The sigmoidal effects observed from these equations by France and Thornley (1984) were the justification for use by the authors because of the fixed (Gompertz) and variable (Richards) inflection points. The Durbin-Watson statistic was used to determine serial correlation for each analysis. Lower residual sums of squares was the determining factor for model superiority when equations were fit to the same dataset with statistically significance analyzed by F-tests. Mean square prediction error was the error measure between the growth parameter estimates of each model and was separated into overall bias, slope deviation, and random variation components. Results showed that for over 85% of the cases analyzed, the simple GMM model was not the appropriate analysis as residual sums of squares was always greatest through goodness-of-fit evaluation. Here, the Durbin-Watson statistic further examined the correlation residuals to determine autocorrelation within the models. Some correlation will exist due to the relationship between time and size in the prediction of growth. Still, R^2 values were high for all models and were only used for fit analysis instead of model comparison. Therefore, pairwise comparisons were made between the models. Overall, the GMM model gave fits that were steeper at the point of inflection and flatter during the initial curve but was able to fit the growth data with similar results as that of the Richards model and was more accurate than that of the Gompertz model with better distribution of residuals and comparable goodness-of-fit. The authors preferred the flexibility and simplicity of the Michaelis-Menten equation to the others because of its sigmoidal tendency for response. This interpretation is in contradiction of other analyses which analyze the linear regression the growth parameters over time (Oltjen et al., 1986b; Vasconcelos and
Galyean, 2008). The preference for the sigmoidal response could be justified as a nonlinear response to growth versus intake and has been repeatedly observed (MacNeil, 1983; Oltjen and Garrett, 1988; Owens et al., 1995).

Growth rate, or average daily gain, is typically used in growth prediction development as opposed to body weight measurements over time (Rattanaronchart et al., 1983) because of increased cost of time and labor of repeatedly running cattle through the chute for data collection (Lawrence et al., 2001). Five least squares equations were used to predict ADG by considering differences in the error of the variance-covariance matrix. Predicted ADG ($\hat{ADG}$) was defined as:

$$\hat{ADG}_i = \hat{b}_1 + (a_1 + a_t)\hat{b}_2$$

from 

$$b_i = (X'V^{-1}X)^{-1}X'V^{-1}y_i$$

where $\hat{b}_1$ and $\hat{b}_2$ are the estimates of linear and quadratic regression coefficients of $a_1$ and $a_t$ at initial and final ages, respectively. Because ordinary least squares obtains minimum variance and therefore unbiased linear estimates, five equations were used for prediction. If matrix V was equal to the identity matrix multiplied by the variance, the estimator of ADG was ordinary least squares (OLS). If V was a known parameter, the estimator was generalized least squares (GLS). If V was estimated from a prior dataset, the estimator was prior estimated generalized least squares (PGLS). If V was estimated from the dataset used by the authors, the estimator was estimated generalized least-squares (EGLS). And if V was estimated from part of the data used by the authors and applied the remaining for comparison, the estimator was Partial estimated generalized least-squares (EGLSP). The comparison was made among simulated data where parameter estimates for fixed effects and variance components were derived from actual
data. The sixth equation was defined as USUAL and is the estimation of initial BW from final BW divided by the days between the two. The relative efficiency of the six methods was evaluated in two ways. First the estimated mean squared error of the estimated ADG ($\overline{MSE(\overline{ADG})}$) and the second, by the sum of the estimated MSE of the estimated variance due to simulated data for side and errors ($\overline{MSE(\sigma_s^2)} + \overline{MSE(\sigma_e^2)}$).

Even though GLS was deemed the most accurate due to true variances and covariances of errors by matrix V, true V is unknown making EGLS the next “best” estimation method for ADG. Sire and error variances estimated from $\overline{ADG}$ were noted to be biased when compared to actual ADG calculations. The usual estimator was 26% and 64% larger for each parameter than $\overline{MSE(\overline{ADG})}$ and $\overline{MSE(\sigma_s^2)} + \overline{MSE(\sigma_e^2)}$, respectively, for EGLS and 24% larger for $\overline{MSE(\sigma_s^2)} + \overline{MSE(\sigma_e^2)}$ for EGLSP. This allowed Rattanarorachart et al., (1983) to conclude that EGLS and EGLSP may be more efficient at predicting ADG because of the smaller error values. However, OLS was more difficult to calculate than the usual estimator but EGLS may be preferred because of the more precise estimates of ADG.

The need for improving accuracy of predicting ADG was determined by Block et al. (2006) with the NRC (1996) models utilizing adjustments to net energy values. This research was derived from historical data collected and used to evaluate predicted gain from the NRC beef cattle model 1 and the NE adjustment requirements to improve prediction accuracy. The adjustments required for individually fed cattle were compared to those for pen-fed finishing trials to determine the variation in thermoneutral conditions as well as individual influence versus pen averages. Weights, DMI, diet composition, and use of ionophores were inputs into the model with energy density of the diet analyzed by
TDN conversion to $\text{NE}_m$ and $\text{NE}_g$. Accuracy, slope, and intercept responses were determined for observed ($y$) versus predicted ($x$) values when values were regressed using SAS and bias and MSPE were calculated. Diet $\text{NE}_m$ and $\text{NE}_g$ were adjusted until predicted met corresponding observed values. The resulting adjustments values were regressed on observed ADG, TDN intake, and TDN concentration using Proc NLIN procedures for prediction equation development for accurate ADG. For environmental influences, $\text{NE}_m$ was adjusted by increasing requirement levels for acclimation and cold stress.

Sensitivity analysis by Block et al. (2006) showed ADG to be rather insensitive to changes in FSBW, BCS, and diet NE$m$, somewhat sensitive to diet NE$g$ changes, and highly sensitive to TDN to DE conversion changes. Use of growing and finishing trial data showed prediction of ADG to be relatively precise, but inaccurate as the regression of observed ADG on predicted ADG was statistically different than the isopeth (1:1). The mean bias and RMSE of prediction bias were 0.24 kg and 0.44 kg, respectively, with RMSE of prediction bias (29%), slope deviation (54%), and lack of perfect correlation (17%) making up that inaccuracy. The prediction of ADG from the individually fed trials differed slightly as it was less precise and was inaccurate with a difference in the regression and the isopeth as seen with the pen-fed analysis. Again mean bias was 0.24 kg and RMSE of prediction was 0.39 kg with 39, 10, and 51% of the inaccuracies accounted for by RSME of prediction bias, deviation of the slope, and lack of perfect correlation, respectively. For those cattle individually fed, NE adjustments were 0.906 to force predicted ADG to meet that of the observed values. The pen-fed trials required
more NE adjustment at 0.820 for accurate prediction. These results indicate an over-prediction problem for ADG with the NRC (1996) model level 1.

Since pen-fed data had an average observed ADG of 1.559 kg, acclimation and cold stress adjustments with actual intake cause predicted ADG to decrease to 1.667 kg from 1.775 kg prior to adjustment, though still greater and statistically different from the observed ADG (Block et al., 2006). Due to significance found, the authors decided to only observe acclimation and cold stress during the times as which such occurred. Upon this correction, predicted ADG (1.598 kg) was not different than the observed values (1.559 kg). Even so, Block et al. (2006) stressed that this did not conclude that the submodel accounting for environmental effects was correct nor would its inclusion always increase accuracy but rather explained the importance of accounting for time variables in environmental changes during the feeding period. Individually-fed trials were not analyzed for environment stress as they were housed and did not experience the cold stress fluctuations of that compared to pen-fed cattle. The influence of NE adjustment for predicted ADG was relatively low but had little variation in the residuals. However, there was a stronger relationship observed between TDN intake and NE adjustment required for prediction of ADG. The best relationship while also having the lowest residual variation was found between TDN concentration and the required NE adjustment for predicting ADG to meet that of the observed ADG. Overall, the issue noted was that the NE adjuster required for accurate prediction of ADG was different for different datasets, depicting the influence of the dataset in which the NE adjusters were derived. Still, it was concluded that further research is needed with regard to modeling energy use in cattle.
Model Development and Validation

Traditional dietary energy values are separated into NE\textsubscript{m} and NE\textsubscript{g} and calculated by multiplying corresponding tabular energy values for feedstuffs by feedstuff inclusion level (NRC, 2000). However, Zinn et al. (2002) published a quadratic formula to estimate NE values of the diet from animal performance:

\[
x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}
\]

where \(a = -0.877\text{DMI}, b = 0.877(0.077\text{BW}^{0.75}) + 0.41\text{DMI} + \text{RE},\) and \(c = -0.41(0.077\text{BW}^{0.75}),\) and \(\text{NE}_{\text{m}} = \left\{-0.877(0.077\text{BW}^{0.75}) + 0.41\text{DMI} + \text{RE}\right\} - \left\{(0.877(0.077\text{BW}^{0.75}) + 0.41\text{DMI} + \text{RE})^2 - (1.438 \times 0.077\text{BW}^{0.75} \times \text{DMI})\right\}^{0.5}\) and \(\text{NE}_{\text{g}} = 0.877\text{NE}_{\text{m}} - 0.41.\) This approach to predicting diet energy level has been used for comparison several times (Zinn et al., 2008; Vasconcelos and Galyean, 2008; McMenimen et al. 2009).

Zinn et al. (2008) utilized a dataset of more than 3.1 million finishing cattle to develop equations to standardize predictions of MFW, DMI, and ADG based off of initial SBW and to revise coefficients for current NE equations for steers and heifers since bias in gain was observed. Additionally, precision and bias of newly developed equations or defined coefficients were analyzed by use of an independent dataset. With over 14,000 pens to be analyzed and considered the experimental unit, fixed NE values for diets were required in order to match predicted DMI to that of the observed data. Dietary NE\textsubscript{m} estimates for each pen were based on diet composition from the sum of tabular NE\textsubscript{m} multiplied by individual feedstuff inclusion levels. Furthermore, calculated DMI from two NRC (1984 and 1996) prediction equations was forced to meet observed DMI across
BW, sex, and ADG and so if the DMIratio (observed:predicted DMI) was 0.98, DMI for that pen was multiplied by 1.02. By doing so, the CV for DMIratio decreased 5.5%.

Models were determined when linear or quadratic terms from the full models as they were deemed to be insignificant by the authors’ set requirements (Zinn et al. 2008). With an assumed variance-covariance structure for regression variables, REML was used to estimate models with the MIXED procedure and COVTEST option for analysis and hypothesis testing of the independent variables, respectively. Selection of the final model was based on Akaike’s (AIC) and Schwarz’s (SBIC) criteria. Regressing Y-adjusted ($\hat{Y}_i +$ residuals) dependent variables against respective observed independent variables resulted in $R^2$ values to determine model fit. The REG procedure in SAS (SAS Int. Inc., Cary, NC) was used to develop model calculation and determination with measurements of MFW, ADG, DMI and dietary NE (dNE) carrying the greatest influence for performance projections.

Because correlation exists between ADG and DMI (i.e., DMI increases, and so does ADG), Zinn et al. (2002) eliminated the bias and predicted retained energy (RE, aka EG) with a new coefficient by forcing DMIratio = 1.00.

$$RE_{steer} = 0.0606 \times (LW \times 478/MFW_{steer})^{0.75} ADG^{0.905}$$

$$RE_{heifer} = 0.0618 \times (LW \times 478/MFW_{heifer})^{0.75} ADG^{0.905}$$

This equation differs from the NRC (1984, 1996) in that RE is shown to increase but at a decreasing rate as ADG increases, rather than increasing at an increasing rate with ADG. And after a multiple-regression analysis, initial shrunk BW (SBW) became the premier determinant of ADG for both steers and heifers.

$$ADG_{steer} = 0.6664 + 0.003091SIW - 0.00000143SIW^2, \quad R^2 = 0.89$$
Zinn et al. (2008) concluded that by scaling MFW for sex the estimation of RE from ADG can account for energy utilization differences.

Through a simulation technique of data development for 100 hypothetical experiments, statistical sensitivity was evaluated by Vasconcelos and Galyean (2008) for dNE concentrations calculated from the quadratic solution (Zinn et al., 2002). Three case studies were conducted from the compiled data. Cattle were assumed to be fed for 150 days and dNE values were calculated based from population means for initial SBW (IBW) and final SBW (FBW). Treated populations had adjustments applied to the performance data to illustrate sensitivity to dNE concentrations. Adjustments were a 12-kg increase in mean SBW applied in case 1; a 19-kg increase in mean SBW and 0.25-kg increase in DMI in case 2; and a 0.43-kg decrease in DMI and no change in ADG in case 3. Case 1 results observed the effects of increasing FBW by 12 kg with no change in DMI, resulting in a 5% increase in G:F. Dry matter intake only differed in 3% of the 100 experiments tested, while ADG was different in 87% of the experiments. Less sensitivity was observed in displaying treatment differences in NE\textsubscript{m} and NE\textsubscript{g} compared to ADG or G:F for treated or control groups for NE concentrations. Intake was increased by 0.25 kg for the treated populations for case 2 with FBW increasing 19 kg compared to those cattle on the control treatments. This adjustment created a 100% difference in FBW and ADG with treated groups carrying higher values than those of the control fed animals in all experiments. However, only 53% of the experiments were different for DMI and converted to only a 52% difference for G:F and less sensitivity for these parameters observed. Additionally, NE\textsubscript{m} and NE\textsubscript{g} were in contrast to results of case 1 and differed

\[ ADG_{\text{heifer}} = 0.4421 + 0.004336SIW - 0.00000429SIW^2, \quad R^2 = 0.92 \]
in only 23% of the experiments. Since, case 3 was altered to decrease DMI by 0.43 kg for cattle fed in the treated group and not change FBW, DMI expectedly was different for 91% of the experiments and G:F was different in 55% of the experiments, resulting in similar sensitivity as case 1 for G:F. However, ADG was only differed in 3% of the experiments which was observed through the NEm and NEg values differing in 78% of the experiments as NE values were deemed the most sensitive among parameters.

As expected, Vasconcelos and Galyean (2008) concluded that sensitivity in detecting treatment effects with animal performance determined that dietary energy values depended on the performance parameter adjustments. In all, the researchers encouraged others to calculate dNE values from performance data because the energy values of feedstuffs from treatment effects can be extrapolated and more easily observed. However, no statistical advantage is attained from the differences based on performance from which concentrations were derived, supporting the need to separate datasets for deriving predictions and testing their values (MacNeil, 1983).

McMenimen et al. (2010) utilized their previous analysis (McMenimen et al. 2009) to conduct prediction equation development for DMI through the use of initial SBW, sex, number per pen, and finishing diet NE_m, NDF, and tallow concentrations which all impact energy intake. Diet composition was determined from dietary ingredient DM records from the feedlot data while ingredient composition was collected from NRC (1996) to determine overall dietary NE_m concentrations. Additionally, all pens were implanted and received monensin as a feed ingredient and DMI prediction equations were adjusted accordingly. Five prediction equations were developed utilizing the MIXED procedure to fit random coefficients, generalized least squares regression with year x
season x feedlot interaction as a random variable in an unstructured variance-covariance matrix.

\[ Eq. 1 \quad DMI = 3.31 + 0.0154 \, ISBW \]

\[ Eq. 2 \quad DMI = 3.73 + 0.0146 \, ISBW \]

\[ Eq. 3 \quad DMI = 3.83 + 0.0143 \, ISBW \]

\[ Eq. 4 \quad DMI = 2.00 + 0.524 \, DMI_{8-28d} + 0.00709 \, ISBW \]

\[ Eq. 5 \quad DMI = 2.55 + 0.470 \, DMI_{8-28d} + 0.00692 \, ISBW \]

All independent variables were included in the initial models while stepwise-regression subsequently eliminated insignificant variables until the final model was obtained based on the criteria of AIC. Because these models were created for empirical purposes and not causal, correlation was not tested for independent variables to demonstrate collinearity. Models were independently analyzed for adequacy and precision which was determined by RMSE of prediction (RMSEP), mean square error of prediction (MSEP), concordance correlation coefficient (CCC), \( R^2 \), and mean bias. Modified bootstrapping and cross-validation techniques were both used for subset sample determination within the dataset to better simulate and test model accuracy.

The researchers found predicted DMI based on ISBW of Eq. [1] accounted for 48.7 to 66.4\% of the variation from observed DMI. When sex was added to the model (Eq. [2]) as well as the interaction of ISBW with sex (Eq. [3]) improvements in \( R^2 \), CCC, accuracy and RMSEP of the models was observed for predicting intake with Eq. [2] increasing DMI 0.3 kg/d for steers compared to heifers. The addition of \( DMI_{8-28d} \) (Eq. [4] and [5]) to the models greatly improved accuracy as overprediction was decreased from 0.21 to 0.05 kg/d while model evaluation parameters were improved compared to Eq. [1],
Predicted intake by Eq. [4] explained 68.0 to 80.7% of the variation in observed DMI with an accuracy of 95.2 to 99.5%. The addition of sex (Eq. [5]) only marginally improved accuracy and $R^2$ values.

Monensin feeding adjustments were applied in two ways by McMenimen et al. (2010) through dietary NE$_m$, which increases the outcome by 12% or through predicted DMI which decreases the value 4%. The authors concluded that the most appropriate adjustment is to apply both as RMSE of prediction was decreased, mean bias was decreased by 0.13 kg, CCC was improved, and accuracy was improved from 94.3 to 98.4%. However, systematic bias of MSEP was increased, thus labeling these adjustments as “less than perfect.” Still, effective prediction of DMI and ADG requires accurate estimation of final SBW as it relates to initial SBW. McMenimen et al. (2010) ultimately determined that, while future research is required, prediction is useful at a commercial level. However, accurate prediction of intake may only be applied from an internal standpoint to the each feedlot by use of results from previously fed groups and feedlot pen averages.

**Research objectives**

Research discussed here explains how prediction of performance parameters like that of DMI, ADG or marbling score can allow producers the opportunity to market cattle at an optimum weight or finishing point while maintaining or anticipating input costs. However, accurate and consistent prediction is difficult with current equations derived from aged performance data and calculated with tabular energy values. The use of performance data tends to increase accuracy for prediction though large numbers are
needed to increase precision. The use of large databases could potentially increase accuracy because variation between animals is increased and included in the modeled prediction equation instead of in the residual bias. Therefore, the objectives of this dissertation are:

1) Evaluate currently published DMI prediction equations and determine accuracy and precision using current methods of calculation.

2) Develop a DMI prediction equation from a dataset of individually fed steers to illustrate inaccuracies with currently published models and feedstuff energy values.

3) Evaluate factors influencing marbling score over the feeding period and to use such parameters to predict marbling score and optimum finishing point of individually fed steers.

4) Determine the optimum marketing strategy for finishing steers at varying corn price whether sold live or on a carcass weight basis.
LITERATURE CITED


Neumeier, C. J. and F. M. Mitloehner. 2013. Cattle biotechnologies reduce environmental impact and help feed a growing planet. Anim. Fron. 3(3) 36-41


Evaluation of diet net energy calculations within intake prediction equations for NRC (1996) feedstuff energy value accuracy
M. F. Wilken², G. E. Erickson², L. L. Berger¹,², M. K. Nielsen², M. L. Spangler², and S. D. Kachman³
¹Department of Animal Sciences, University of Illinois at Urbana-Champaign, Champaign, IL, 61280
²Department of Animal Sciences, University of Nebraska-Lincoln, Lincoln, NE 68583
³Department of Statistics, University of Nebraska-Lincoln, Lincoln, NE 68583

ABSTRACT: A dataset complied from four years of research conducted with individually fed calf-fed steers (n = 1,794) was utilized to 1) test currently published DMI prediction equations (NRC-84, NRC, 1984; NRC-96, NRC, 1996; Owens-02, Owens et al., 2002) and 2) utilize data from animals in yr 1, 2, and 3 to develop intake prediction equations to be tested on intake during yr 4. Individual intakes were measured daily for calf-fed steers fed 13 diets varying in diet NEₘ values by the use of GrowSafe feeding system (GrowSafe Systems Ltd.). Dietary NEₘ values were calculated by 1) using the sum of the product of traditional NRC (1996) feedstuff NEₘ values and the feedstuff inclusion (dNEₘ-NRC) and 2) by a quadratic equation from Zinn et al. (2002; dNEₘ-Zinn) from animal performance in response to dietary intake. Results showed predicting intake from animal performance is more accurate and allowed for better model fit than using assigned energy values from the 1996 NRC. Additionally, Owens-02 was more accurate in predicting intake by having lower absolute bias within treatments compared to NRC-84 and NRC-96. Models tested against yr 4 data were developed using dNEₘ-Zinn values, initial BW, shrunk BW and metabolic shrunk BW. Models were tested against yr 4 using both dNEₘ-NRC and dNEₘ-Zinn with initial BW, shrunk BW and metabolic shrunk BW. Models containing dNEₘ and initial BW were determined to be the most accurate with intermediate mean absolute bias, greatest r-squared values, the mean
residual bias closest to zero compared to all other models with dNEm, shrunk BW, and metabolic shrunk BW including NRC-96. However, models containing dNEm and shrunk BW had the least mean absolute bias results but had the lowest r-squared values overall. No difference was found between dNEm-NRC and dNEm-Zinn when testing against yr 4 data. Ultimately, it was concluded that in relationship to diet energy values, the addition of ethanol byproducts into feedlot diets limits model potential to accurately predict DMI as model fit decreases and absolute mean bias increases with inclusion of byproducts in diets. The inclusion of a BW variable is necessary to improve accuracy. These results suggest further research into feedstuff energy value prediction is recommended.

**Keywords:** Dry matter intake, prediction equations, finishing cattle, byproducts.

**INTRODUCTION**

Due to increased availability of ethanol byproducts and the increased feeding rate of such high energy feedstuffs over the last decade, great interest has been observed for the actual feeding value of byproducts like corn gluten feed (CGF) or corn distillers grains with solubles (DGS). Feeding DGS or CGF has been shown to increase efficiency and performance of finishing cattle (Klopfenstein et al., 2008). Energy values of the feedstuffs have yet to be determined even though relative feeding value compared to corn-based diets has been analyzed in both finishing diets (Stock et al. 2000; Klopfenstein et al., 2008) and forage-based diets for backgrounding calves (Nuttleman et al., 2009).
The energy value of ethanol byproducts on a TDN or NE_{m} and NE_{g} basis within the NRC (2000 update) is equal to that of soybean hulls, and less than corn even though DGS contains 3 times the amount of protein, fiber, and fat compared to corn (Klopfenstein et al., 2008) with CGF comparable to DGS from a feeding value standpoint (Stock et al., 2000; Klopfenstein et al., 2008).

McMenimen et al. (2009) conducted a study to analyze DMI prediction equations from NRC (1996) to determine if initial BW or dietary NE_{m} was more accurate for predicting intake over the feeding period. From this analysis, initial BW may result in simpler and more accurate predictions because initial BW is taken upon arrival while dietary NE_{m} is an arbitrary value (McMenimen et al., 2009). Still, energy values of the feedstuffs drive carcass composition and value product potential (Owens et al., 1995). Additionally, McMenimen et al. (2009) found the lack of association between dietary NE_{m} adjusted intake and feed efficiency required further analysis. Therefore, the objective of this analysis was to determine if reevaluation of feedstuff energy values is required by use of predicted intake results from current models and to derive a new DMI prediction equation for more accurate intake estimation.

**MATERIALS and METHODS**

*Data collection*

Data from 1,794 individually fed Angus, Simmental, and Simmental-Angus cross calf-fed steers were collected over 4 yr and used to analyze predictability of three currently published and well-known DMI equations for growing and finishing steers. Animals were transported from the same Montana and Wyoming based ranches to the
University of Illinois-Urbana for studies relating to ethanol byproduct feeding effects on performance, as well as to evaluate growth and carcass changes over the feeding period by intermittent ultrasound and weight collection. Cattle were housed in open back barns with approximately 40 hd per pen and fed once daily. Daily intakes were measured for individual animals by use of the GrowSafe feeding system (Model 4000E, GrowSafe Systems Ltd., Airdie, Alberta, Canada).

Thirteen diets were fed over the 4 yr ranging in diet $\text{NE}_\text{m}$ from 1.92 to 2.13 Mcal/kg and diet $\text{NE}_\text{g}$ from 1.28 to 1.48 Mcal/kg as calculated using the NRC (1996) feedstuff energy values. All animals received implants and were fed monensin (Rumensin, Elanco Animal Health, Indianapolis, IN) at 330 mg/hd/d during the finishing period. The implant program consisted of yr 1, 3, and 4 steers receiving Component TE-IS (80 mg trenbolone acetate, 16 mg estradiol, 29 mg tylosin tartate; Elanco Animal Health, Indianapolis, IN) at the initiation of finish phase feeding, and re-implanted with Component TE-S (120 mg trenbolone acetate, 24 mg estradiol, 29 mg tylosin tartate; Elanco Animal Health, Indianapolis, IN) at 76 d on feed. The implant strategy for steers fed in yr 2 were composed of Revalor-G (40 mg trenbolone acetate and 8 mg estradiol; Merck Animal Health, Summit, NJ) given at trial initiation and re-implanted with Component TE-S (120 mg trenbolone acetate, 24 mg estradiol, 29 mg tylosin tartate; Elanco Animal Health, Indianapolis, IN) after 84 d on feed. All diets fed were formulated to meet or exceed the minimum NRC (1996) requirements for maintenance and gain and can be found in Table 1.

Animals used in these trials were managed according to the guidelines recommended in the *Guide for the Care and Use of Agriculture Animals in Agriculture*
Research and Teaching Consortium (1988). Experimental protocols were submitted and approved by the University of Illinois Institutional Animal Care and Use Committee.

**Prediction Equation Analysis**

The three equations analyzed were originally published in the 1984 NRC (NRC-84), the 1996 NRC (NRC-96), and Owens (2002; Owens-02). The 1984 NRC published equation was the initial equation to predict DMI and is calculated from metabolic shrunk BW (SBW\(^{0.75}\)) and diet NE\(_m\) (dNE\(_m\)) as shown:

\[
DMI, \ kg/d = SBW^{0.75} * (0.1493 * dNE_m - 0.046 * dNE_m^2 - 0.0196).
\]

In 1996, the NRC published a DMI equation that corrected for sex, frame size, and age. Coefficients were altered slightly compared to NRC-84 while maintaining the basis of metabolic SBW (SBW\(^{0.75}\)) and diet NE\(_m\) (dNE\(_m\)) and is below:

\[
DMI, \ kg/d = [SBW^{0.75} * (0.2435 * dNE_m - 0.0466 * dNE_m^2 - 0.1128)/NE_m],
\]

where the intercept term is -0.0869 for yearling steers and heifers, instead of -0.1128 which is for calf-fed animals. This equation contains options for breed, ionophore feeding, body fat content, temperature, mud, and implant adjustment as explained in the 1996 NRC and the 2000 update, which are multiplied to the listed equation. Besides this equation, the NRC (1996) also contains a DMI prediction equation based on initial BW. McMenimen et al. (2009) analyzed the difference between the 1996 NRC initial BW based equation versus that based on metabolic SBW and dNE\(_m\) values and observed that initial BW was a simpler prediction parameter. The third equation by Owens (2002) was selected because it combined the concepts of initial BW (IBW), metabolic SBW, and dNE\(_m\) values to predict intake levels over the feeding period as shown:
\[ DMI, \text{ kg/d} = \left[ (-3.99 + 0.3885 \times SBW^{0.678}) - 3.788 \times dNE_m - 0.000023 \times IBW^2 \right], \]

where the metabolic SBW power is 2/3 because of the analysis conducted by Heusner (1991) that revealed a relationship between large and small mammals is parallel in regression lines with the slope of 0.678, thus maintaining the 2/3 power coefficient.

The previous equations discussed were compared through two ways of determining \( dNE_m \). The first method utilized the NRC (1996) ingredient NE\(_m\) values listed in Table 2 to calculate diet energy composition (dNE\(_m\)-NRC; Table 3). The second method was a quadratic equation developed by Zinn et al. (2002) calculating dietary energy values (dNE\(_m\)-Zinn) from animal performance and is shown:

\[
dNE_m, \text{ Mcal/kg} = \frac{\left[ -b - \left( b^2 - 4ac \right)^{0.5} \right]}{2a},
\]

where \( a = -0.877 \text{ DMI}, \ b = 0.877 \text{ SBW}^{0.75} + 0.41 \text{ DMI} + \text{RE}, \) and \( c = -0.41 \text{ SBW}^{0.75} \).

Because dietary energy for gain (dNE\(_g\)) is total energy intake subtract that required for maintenance, the calculation is \( \text{dNE}_g = 0.877\times \text{dNE}_m - 0.41 \). Because animal performance is required for this calculation, dietary energy values will vary for each animal thus, creating a varying dietary energy value and not a standardized value within diet feeding group.

With animal as the experimental unit, DMI was calculated using the three prediction equations with energy values derived from the NRC composition (dNE\(_m\)-NRC; Table 3) and animal performance (dNE\(_m\)-Zinn) resulting in six DMI predictions. Prediction equation parameters were applied for each animal and each predicted intake was analyzed within each treatment. Mean absolute bias was calculated for prediction equation within diet to illustrate average bias regardless of over or under estimation compared to observed animal intake (Table 4). This bias is the absolute value of the
difference between the observed intakes and the predicted mean intake from each prediction equation within diet. Coefficients of determination were calculated as the variance of the residuals over the product of the variance of the predicted values, and the variance of the observed intake from one for each diet by prediction equation effect (Table 5).

\[ R^2 = 1 - \left[ \frac{\sigma_{res}^2}{\sigma_{obs}^2} \right] \]

**Dataset-Specific Prediction Equation Development**

The dataset was further used to create DMI prediction equations using different combinations of parameters measured, dNEm-NRC or dNEm-Zinn, with IBW, SBW, or metabolic SBW. Parameters were also analyzed independently for correlations and the correlation matrix is shown in Table 6. Models were derived from yr 1, 2, and 3 data and were tested against animals fed during yr 4 with dNEm-Zinn (Table 7). If the quadratic function of the parameter tested was not significant, the linear response was used. Because weight gain is influenced by energy intake, the variables utilized are not completely independent. However, variables relating to body weight were not included in the same model nor were the two comparative dNEm values. The NRC-96 model was also evaluated against the dataset performance models.

Observed DMI was tested as the dependent variable using the GLIMMIX procedure of SAS against the independent variables of diet and residual bias of each prediction equation (Observed DMI – Predicted DMI) within diet with animal as the experimental unit. Year, breed, and their interactions were treated as random effects. Mean absolute bias was used to determine the average bias of prediction equation
regardless of over or under prediction (Table 8). R-squared values were calculated as previously discussed to determine model fit (Table 9). Residual bias of prediction equation was also calculated to illustrate the over- and under-prediction of intake compared to the observed DMI (Figures 1-4).

RESULTS

Prediction Equation Comparison

Results shown in Table 4 of absolute mean bias of predicted intakes calculated from either dNE_{m}-NRC of dNE_{m}-Zinn energy values were the lowest most often for Owens-02. This means that on average Owens-02 offers the best prediction of intake in comparison with the observed animal intakes. On the other hand, both NRC prediction equations displayed greater deviation from the observed animal intakes, though improvement in prediction was noted when energy values were calculated using Zinn et al. (2002) quadratic formula compared to NRC assigned feedstuff energy values. The decrease in bias from the observed for dNE_{m}-Zinn was expected considering the energy values are based on actual animal performance instead of arbitrary book values. By using animal performance, Zinn et al. (2002) addresses the energy utilization efficiency each animal has on a diet and therefore, performance alters diet energy values based on each animal’s metabolic efficiency of production.

Mean absolute bias varied across diets for each of the prediction equations. As byproducts were included in the diets fed, predicted animal intakes tended to vary more from the observed intakes than those with 60% or more corn inclusion. The predicted intakes from animals fed with no corn had the greatest mean absolute bias and the most
deviation from the observed (Table 4). However, the anomaly which cannot be explained from the data is that the animals fed diet 12 containing 50% corn and 25% modified DGS and had a dNE$_{m}$-NRC of 2.130 Mcal/kg consuming 12.62 kg daily, while those fed diets 1 and 2 with similar energy and feedstuff inclusion consumed only 9.59 and 9.70 kg per d, respectively (Table 3).

Model fit measured via R-squared values were variable between predicted intakes for all diets compared to the observed regardless of prediction equation. Differences in trends for accuracy were noted between predictions based on dNE$_{m}$-NRC or dNE$_{m}$-Zinn. For predicted intakes from dNE$_{m}$-NRC, NRC-96 offered the greatest R-squared values more often than the NRC-84 with Owens-02 calculating the least model fit. This response is inverse compared to the results of mean absolute bias with lower difference and variance for the overall prediction versus observed data for intakes predicted via Owens-02 compared to NRC-84 and NRC-96. Even so when energy values were calculated from performance (dNE$_{m}$-Zinn), NRC-84 had the best model fit within treatment eight out of thirteen times. The model from Owens (2002) predicted intakes similar to that observed intakes from animals fed the remaining five diets. The intake prediction equation, NRC-96, was the least accurate for fit regardless of diet energy calculation which mirrors the results of the mean absolute bias calculations.

Interestingly, NRC-96 adjusts for implant administration, monensin feeding, breed type, and environment (NRC, 2000) which should reduce bias. The lack of fit from NRC-96 within this dataset could be due to the lack of variation between animals and diets since animals were obtained from the same ranches every year, with the same sires, in the same housing and fed diets similar in energy concentration.
Regardless of equation, predicted intake varied 1.0 kg or greater from that of the observed intake for diet 1. Diet 1 is an industry standard corn and corn silage based diet (Klopfenstein et al., 2008), and the prediction equations were originally derived from animals fed similar diets with energy values based from TDN calculations (NRC, 2000). Bias for the observed values shows one of two potential parameter problems as both are included in all models: 1) the energy value of corn has changed and therefore, all feedstuff energy values may need to be reevaluated for more accurate predictability in calculating diet energy values; or 2) the calculation of metabolic SBW may need to be reconsidered, as growth and breed effects have potentially changed in the last 50 years (Owens et al., 1995; Ferrell and Jenkins, 2008). Therefore, diet energy values calculations and weight factors were evaluated.

**Developed Prediction Equation Analysis**

Models were developed from yr 1, 2, and 3 data with dNE\textsubscript{m}-Zinn to predict intake for animals fed during yr 4. Variables of IBW, SBW, and metabolic SBW were evaluated to predict DMI in relationship to both dNE\textsubscript{m}-NRC and dNE\textsubscript{m}-Zinn. Intakes for models A, B, and C were calculated using dNE\textsubscript{m}-NRC with IBW, SBW, and metabolic SBW, respectively. Similarly, intakes for models D, E, and F were calculated using dNE\textsubscript{m}-Zinn for the corresponding variables to create a pairwise comparison between dNE\textsubscript{m}-NRC and dNE\textsubscript{m}-Zinn. Additionally, models G and K were created strictly on the basis of dNE\textsubscript{m} influence on DMI with each tested with dNE\textsubscript{m}-NRC and dNE\textsubscript{m}-Zinn respectively. Model H is based on the influence IBW has on predicting DMI, with model I depicting DMI response to SBW, and model J illustrating the influence of metabolic
SBW to predict DMI. Interestingly, dNE\textsubscript{m} was only significant for the quadratic term in models G and K, so the linear term was used in models A – F (Table 7).

Results from testing of models on yr 4 data showed models G, H, and K to be unusable when predicting DMI after evaluation of mean absolute bias (Table 8) and r-squared values (Table 9) from prediction, therefore illustrating dNE\textsubscript{m} and metabolic SBW alone do not accurately predict DMI. With the exclusion of these three, the remaining models from the performance data of yr 1, 2, and 3 resulted in less variation in predicted DMI from the observed values compared to NRC-96 regardless of dNE\textsubscript{m} calculation.

Pairwise comparisons were made between models A and D, B and E, and C and F with dNE\textsubscript{m} -NRC energy values used in A, B, and C prediction equations while D, E, and F were calculated with dNE\textsubscript{m} -Zinn values. Models B and E calculated the least mean absolute bias which included dNE\textsubscript{m} and SBW as independent variables compared to all other models. Models A and D had the greatest variation in prediction from performance derived equations with models C and F being intermittent in the pairwise comparison. Models I and J were intermittent of the performance derived models even if being singularly calculated from SBW and metabolic SBW, respectively.

R-squared values are shown in Table 9 with the best model fit observed by models A and D regardless of diet. Models I and J calculated the lowest model fit values while C, F, and NRC-96 calculated by either dNE\textsubscript{m} -NRC or dNE\textsubscript{m} -Zinn were intermittent. The results of the pairwise comparisons depict no differences in model fit r-squared values, even though modest differences are noticed with the mean absolute bias calculations. From the mean absolute bias values in combination with the coefficients of determination, model D more accurately calculates DMI for animals consuming diets 1
and 4 while model A more accurately predicts intake for animals fed diets 7 and 13. This is concerning from the standpoint that diet 1 was the traditional corn and corn silage-based diet in which the NRC values were derived, but animal performance allows for better parameter fit, substantiating the need for the reevaluated of feedstuff energy values.

With models A and D offering the best combination of bias and r-squared values for the prediction of DMI for animals in yr 4, Figures 1 – 4 show each to have the greatest variance in residual bias but the mean is closest to zero compared to all other models. Even though NRC-96 minimizes the variation in bias more often than all other models, the mean for each prediction of DMI is the farthest from zero which corresponds with the mean absolute bias calculations and the lower model fit r-squared values compared to models A and D. These results reinforce the need for the combination of IBW and dNE values to predict DMI. Even though SBW and metabolic SBW decrease the residual bias variation comparatively, the mean predicted bias is no closer to zero than that of the NRC-96 predictions.

DISCUSSION

Vasconcelos and Galyean (2008) conducted a technical review of determining net energy values for treatments and analyzed the differences in calculations from performance data using Zinn et al. (2002) and the NRC (1996) listed values. These researchers concluded, as was determined in the current analysis, calculating energy values based on performance data results in a more accurate intake prediction. Vasconcelos and Galyean (2008) also concluded that if the same animals are fed year after year, data collected can be used to determine more accurate intake predictions than
that available from NRC (1996). Even though using the quadratic equation to calculate diet energy value (Zinn et al., 2002) creates increased accuracy and model fit to predict DMI, the use of observed animal performance increases the variability in diet energy values as it relies on the efficiency of the animal’s use of energy available from the diet. This means energy values will vary between animals and a constant diet energy value is not available unless averaged over individual animal intake. Agreed, variation is reduced when calculations are applied on a pen level with numerous animals able to dilute the outliers (MacNeil, 1983; McMenimen et al., 2009). However, animal performance is collected at the end of the feeding period so diet energy values will not be available at feeding initiation.

Regardless of the process for calculation of DMI for a feeding period, all systems adjust feed values relative to intake and plane of nutrition (Ferrell and Oltjen, 2008). The California Net Energy System (CNES) first calculated NE_m and NE_g from ME for feedstuffs even though some were calculated from TDN values and others were measured (Ferrell and Oltjen, 2008). The CNES was widely accepted by professionals and consultants alike and incorporated into the 1976 NRC. However, the CNES was not easily adaptable to changing environments, age, growth rate, or intake.

To more appropriately include rumen fermentation into the modeling of intake and energy prediction, the Cornell Net Carbohydrate and Protein System (CNCPS) predicted rates of rumen degradation, undegraded feedstuff passage rate, and the amount of TDN and protein available to the animal. The CNCPS was incorporated into editions of the NRC after 1987. Therefore, the 1996 NRC includes the most updated listed energy values to include in the prediction of DMI. Among a diverse group of animals, the NRC-
96 model increases the accuracy of predicting intake by including breed, frame size, age, and growing promoting technologies (McMenimen et al., 2009). With the listed values and the animal adjustments within the 1996 NRC, DMI can be predicted more accurately than done previously when using diet energy values (McMenimen et al., 2010). However, using animal performance is still a more accurate determinate of intake (Vasconcelos and Galyean, 2008) like that of initial BW (NRC, 1996; McMenimen et al., 2010).

To better illustrate the potential issues with CNCPS, feedstuff energy value calculated feedstuff values are listed in Table 2. The corn included in diets fed to animals in this analysis has the highest listed energy value in the NRC (2000). Even though DGS can have upwards of 140% the feeding value of corn in applied feeding studies (Klopfenstein et al., 2008), the reported energy values for each ME, NE_m and NE_g are the exact same as fine ground corn and lower than dry rolled corn. Additionally, CGF is listed as having the same energy values as that of soybean hulls outside of the fact that CGF can have a relative feeding value of 120% compared to a traditional corn diet without byproducts (Stock et al., 2000; Klopfenstein et al., 2008). The energy values assigned by the NRC (2000) are based off of TDN calculations and because the NDF and ADF components are still within the DGS and CGF, the calculated energy available is decreased since fiber has a lower energy value compared to carbohydrate or protein portions (Ferrell and Oltjen, 2008). Simply put, fiber contains less energy than concentrates and the NRC TDN potentially calculates the portion of fiber to concentrate values within the DGS and CGF incorrectly. The NDF within the grains have been shown to be highly digestible and the threefold addition of protein and fat to DGS and
CGF as compared to corn, and increases the energy density of the feedstuffs (Klopfenstein et al., 2008). It is incorrect to assume that the fiber portion of byproducts is not as highly digestible as corn considering that further processing of corn at any time increases the fiber digestibility and starch availability of corn (Zinn et al., 2002; Macken et al., 2004). Distillers grains have been shown to have greater NDF digestibility than corn with any type of processing (Corrigan et al., 2009).

While systems for predicting energy in feedstuffs and for intake have not changed much for many years, the main corrections have been to account for changes in physiological states and to more appropriately represent advancements in determining impacts of diverse genotypes (Ferrell and Oltjen, 2008). Issues are notable in Table 3 when comparing diet energy values for the current analysis. The traditional corn/corn silage based diet 1 calculated the highest ME and NE\textsubscript{m} values from the assigned NRC (2000) values. However, diet 9 offers the most energy for gain (1.486 Mcal/kg) by having the second highest corn inclusion level at 57% of the diet DM. However, diet 9 consists of only 8% corn silage while all other diets contained 15% corn silage. The difference between diets 10 and 11 compared to diet 9 is that each corn silage portion was replaced with fiber from brome hay and soybean hulls, respectively (Table 1). Less forage or fiber in a diet can increase digestibility and decrease bulk density (Ferrell and Oltjen, 2008; Klopfenstein et al., 2008), and therefore, diet 9 is more energy dense than all other diets and is shown by the maximized diet NE\textsubscript{g} values in Table 3. Interestingly, diet 1 and diet 9 calculate similar diet ME values. However, with the more current TDN based feedstuff energy values calculation, the lower forage level in diet 9 increases the
energy available to the animal through passage rate and NDF as compared to that calculated from animal performance.

In 2010, Owens et al. conducted an analysis of what was considered apparent TDN and true TDN. Apparent TDN is that uncorrected for metabolic energy loss while true TDN accounted for fecal energy loss from the digestive tract. Overall, results determined better correlations of feedstuff energy values that were calculated from ADF values compared to those from NDF. Additionally, a close relationship between fiber intake and diet digestibility was found with low apparent digestibility of high fiber diets, inaccurate prediction of digestibility from in vitro measurements, and increased energy requirement within the digestive tract with high-fiber diets.

Therefore from the current analysis and that of Owens et al. (2010), it is suggested that further research is required to determine a more accurate method of determining feedstuff energy values past that of the current TDN and ME system available within the NRC. While animal performance may be the most accurate measure of determining feed energy value, it is suggested that extensive work be conducted from large nationwide database analysis on feed digestibility and utilization for more accurate determination of feedstuff net energy values.

IMPLICATIONS

The model developed in this analysis is an example of the increased need for improved accuracy of model coefficients and diet energy values applied. It was developed from a specific set of steers which offers some limitation for industry application and therefore should be used with accepted knowledge of potential error in
application. Further analysis with variations in breed, sex, age, and growth promoting technologies is needed to increase model accuracy as a whole.
LITERATURE CITED


Table 1. Diet composition fed from 4 yr of data collected at the University of Illinois – Urbana.

<table>
<thead>
<tr>
<th>Itema</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Dry, cracked</td>
<td>75</td>
<td>50</td>
<td>35</td>
<td>57</td>
<td>7</td>
<td>50</td>
<td>7</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DDGS</td>
<td>25</td>
<td>40</td>
<td>25</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MDGS</td>
<td>40</td>
<td>20</td>
<td>40</td>
<td>25</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DCGF</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WCGF</td>
<td>40</td>
<td>40</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean Hulls</td>
<td>40</td>
<td>40</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn Silage, 50%</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>8</td>
<td>7.5</td>
<td>8</td>
<td>15</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brome Hay, mature</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>8</td>
<td>7.5</td>
<td>8</td>
<td>15</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplementb</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

**Diet Composition**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM%</td>
<td>71</td>
<td>73</td>
<td>71</td>
<td>51</td>
<td>56</td>
<td>51</td>
<td>53</td>
<td>74</td>
<td>79</td>
<td>49</td>
<td>79</td>
<td>53</td>
<td>52</td>
</tr>
<tr>
<td>CP</td>
<td>13.2</td>
<td>14.6</td>
<td>18</td>
<td>18.6</td>
<td>14.5</td>
<td>17.8</td>
<td>17.9</td>
<td>14.3</td>
<td>15.4</td>
<td>21.4</td>
<td>20.0</td>
<td>18.3</td>
<td>19.1</td>
</tr>
<tr>
<td>ADF</td>
<td>8.1</td>
<td>7.3</td>
<td>23.1</td>
<td>22.3</td>
<td>23.9</td>
<td>23.4</td>
<td>23.3</td>
<td>7.4</td>
<td>25.6</td>
<td>19.8</td>
<td>17.1</td>
<td>24.2</td>
<td></td>
</tr>
<tr>
<td>NDF</td>
<td>14.7</td>
<td>17.3</td>
<td>38.7</td>
<td>42.1</td>
<td>43.0</td>
<td>38.8</td>
<td>40.1</td>
<td>40.1</td>
<td>17.3</td>
<td>45.1</td>
<td>33.8</td>
<td>36.9</td>
<td>38.5</td>
</tr>
<tr>
<td>Ca</td>
<td>0.40</td>
<td>0.55</td>
<td>0.66</td>
<td>0.74</td>
<td>0.61</td>
<td>0.60</td>
<td>0.60</td>
<td>0.70</td>
<td>0.54</td>
<td>0.88</td>
<td>0.61</td>
<td>0.62</td>
<td>0.63</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.35</td>
<td>0.46</td>
<td>0.47</td>
<td>0.46</td>
<td>0.45</td>
<td>0.49</td>
<td>0.44</td>
<td>0.39</td>
<td>0.43</td>
<td>0.49</td>
<td>0.47</td>
<td>0.47</td>
<td>0.48</td>
</tr>
</tbody>
</table>

aDDGS = dry distillers grains plus solubles; MDGS = modified distillers grains plus solubles; DCGF = dry corn gluten feed; WCGF = wet corn gluten feed.
bSupplement for Diet 1 contained: 46.3% protein, 4.1% Ca, 1.1% P, 3.3% salt, 0.41% Mg, 1.31% K, 0.35% S, 940 mg/kg Zn, 2.49 mg/kg of Co, 18.0 mg/kg Cu, 1.0 mg/kg I, 730 mg/kg Mn, 228 mg/kg of Se, 14,000 IU/kg vit A, 1,500 IU/kg vit D, and 41.6 IU/kg of vit E.
Diets 2 to 13 contained: 14.4% protein, 4.1% Ca, 1.1% P, 3.3% salt, 0.41% Mg, 1.31% K, 0.35% S, 940 mg/kg Zn, 2.49 mg/kg of Co, 18.0 mg/kg Cu, 1.0 mg/kg I, 730 mg/kg Fe, 326 mg/kg Mn, 228 mg/kg of Se, 14,000 IU/kg vit A, 1,500 IU/kg vit D, and 41.6 IU/kg of vit E.
Table 2. 1996 NRC feedstuff energy values.

<table>
<thead>
<tr>
<th>Item</th>
<th>DM%</th>
<th>TDN, %DM</th>
<th>ME, Mcal/kg</th>
<th>NEm, Mcal/kg</th>
<th>NEg, Mcal/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Dry, cracked</td>
<td>88%</td>
<td>90.00</td>
<td>3.52</td>
<td>2.24</td>
<td>1.55</td>
</tr>
<tr>
<td>DDGS</td>
<td>91%</td>
<td>88.00</td>
<td>3.18</td>
<td>2.18</td>
<td>1.50</td>
</tr>
<tr>
<td>MDGS</td>
<td>50%</td>
<td>88.00</td>
<td>3.18</td>
<td>2.18</td>
<td>1.50</td>
</tr>
<tr>
<td>DCGF</td>
<td>90%</td>
<td>80.00</td>
<td>2.89</td>
<td>1.94</td>
<td>1.30</td>
</tr>
<tr>
<td>WCGF</td>
<td>45%</td>
<td>80.00</td>
<td>2.89</td>
<td>1.94</td>
<td>1.30</td>
</tr>
<tr>
<td>Soybean Hulls</td>
<td>91%</td>
<td>80.00</td>
<td>2.89</td>
<td>1.94</td>
<td>1.30</td>
</tr>
<tr>
<td>Corn Silage, 50%</td>
<td>35%</td>
<td>75.00</td>
<td>2.71</td>
<td>1.79</td>
<td>1.16</td>
</tr>
<tr>
<td>BromeHay, mature</td>
<td>92%</td>
<td>53.00</td>
<td>1.92</td>
<td>1.07</td>
<td>0.52</td>
</tr>
<tr>
<td>Fine Ground Corn</td>
<td>88%</td>
<td>88.00</td>
<td>3.18</td>
<td>2.18</td>
<td>1.50</td>
</tr>
</tbody>
</table>

*DDGS = dry distillers grains plus solubles; MDGS = modified distillers grains plus solubles; DCGF = dry corn gluten feed; WCGF = wet corn gluten feed.*
Table 3. Diet energy values\(^a\) as calculated from 1996 NRC feedstuff energy values by inclusion level.

<table>
<thead>
<tr>
<th>Diet</th>
<th>n</th>
<th>DMI, kg/d</th>
<th>ME</th>
<th>NE(_m)</th>
<th>NE(_g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>162</td>
<td>9.59</td>
<td>3.32</td>
<td>2.134</td>
<td>1.464</td>
</tr>
<tr>
<td>2</td>
<td>127</td>
<td>9.70</td>
<td>3.25</td>
<td>2.130</td>
<td>1.459</td>
</tr>
<tr>
<td>3</td>
<td>129</td>
<td>10.84</td>
<td>2.98</td>
<td>2.016</td>
<td>1.364</td>
</tr>
<tr>
<td>4</td>
<td>192</td>
<td>10.48</td>
<td>2.98</td>
<td>2.016</td>
<td>1.364</td>
</tr>
<tr>
<td>5</td>
<td>115</td>
<td>11.07</td>
<td>2.86</td>
<td>1.920</td>
<td>1.284</td>
</tr>
<tr>
<td>6</td>
<td>126</td>
<td>9.77</td>
<td>3.08</td>
<td>2.025</td>
<td>1.372</td>
</tr>
<tr>
<td>7</td>
<td>279</td>
<td>11.14</td>
<td>2.92</td>
<td>1.968</td>
<td>1.324</td>
</tr>
<tr>
<td>8</td>
<td>54</td>
<td>10.19</td>
<td>2.86</td>
<td>1.920</td>
<td>1.284</td>
</tr>
<tr>
<td>9</td>
<td>116</td>
<td>9.81</td>
<td>3.30</td>
<td>2.161</td>
<td>1.486</td>
</tr>
<tr>
<td>10</td>
<td>107</td>
<td>10.36</td>
<td>2.92</td>
<td>1.962</td>
<td>1.316</td>
</tr>
<tr>
<td>11</td>
<td>65</td>
<td>11.27</td>
<td>3.03</td>
<td>2.047</td>
<td>1.391</td>
</tr>
<tr>
<td>12</td>
<td>94</td>
<td>12.62</td>
<td>3.25</td>
<td>2.130</td>
<td>1.459</td>
</tr>
<tr>
<td>13</td>
<td>228</td>
<td>10.69</td>
<td>2.90</td>
<td>1.953</td>
<td>1.310</td>
</tr>
</tbody>
</table>

\(^a\)In Mcal/kg; sum of all (feedstuff energy value as listed in the NRC (2000) * inclusion level).
Table 4. Mean absolute bias\textsuperscript{a} of prediction equation\textsuperscript{b} with diet energy calculated one of two ways\textsuperscript{c}.

<table>
<thead>
<tr>
<th>Diet\textsuperscript{d}</th>
<th>n</th>
<th>NRC-84</th>
<th>dNEm-NRC</th>
<th>NRC-96</th>
<th>Owens-02</th>
<th>NRC-84</th>
<th>dNEm-Zinn</th>
<th>NRC-96</th>
<th>Owens-02</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>162</td>
<td>1.112</td>
<td>1.041</td>
<td>1.045</td>
<td>1.027</td>
<td>1.000</td>
<td>1.185</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>127</td>
<td>1.149</td>
<td>1.074</td>
<td>0.921</td>
<td>1.084</td>
<td>1.031</td>
<td>1.069</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>129</td>
<td>1.503</td>
<td>1.568</td>
<td>0.974</td>
<td>1.453</td>
<td>1.516</td>
<td>1.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>192</td>
<td>1.313</td>
<td>1.364</td>
<td>0.998</td>
<td>1.387</td>
<td>1.377</td>
<td>1.043</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>115</td>
<td>1.576</td>
<td>1.751</td>
<td>0.880</td>
<td>1.531</td>
<td>1.689</td>
<td>0.860</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>126</td>
<td>0.952</td>
<td>0.974</td>
<td>1.344</td>
<td>1.259</td>
<td>1.101</td>
<td>1.054</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>279</td>
<td>1.543</td>
<td>1.675</td>
<td>0.891</td>
<td>1.665</td>
<td>1.724</td>
<td>0.926</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>54</td>
<td>0.939</td>
<td>1.036</td>
<td>1.090</td>
<td>1.227</td>
<td>1.191</td>
<td>0.967</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>116</td>
<td>1.086</td>
<td>0.936</td>
<td>0.951</td>
<td>1.016</td>
<td>0.892</td>
<td>1.065</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>107</td>
<td>1.048</td>
<td>1.148</td>
<td>0.945</td>
<td>1.047</td>
<td>1.146</td>
<td>1.038</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>65</td>
<td>1.921</td>
<td>1.945</td>
<td>0.959</td>
<td>1.434</td>
<td>1.653</td>
<td>0.813</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>94</td>
<td>3.693</td>
<td>3.537</td>
<td>2.557</td>
<td>2.596</td>
<td>2.862</td>
<td>1.006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>228</td>
<td>1.255</td>
<td>1.349</td>
<td>1.073</td>
<td>1.522</td>
<td>1.484</td>
<td>0.997</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{a} Mean absolute bias = |Observed DMI – predicted mean DMI|/hd per diet within model.
\textsuperscript{b}NRC-84: DMI, kg/d = SBW^{0.75} \times (0.1493 \times dNE_m - 0.046 \times dNE_m^2 - 0.0196) (NRC, 1984); NRC-96: DMI, kg/d = [SBW^{0.75} \times (0.2435 \times dNE_m - 0.0466 \times dNE_m^2 - 0.1128)/dNE_m] (NRC, 1996); Owens-02: DMI, kg/d = [(-3.99 + 0.3885 \times SBW^{0.678}) - 3.788 \times dNE_m - 0.000023 \times IBW^2] (Owens et al., 2002).
\textsuperscript{c}Dietary energy values: dNEm-NRC = sum of all feedstuffs (1996 NRC feedstuff energy values \times feedstuff inclusion level); dNEm-Zinn = quadratic equation reported by Zinn et al. (2003) using animal performance.
\textsuperscript{d}Diet composition listed in Table 1. Diet energy values listed in Table 3.
Table 5. R-squared values\(^a\) for prediction equation\(^b\) with diet energy calculated one of two ways\(^a\).

<table>
<thead>
<tr>
<th>Diet(^d)</th>
<th>n</th>
<th>NRC-84</th>
<th>NRC-96</th>
<th>Owens-02</th>
<th>NRC-84</th>
<th>NRC-96</th>
<th>Owens-02</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>162</td>
<td>0.5892</td>
<td>0.7048</td>
<td>0.2917</td>
<td>0.7381</td>
<td>0.7290</td>
<td>0.3998</td>
</tr>
<tr>
<td>2</td>
<td>127</td>
<td>0.4225</td>
<td>0.6111</td>
<td>0.0858</td>
<td>0.6665</td>
<td>0.6554</td>
<td>0.1623</td>
</tr>
<tr>
<td>3</td>
<td>129</td>
<td>0.6262</td>
<td>0.7553</td>
<td>0.4683</td>
<td>0.7777</td>
<td>0.7815</td>
<td>0.5152</td>
</tr>
<tr>
<td>4</td>
<td>192</td>
<td>0.4995</td>
<td>0.7359</td>
<td>0.3663</td>
<td>0.7678</td>
<td>0.7716</td>
<td>0.4875</td>
</tr>
<tr>
<td>5</td>
<td>115</td>
<td>0.6815</td>
<td>0.7771</td>
<td>0.4490</td>
<td>0.7686</td>
<td>0.7781</td>
<td>0.5528</td>
</tr>
<tr>
<td>6</td>
<td>126</td>
<td>0.4351</td>
<td>0.7496</td>
<td>0.2318</td>
<td>0.8275</td>
<td>0.8299</td>
<td>0.4738</td>
</tr>
<tr>
<td>7</td>
<td>279</td>
<td>0.6317</td>
<td>0.7321</td>
<td>0.4177</td>
<td>0.7283</td>
<td>0.7371</td>
<td>0.4513</td>
</tr>
<tr>
<td>8</td>
<td>54</td>
<td>0.5776</td>
<td>0.7289</td>
<td>0.4065</td>
<td>0.7347</td>
<td>0.7466</td>
<td>0.5505</td>
</tr>
<tr>
<td>9</td>
<td>116</td>
<td>0.4680</td>
<td>0.7555</td>
<td>0.2671</td>
<td>0.8306</td>
<td>0.8219</td>
<td>0.4012</td>
</tr>
<tr>
<td>10</td>
<td>107</td>
<td>0.3531</td>
<td>0.3350</td>
<td>0.3139</td>
<td>0.6931</td>
<td>0.7037</td>
<td>0.2295</td>
</tr>
<tr>
<td>11</td>
<td>65</td>
<td>0.7213</td>
<td>0.7857</td>
<td>0.5319</td>
<td>0.8021</td>
<td>0.8032</td>
<td>0.4639</td>
</tr>
<tr>
<td>12</td>
<td>94</td>
<td>0.6901</td>
<td>0.7346</td>
<td>0.4595</td>
<td>0.7766</td>
<td>0.7686</td>
<td>0.4269</td>
</tr>
<tr>
<td>13</td>
<td>228</td>
<td>0.6292</td>
<td>0.7493</td>
<td>0.3853</td>
<td>0.7100</td>
<td>0.7207</td>
<td>0.3572</td>
</tr>
</tbody>
</table>

\(^a\)\(R^2 = 1 - \left[ \frac{\sigma_{res}^2}{\sigma_{obs}^2} \right]\)

\(^b\)NRC-84: \(DMI, kg/d = SBW^{0.75} * (0.1493 \times dNE_m - 0.046 \times dNE_m^2 - 0.0196)\) (NRC, 1984); NRC-96: \(DMI, kg/d = [SBW^{0.75} * (0.2435 \times dNE_m - 0.0466 \times dNE_m^2 - 0.1128) / NE_m]\) (NRC, 1996); Owens-02: \(DMI, kg/d = [(3.99 + 0.3885 \times SBW^{0.678}) - 3.788 \times dNE_m - 0.000023 \times IBW^2]\) (Owens et al., 2002).

\(^c\)Dietary energy values: \(dNEm-NRC = \) sum of all feedstuffs (1996 NRC feedstuff energy values \(*\) feedstuff inclusion level); \(dNEm-Zinn = \) quadratic equation reported by Zinn et al. (2003) using animal performance.

\(^d\)Diet composition listed in Table 1. Diet energy values listed in Table 3.
Table 6. Correlation matrix for parameters\textsuperscript{a} to predict DMI.

<table>
<thead>
<tr>
<th></th>
<th>DMI</th>
<th>dNEm-NRC, Mcal/kg</th>
<th>dNEm-Zinn, Mcal/kg</th>
<th>IBW, kg</th>
<th>SBW, kg</th>
<th>SBW\textsuperscript{0.75}, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMI, kg/d</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dNEm-NRC, Mcal/kg</td>
<td>-0.126</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dNEm-Zinn, Mcal/kg</td>
<td>-0.244</td>
<td>-0.029</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;0.01</td>
<td>0.49</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IBW, kg</td>
<td>0.471</td>
<td>0.004</td>
<td>-0.018</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;0.01</td>
<td>0.93</td>
<td>0.66</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBW, kg</td>
<td>0.646</td>
<td>-0.061</td>
<td>-0.055</td>
<td>0.93</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;0.01</td>
<td>0.15</td>
<td>0.19</td>
<td>&lt;0.01</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>SBW\textsuperscript{0.75}, kg</td>
<td>0.647</td>
<td>-0.061</td>
<td>-0.055</td>
<td>0.928</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>&lt;0.01</td>
<td>0.14</td>
<td>0.19</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>1.00</td>
</tr>
</tbody>
</table>

\textsuperscript{a}dNEm-NRC = sum of all feedstuffs (1996 NRC feedstuff energy values \ast feedstuff inclusion level); dNEm-Zinn = quadratic equation reported by Zinn et al. (2003) using animal performance; IBW = initial BW; SBW = average shrunk BW; SBW\textsuperscript{0.75} = average metabolic BW.
Table 7. Dry matter intake prediction models\textsuperscript{a} developed with parameters\textsuperscript{b} from 1,794 animals with daily intake measurements.

<table>
<thead>
<tr>
<th>Item\textsuperscript{c}</th>
<th>Intercept</th>
<th>dNEm-Zinn</th>
<th>IBW</th>
<th>SBW</th>
<th>MSBW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Linear</td>
<td>Quadratic</td>
<td>Linear</td>
<td>Quadratic</td>
<td>Linear</td>
</tr>
<tr>
<td>A/D</td>
<td>10.935</td>
<td>-4.1518</td>
<td>0.03572</td>
<td>-0.00004</td>
<td>0.05668</td>
</tr>
<tr>
<td>B/E</td>
<td>2.4043</td>
<td>-4.6102</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>C/F</td>
<td>-5.9989</td>
<td>-4.6125</td>
<td>0.05668</td>
<td>-0.00004</td>
<td>0.01837</td>
</tr>
<tr>
<td>G/K</td>
<td>16.3848</td>
<td>-1.2765</td>
<td>0.0725</td>
<td>-0.00008</td>
<td>0.01837</td>
</tr>
<tr>
<td>H</td>
<td>-4.2924</td>
<td>-1.2765</td>
<td>0.0725</td>
<td>-0.00008</td>
<td>0.01837</td>
</tr>
<tr>
<td>I</td>
<td>1.9316</td>
<td>-1.2765</td>
<td>0.0725</td>
<td>-0.00008</td>
<td>0.01837</td>
</tr>
<tr>
<td>J</td>
<td>-0.8905</td>
<td>-1.2765</td>
<td>0.0725</td>
<td>-0.00008</td>
<td>0.01837</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Prediction models to evaluate influence of parameter from yr 1, 2, and 3 data and tested against yr 4 animal DMI.

\textsuperscript{b}dNEm-Zinn = quadratic equation reported by Zinn et al. (2003) using animal performance; IBW = initial BW; SBW = shrunk BW; SBW\textsuperscript{0.75} = metabolic SBW.

\textsuperscript{c}Models A, B, C, and G were tested with dNEm-NRC as the dNEm in the equation; D, E, F, and H were tested with dNEm-Zinn as the dNEm in the equation.
Table 8. Mean absolute bias\(^a\) of prediction equation\(^b\) tested against animal intakes of diets during yr 4.

<table>
<thead>
<tr>
<th>Diet(^c)</th>
<th>n</th>
<th>NRC-96, NRC</th>
<th>NRC-96, Zinn</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>39</td>
<td>1.043</td>
<td>0.834</td>
<td>0.799</td>
<td>0.499</td>
<td>0.549</td>
<td>0.685</td>
<td>0.715</td>
<td>0.534</td>
<td>0.829</td>
<td>81.977</td>
<td>0.587</td>
<td>0.588</td>
<td>0.862</td>
</tr>
<tr>
<td>4</td>
<td>72</td>
<td>1.635</td>
<td>1.609</td>
<td>1.237</td>
<td>0.684</td>
<td>0.869</td>
<td>1.219</td>
<td>0.677</td>
<td>0.852</td>
<td>1.067</td>
<td>82.337</td>
<td>0.793</td>
<td>0.790</td>
<td>1.050</td>
</tr>
<tr>
<td>7</td>
<td>230</td>
<td>1.702</td>
<td>1.731</td>
<td>1.267</td>
<td>0.698</td>
<td>0.851</td>
<td>1.313</td>
<td>0.714</td>
<td>0.887</td>
<td>1.147</td>
<td>83.419</td>
<td>0.883</td>
<td>0.881</td>
<td>1.186</td>
</tr>
<tr>
<td>13</td>
<td>228</td>
<td>1.218</td>
<td>1.344</td>
<td>0.956</td>
<td>0.854</td>
<td>0.774</td>
<td>1.104</td>
<td>0.773</td>
<td>0.830</td>
<td>0.968</td>
<td>81.910</td>
<td>0.791</td>
<td>0.789</td>
<td>1.062</td>
</tr>
</tbody>
</table>

\(^a\) Mean absolute bias = |Observed DMI – predicted mean DMI|/hd per diet within model.

\(^b\) NRC-96: DMI, kg/d = [SBW^{0.75} \times (0.2435 \times dNE_m – 0.0466 \times dNE_m^2 – 0.1128)/NE_m] (NRC, 1996) using dNEm-NRC or dNEm-Zinn; A – K tested against yr 4 data and derived from yr 1, 2, and 3. Listed in table 4.

\(^c\) Diet composition listed in Table 1. Diet energy values listed in Table 3.
Table 9. R-squared values\(^a\) of prediction equation\(^b\) tested against animal intakes of diets during yr 4.

<table>
<thead>
<tr>
<th>Diet(^c)</th>
<th>n</th>
<th>NRC-96, NRC</th>
<th>NRC-96, Zinn</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>39</td>
<td>0.7152</td>
<td>0.7596</td>
<td>0.9119</td>
<td>0.4260</td>
<td>0.5353</td>
<td>0.9119</td>
<td>0.4260</td>
<td>0.5353</td>
<td>1.00</td>
<td>-351.5</td>
<td>0.4290</td>
<td>0.4379</td>
<td>1.00</td>
</tr>
<tr>
<td>4</td>
<td>72</td>
<td>0.7269</td>
<td>0.7864</td>
<td>0.8651</td>
<td>0.3106</td>
<td>0.4346</td>
<td>0.8651</td>
<td>0.3106</td>
<td>0.4346</td>
<td>1.00</td>
<td>-461.8</td>
<td>0.3510</td>
<td>0.3568</td>
<td>1.00</td>
</tr>
<tr>
<td>7</td>
<td>230</td>
<td>0.7410</td>
<td>0.7487</td>
<td>0.9155</td>
<td>0.5820</td>
<td>0.6640</td>
<td>0.9155</td>
<td>0.5820</td>
<td>0.6640</td>
<td>1.00</td>
<td>-284.4</td>
<td>0.5799</td>
<td>0.5870</td>
<td>1.00</td>
</tr>
<tr>
<td>13</td>
<td>228</td>
<td>0.7501</td>
<td>0.7379</td>
<td>0.9286</td>
<td>0.5743</td>
<td>0.6516</td>
<td>0.9286</td>
<td>0.5743</td>
<td>0.6516</td>
<td>1.00</td>
<td>-249.4</td>
<td>0.5941</td>
<td>0.5984</td>
<td>1.00</td>
</tr>
</tbody>
</table>

\(^a\)\(R^2 = 1 - \left(\sigma^2_{\text{res}} / \sigma^2_{\text{obs}}\right)\).

\(^b\)NRC-96: \(DMI, kg/d = [SBW^{0.75} \times (0.2435 \times dNE_m - 0.0466 \times dNE_m^2 - 0.1128)/NE_m]\) (NRC, 1996) using dNEm-NRC or dNEm-Zinn; A – K tested against yr 4 data and derived from yr 1, 2, and 3. Listed in table 4.

\(^c\)Diet composition listed in Table 1. Diet energy values listed in Table 3.
Figure 1. Bias of observed dry matter intake versus predicted dry matter intake from prediction model for Diet 1 of Year 4.
Figure 2. Bias of observed dry matter intake versus predicted dry matter intake from prediction model for Diet 4 of Year 4.
Figure 3. Bias of observed dry matter intake versus predicted dry matter intake from prediction model for Diet 7 of Year 4.
Figure 4. Bias of observed dry matter intake versus predicted dry matter intake from prediction model for Diet 13 of Year 4.
Factors influencing intramuscular fat deposition over the feeding period determined by interim ultrasonic carcass measurements and model development from repeated measures
M. F. Wilken\textsuperscript{a,2}, G. E. Erickson\textsuperscript{2}, M. L. Spangler\textsuperscript{2}, J. C. MacDonald\textsuperscript{2}, L. L. Berger\textsuperscript{1,2}, and S. D. Kachman\textsuperscript{3}.
\textsuperscript{1}Department of Animal Sciences, University of Illinois at Urbana-Champaign, Champaign, IL, 61280
\textsuperscript{2}Department of Animal Sciences, University of Nebraska-Lincoln, Lincoln, NE 68583
\textsuperscript{3}Department of Statistics, University of Nebraska-Lincoln, Lincoln, NE 68583

ABSTRACT: Four years of data were used to determine the impact of performance parameters on predicting marbling score over the feeding period. Calf-fed steers (n = 1,761) were individually fed thirteen diets using the GrowSafe feeding system (GrowSafe Systems Ltd.) over the 4 yr. All animals were weighed and ultrasound measurements of marbling score (UMS) and backfat (UBF) were taken either every 28 d (yr 1) or 42 d (yr 2, 3, and 4). Ultrasound measurements were utilized in repeated measures regression analysis of UBF, BW, and DMI to predict UMS. Regression analysis using GLIMMIX determined all parameters to be significantly quadratic except for BW when all variables were included. However, BW can be collected at trial initiation while actual DMI cannot be measured until after time on feed, and therefore, BW and DMI were included in separate models with Day and UBF to determine accuracy of predicting UMS. After initial analysis determining relationship of independent variables to MS, data from yr 1, 2, and 3 were used to derive model coefficients to be tested against yr-4 data. The previous two models were evaluated as well as the independent variables separately against UMS to determine individual influence of each. Mean absolute bias, residual bias and coefficients of determination were used to evaluate accuracy and precision of model prediction. Results from the evaluation showed predictions from models including Day and UBF had the greatest fit through coefficients of determination while the model with
Day, UBF and BW had the lowest mean absolute bias and least residual bias of all models compared. The models that included DMI as an independent variable predicted UMS with the greatest bias even though model fit was high. In conclusion, UMS was best predicted using the quadratic terms of Day, UBF, and BW.

**Keywords:** Backfat, finishing cattle, marbling score, prediction equations

**INTRODUCTION**

Fat deposition in feedlot cattle is presumed to increase in a quadratic manner compared to protein, which is more linear (Owens et al., 1995; Carter et al., 2002). Through modeling efforts of determining fat deposition, protein accretion and weight gain over the feeding period, Owens et al. (1995) found fat accretion has the potential to reach a maximum whereas, protein accretion may not plateau and may actually be more dependent on the animal’s maturity level. Additionally, Ferrell and Jenkins (2008) found animal genotype has a large impact on feed intake and utilization, ADG, mature size, and body composition.

Though fat and protein accretion rates have been shown to be strongly correlated, separation in measuring the two is difficult as tissue accretion through maintenance requirements and growth performance are highly connected in the development of the animal (Owens et al., 1995). Even so, Brethour (2004) observed that carcass backfat was a poor predictor of marbling score even though backfat is important in predicting empty body fat percentage. Ultimately, Brethour (2004) concluded body composition (i.e. carcass back fat) to have little relationship with marbling score.
An economic incentive remains for producers to maximize return with increased carcass value from weight and USDA Quality Grade while avoiding discounts (Koontz et al., 2000) making the ability to predict carcass value important. Therefore, the objective of the current study was to use ultrasound marbling score and backfat measurements along with production measures from 4 yr of data collected from calf-fed steers to predict marbling score over the feeding period and the optimum harvest endpoint.

**MATERIALS and METHODS**

*Data collection*

Data from 1,761 individually-fed Angus, Simmental, and Simmental-Angus cross calf-fed steers were collected over 4 yr and used to develop an intramuscular fat deposition prediction model. Animals were received from the same Montana- and Wyoming-based ranches by the University of Illinois-Urbana for nutritional studies, and to evaluate growth and carcass changes over the feeding period using intermittent ultrasound and weight measures. Cattle were housed in open back barns with approximately 40 hd per pen and fed once daily. Daily intakes were measured for individual animals by use of the GrowSafe feeding system (Model 4000E, GrowSafe Systems Ltd., Airdie, Alberta, Canada).

Over the 4 yr collected, thirteen diets were fed ranging in diet $\text{NE}_m$ from 1.92 to 2.13 Mcal/kg and diet $\text{NE}_g$ from 1.28 to 1.48 Mcal/kg as calculated using the NRC (1996) feedstuff energy values. An implant program was applied to all animals with monensin (Rumensin, Elanco Animal Health, Indianapolis, IN) fed to provide 330 mg/steer daily during the finishing period. Animals fed in yr 1, 3, and 4 steers received Component TE-
IS (80 mg trenbolone acetate, 16 mg estradiol, 29 mg tylosin tartate; Elanco Animal Health, Indianapolis, IN) at the initiation, and were re-implanted with Component TE-S (120 mg trenbolone acetate, 24 mg estradiol, 29 mg tylosin tartate; Elanco Animal Health, Indianapolis, IN) at 76 d on feed all 3 yr. The implant strategy for the second yr used Revalor-G (40 mg trenbolone acetate and 8 mg estradiol; Merck Animal Health, Summit, NJ) administered to steers at trial initiation followed by Component TE-S after 84 d on feed. All diets were formulated to meet or exceed the minimum NRC (1996) requirements for maintenance and gain (Table 1).

Days on feed across year ranged from 134 to 195 d with 2 or 3 slaughter groups per year. For the first year, groups were harvested at 134, 147, and 168 d on feed (DOF). Year 2 groups were fed for 146, 169, and 195 d. Year 3 steers were harvested at 145 and 170 d after trial initiation. Steers were harvested after 141 and 171 DOF for the final year. Slaughter date or harvest group was determined by rate at which an animal had or would achieve 1 cm backfat (BF) and/or 550 kg shrunk BW. Interim weights and ultrasound measurements were taken every 28 or 42 d for yr 1 or 2, 3, and 4, respectively. After yr 1 data were collected and analyzed, it was decided that 42 d measurements until d 120 was sufficient resulting in 4 measurements over the feeding period for yr 2, 3, and 4 to predict optimal finish date. Ultrasound measurements were taken using an Alkoa 500V (Wallingford, CT) B-mode instrument with 3.5-MHz general purpose transducer array. Backfat and marbling measurements were taken between the 12th and 13th ribs in a transverse orientation approximately 10 cm distal from the midline with marbling analysis performed in accordance with Brethour (1994). Adjusted final BW, calculated
from hot carcass weight divided by average dressing percent of harvest group, was used to calculate final individual animal ADG and G:F.

Hot carcass weights were collected on the day of harvest at a commercial abattoir, while backfat thickness (BF), kidney, pelvic, and heart fat percentage (KPH), and marbling score (MS) were collected after a 24-hr chill at -4°C by trained university personnel. Longissimus muscle area was recorded by a planometer and chromatography paper was used to take an image of the longissimus dorsi.

Animals used in these trials were managed according to the guidelines recommended in the Guide for the Care and Use of Agriculture Animals in Agriculture Research and Teaching Consortium (1988). Experimental protocols were submitted and approved by the University of Illinois Institutional Animal Care and Use Committee.

**Prediction Equation Development**

Ultrasound measurement of marbling (UMS) was used as the dependent variable to predict marbling score over the feeding period. Day of measurement (DOM) was included in all models because DOM are known at any point during the feeding period. Body weight, ultrasound BF (UBF), and DMI were also analyzed and included in model development after limited collinearity was determined. Because BW, BF, and DMI increase as cattle grow with increased DOF, these variables were not completely independent of each other. Intake measurements were averaged for the DOF between ultrasound dates so DMI at d 0 was equal to 0 while intake was averaged for the period between DOM and reported as final DOM for the corresponding period.
Ultrasound marbling score was regressed on independent variables using the GLIMMIX procedure in SAS as repeated measures to evaluate response in marbling deposition over the feeding period. Year, treatment, breed, and their interactions were fitted as random effects. Covariance structures were tested and an unstructured covariance matrix was selected based on the greatest Akaike Information Criterion. Steers that had greater UBF measurements at the beginning of the trial were marketed earlier in the feeding period, slaughter group was considered as the random effect. Animal was the experimental unit. Full response coefficients and response significance can be found in Table 2.

The full model to determine the influence of UBF measurement, BW, and DMI on prediction of UMS over the feeding period showed BW to be insignificant in the model (Linear P = 0.23, Quadratic P = 0.15; Table 2). However, the most important part of predicting optimum slaughter date is accurate BW and composition criteria according to Oltjen et al. (1986). Therefore, day and UBF were included with DMI and BW separately and models were evaluated accordingly.

After initial investigation of marbling response from the full dataset, the data were subjected to the same development methods but only included the first 3 yr of data. Year-4 data were used to test the models developed from the first 3 yr of data to determine model fit and accuracy of prediction of UMS over the feeding period. Individual independent variables were regressed on UMS with effects listed in Table 2. Mean absolute bias was calculated as the average of absolute values of the deviation of measured UMS from the predicted UMS. To determine model fit, coefficients of determination were calculated as follows:
\[ R^2 = 1 - \left[ \frac{\sigma^2_{res}}{\sigma^2_{obs}} \right] \]

**RESULTS**

The full model including Day, UBF, BW, and DMI as independent variables is provided in Table 3, along with all other models tested against yr 4 after being derived from data collected during yr 1, 2, and 3. Model coefficients were all significant for the quadratic term except for the full model where BW was not significant. Even though it was not significant, BW was included with UBF and Day in a separate model. Body weight and backfat can be collected day of receiving or beginning of the feeding period. Therefore, BW and UBF are easily incorporated into a prediction model. Intake was analyzed because of its significant influence within the model for predicting MS during the feeding period. However, DMI is not known at trial initiation and requires DOF before full feed intake can be determined and included for prediction accuracy.

The average predicted response across animals for d 0, 42, 84, and 120 for models A-I (Table 3) are listed in Table 4. Model A composed of Day, UBF, and DMI as independent variables, predicted an UMS of 492 on d 0, predictions then decreased from d 0 to d 42 and increased from d 42 to d 120, with UMS of 405, 435, and 486, respectively. The initial decrease from d 0 to d 42 is potentially due to the lack of DMI included in the model since DMI was not given on d 0 and instead was calculated for the period following trial initiation. As soon as DMI was included in the model, the predicted marbling was less than that of the average MS on d 42, 84, and 120 (Table 4). With DMI in the models, d 0 predicted UMS was always greater than predicted UMS at d 42 and less than average UMS. Table 4 also lists the slope of the predicted UMS over DOM.
Model A had a linear slope of 0.007 compared to a 1.06 linear slope of average UMS across DOM. Instead of being able to create a linear slope with all data points included, the slope is forced between d 0 and d 42 which in turn flattens the line. Additionally, the lower predicted UMS at d 120 of 486 aids in the reduction of the slope compared to the 531 UMS at d 120. However, when d 0 predicted UMS was not considered because DMI is not available on d 0, calculated linear slope for predicted UMS from model A improves to 1.026. The limitation to this calculation is that UMS cannot be predicted at trial initiation or until DMI can be obtained from a period of feeding.

Model B differed from model A in that BW was substituted for DMI as an independent variable with Day and UBF. Marbling scores from model B increased at an increasing rate like that of average UMS. Predicted UMS from model B and average UMS had similar initial UMS at 396 and 397, respectively, and had more similar slopes (0.978 and 1.064, respectively) than that of model A predictions to observed UMS. Initial BW was collected at trial initiation which was able to be included in the model B prediction calculations at d 0, unlike DMI included in model A where DMI is not measured on d 0. Model B also had the most similar predicted UMS at d 120 to that of observed UMS compared to all other models analyzed. Overall, model B increased at an increasing rate for predicted UMS which mirrors the observed UMS response to marbling deposition over the feeding period.

The difference between the observed and the predicted UMS slopes from model A is reiterated by the average absolute bias of model A found in Table 5. At d 0, model A on average has a UMS that was 101.1 different from the average UMS of animals fed during yr 4. While model prediction is improved at d 42 and d 84 with biases of 52.6 and
56.1 in UMS from the observed UMS, predicted UMS at d 120 increases in mean absolute bias to a difference of 72.7 compared to average UMS. As also shown in Table 5, model B offers the most accurate prediction of marbling compared to the observed UMS since there was the least amount of mean absolute bias, especially at d 120.

By including BW instead of DMI in the model with Day and UBF, accuracy of prediction increased by validation of R-squared values given in Table 6. Accuracy of predicting UMS decreased with DOM but model B still maintained greater accuracy than model A over the feeding period. Model B R-squared values are above 0.90 for all time points measured allowing for the conclusion that model B is the more accurate multivariate model compared to model A.

Models C - I allow for the evaluation of individual independent variable influence and response to marbling over the feeding period (Table 3). Model C includes only Day to illustrate the effect of marbling deposition over the feeding period which was significantly quadratic. The positive quadratic term for model D suggests that marbling increases at an increasing rate but since the term is relatively small (0.0019), the increasing rate will tend to slow and plateau towards the end of the feeding period. This plateau effect is noted in Table 4 where the predicted UMS increases 30 points from d 0 to 42, 37 from d 42 to 84 and 37 from d 84 to 120. The limitation of the dataset is that DOM only extended to 120 DOF while full DOF reached 195. The full quadratic relationship may not yet be realized. The other potential problem with this model is inherent dependence on the intercept for prediction of UMS over the feeding period. As long as cattle are calf-fed steers like those from this dataset, fed similar diets and with similar genetics, model C will be relatively accurate as it provides similar estimates and
slope (Table 4), small mean absolute bias (Table 5), and perfect model fit ($R^2 = 1.0$; Table 6). Producers would need to base the derived model from previous data on similar sets of animals for Day to be the most accurate independent variable of predicting UMS.

The influence of UBF is determined through models D (with Day) and E (without Day). Model D has the next closest predicted UMS to observed UMS compared to that of model B (Table 4). Additionally, model D has a slope very similar to that of the average UMS from the yr 4 data at 0.947 and 1.064, respectively. When comparing mean absolute bias, model D offers the least bias at d 0 (43.5) and d 84 (51.7) compared to all other models and calculates the second least amount of bias on d 42 (43.9; Table 5). Even so, model E has the least amount of absolute mean bias at d 42 at 42.5. Still, model E mean absolute bias increases with DOM with the most deviation from the measured UMS on d 120 (94.7) compared to all other models. Without d in the model, UBF is not enough to accurately predict marbling since model fit decreases significantly from d 0 to d 120 as shown in Table 6. The resulting decrease in accuracy simulates the poorer correlation between UBF and UMS (0.22; Table 2) than all other variables included. Still, model D offered the most accurate model fit to predict UMS over the feeding period outside of modeling marbling deposition itself over time (model C).

Because BW is easily measured at any point in the feeding period, models F and G predicted UMS from BW with and without Day in the model, respectively. Model F predicted UMS found in Table 4 illustrates the increasing rate of fat deposition over the feeding period. The linear slope of 0.9 adds evidence to the strong increase with DOF. Model G has a similar response compared to model F and average UMS increasing at an increasing rate over DOM with a slope of 0.875. However, Model F calculates lower
mean absolute bias at each DOM and has better model fit with R-squared values above 0.90 over the feeding period compared to model G.

Dry matter intake has been difficult to understand as a cause variable thus far in the analysis. Models H and I depict the effect DMI has on predicting UMS over the feeding period. Ultrasound marbling score predicted on d 0 was greater than d 42 on both accounts. However, model I predicted UMS did not significantly increase when DMI alone was incorporated into the model. And even though a slight increase in predicted deposition is noted between d 42 and 84, model I increased predicted UMS by less than 10 points from d 42 to d 84 to 120. The lack of significant change in marbling prediction is demonstrated by the negative linear calculated slope (-0.154; Table 4). Because DMI is not available on d 0, removing the predicted UMS improves the slopes for models H (1.043) and I (0.116) but limits the ability to predict UMS until later in the feeding period instead of at trial initiation. Additionally, models H and I calculated the greatest mean absolute biases in relation to the separately analyzed independent variable models. Still, model fit was 0.96 or greater for each model H and model I at all DOM.

Because excluding Day from the models added no benefit for prediction, only models with Day included were evaluated for residual bias (measured UMS – predicted UMS). Figures 1 - 4 illustrate over and underestimation of marbling on d 0, 42, 84, and 120, respectively, for models A, B, D, F, and H. Predicted marbling deviation in Figures 1 - 4 is shown by day for each model to compare model prediction instead of comparing prediction based on DOM. Notably, model D calculated the least amount of residual bias compared to all other models across all DOM. Furthermore, models B and F observed similar prediction to measured results though more outliers were observed in comparison
to model D. Models A and H are those which include DMI as an independent variable for prediction and both tended to have more residual bias than model D at any time point.

**DISCUSSION**

When predicting fat deposition, or any tissue accretion, repeated measurement of the same animal is more desirable (Owens et al., 1995) since changes in the animal can be determined over the feeding period compared to serial slaughter analysis where composition is only measured once (Brethour, 1992). Actual and ultrasound measurements of fat thickness have been found to be highly correlated on several different occasions (0.90, Brethour, 1992; 0.81, Griffin et al., 1999; 0.89, Greiner et al., 2003). Ultrasound measurements are considered accurate and useful (Brethour, 2000), validating the use of measurements within this dataset for model analysis and development.

However, increased subcutaneous fat deposition can increase the difficulty of obtaining clear and accurate measures of LM area and marbling score as the additional fat layers can skew the image from light refractions (Greiner et al., 2003). Similar results were observed with the current analysis when looking at the predicted values based from BF measurements in model E. As DOF and UBF increased, accuracy of predicting UMS decreased and mean absolute bias increased. Even so, Oltjen and Garrett (1988) found that energy, protein and fat content of gain varied less with rate of gain than with body weight and body type. Still, ADG was not included in the current analysis due to lack of actual DMI at trial initiation and correlation with BW.
Because ultrasound measurements were not taken after DOM 120 for the current analysis, final MS was forecasted by use of derived model B. The correlation between forecasted UMS and final MS was 0.506. This correlation was low compared to previous research and led to the conclusion that measurements past 120 DOF are necessary to better calculate the relationship between final MS and ultrasound measures. Hassen et al. (1999) determined that increasing the number of images taken per animal should be conducted to improve precision. Even so, Brethour (2004) found the correlation of marbling to UBF measurements was greater with pen averages than with individual measurements (0.72 to 0.10, respectively). Individual measurements are advantageous for prediction model development because the model will then account for variation instead of the residual error (Oltjen et al., 1986). But when analyzing main effects of a research trial, the variation is accounted for by animals within pen. Still, measuring BF thickness and marbling over the feeding period via ultrasound has been an accurate way to predict carcass merit and value at slaughter (Hassen et al., 1999; Griffin et al., 1999; Brethour, 2000; Crews et al., 2002).

Data have revealed that intramuscular fat deposition occurs at a rate similar to that of other fat depots (Zinn et al., 1970; Pethick et al., 2004). If an animal is supplied dietary energy past what is required from maintenance, growth rate increases causing increased rate of protein accretion and fat deposition. The excess energy supplied is utilized in all facets of growth and development including that of marbling as explained by Pethick et al. (2004). Bruns et al. (2004) found that intramuscular fat is not necessarily a late-developing tissue but instead increases with increased diet energy content in calf-fed steers. Similarly, Zinn et al. (1970) noted marbling score to increase
linearly as days on feed increased for both steers and heifers. However, Duckett et al. (1992) and May et al. (1992) found marbling to increase in a quadratic manner with days on feed. Like that of Bruns et al. (2004) and Zinn et al. (1970), Rhoades et al. (2009) found marbling to increase linearly when expressed as a function of HCW. Both the quadratic and linear functions for marbling deposition are correct, because MS and HCW are both quadratic as function of days on feed but linear to each other (Rhoades et al., 2009). Results from this analysis showed a quadratic response because each model is based on DOM over the feeding period. Even so, when UMS was regressed on only BW, model G was significantly quadratic.

Oltjen et al. (1986) first analyzed the difference between static and simulation models and determined the availability to include biological responses of animals to inputs makes the models more flexible and useful on an industry scale. Developing models from large database information can improve predictability and overall accuracy, ensuring that the model is not tested against the data it was previously developed from. The usefulness of a model cannot be determined until tested on independent data (MacNeil, 1983). The availability of repeated years of data with similar animals allows for accurate model development and testing with the model trained from the previous three years and tested on the fourth year. Increased variation in breed, sex, and end point can increase the accuracy of prediction as shown by Rhoades et al. (2009). There may not have been enough population diversity from yr 1, 2, and 3 to yr 4 to fully determine model validity.

Limitations exist when only reporting correlation coefficients as correlations could be affected by population variation such numbers and inability to reflect bias, and
producers may not understand the true interpretation of the correlations (Houghton and Turlington, 1992). These potential limitations for understanding the data explain the value in the information presented. R-squared values are important in determining model fit and the values reported here were calculated to correct for bias and variance simultaneously. Even if producers may not understand the model fit, bias was presented to illustrate the potential for over and underestimation of marbling over the feeding period by both the difference in observed UMS and predicted UMS and mean absolute bias. Data presented in this manner provide information of model response directly to the observed UMS and around the mean UMS of the dataset.

Overall, all models reasonably predict UMS over the feeding period. However, model accuracy increased with additional independent variables that influenced UMS most. Model B maintained accurate prediction through minimum mean absolute bias, low deviation in residual bias, and adequate coefficient of determination values. Even though predictions from model D with UBF and Day observed greater model fit R-squared values, the addition of fat at the end of the feeding period may skew data collected from ultrasonic measurement. Therefore, BW is an advantageous addition to the model and should be included in the calculation to predict marbling score over the feeding period.
LITERATURE CITED


Table 1. Diet composition fed from 4 yr of data collected at the University of Illinois – Urbana.

<table>
<thead>
<tr>
<th>Item 1</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Dry, cracked</td>
<td>75</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>57</td>
<td></td>
<td></td>
<td>7</td>
<td>50</td>
</tr>
<tr>
<td>DDGS</td>
<td>25</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25</td>
<td>40</td>
<td>40</td>
<td>25</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MDGS</td>
<td></td>
<td>40</td>
<td></td>
<td></td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DCGF</td>
<td></td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WCGF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Soybean Hulls</td>
<td></td>
<td></td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn Silage, 50%</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>8</td>
<td>7.5</td>
<td>8</td>
<td>15</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Brome Hay, mature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplement 2</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diet Composition</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DM%</td>
<td>71</td>
<td>73</td>
<td>71</td>
<td>51</td>
<td>56</td>
<td>51</td>
<td>53</td>
<td>74</td>
<td>79</td>
<td>49</td>
<td>79</td>
<td>53</td>
<td>52</td>
</tr>
<tr>
<td>CP</td>
<td>13.2</td>
<td>14.6</td>
<td>18</td>
<td>18.6</td>
<td>14.5</td>
<td>17.8</td>
<td>17.9</td>
<td>14.3</td>
<td>15.4</td>
<td>21.4</td>
<td>20.0</td>
<td>18.3</td>
<td>19.1</td>
</tr>
<tr>
<td>ADF</td>
<td>8.1</td>
<td>7.3</td>
<td>23.1</td>
<td>22.3</td>
<td>23.9</td>
<td>13.4</td>
<td>22.3</td>
<td>23.3</td>
<td>7.4</td>
<td>25.6</td>
<td>19.8</td>
<td>17.1</td>
<td>24.2</td>
</tr>
<tr>
<td>NDF</td>
<td>14.7</td>
<td>17.3</td>
<td>38.7</td>
<td>42.1</td>
<td>43.0</td>
<td>23.8</td>
<td>40.4</td>
<td>40.1</td>
<td>17.3</td>
<td>45.1</td>
<td>33.8</td>
<td>36.9</td>
<td>38.5</td>
</tr>
<tr>
<td>Ca</td>
<td>0.40</td>
<td>0.55</td>
<td>0.66</td>
<td>0.74</td>
<td>0.61</td>
<td>0.60</td>
<td>0.60</td>
<td>0.70</td>
<td>0.54</td>
<td>0.88</td>
<td>0.61</td>
<td>0.62</td>
<td>0.63</td>
</tr>
<tr>
<td>P</td>
<td>0.35</td>
<td>0.46</td>
<td>0.47</td>
<td>0.46</td>
<td>0.45</td>
<td>0.49</td>
<td>0.44</td>
<td>0.39</td>
<td>0.44</td>
<td>0.38</td>
<td>0.49</td>
<td>0.47</td>
<td>0.48</td>
</tr>
</tbody>
</table>

DDGS = dry distillers grains plus solubles; MDGS = modified distillers grains plus solubles; DCGF = dry corn gluten feed; WCGF = wet corn gluten feed.

Supplement for Diet 1 contained: 46.3% protein, 4.1% Ca, 1.1% P, 3.3% salt, 0.41% Mg, 1.31% K, 0.35% S, 940 mg/kg Zn, 2.49 mg/kg of Co, 18.0 mg/kg Cu, 1.0 mg/kg I, 730 mg/kg Fe, 326 mg/kg Mn, 2.28 mg/kg of Se, 14,000 IU/kg vit A, 1,500 IU/kg vit D, and 41.6 IU/kg of vit E.

Diets 2 to 13 contained: 14.4% protein, 4.1% Ca, 1.1% P, 3.3% salt, 0.41% Mg, 1.31% K, 0.35% S, 940 mg/kg Zn, 2.49 mg/kg of Co, 18.0 mg/kg Cu, 1.0 mg/kg I, 730 mg/kg Fe, 326 mg/kg Mn, 2.28 mg/kg of Se, 14,000 IU/kg vit A, 1,500 IU/kg vit D, and 41.6 IU/kg of vit E.
Table 2. Correlation matrix for parameters\textsuperscript{1} to predict marbling score.

<table>
<thead>
<tr>
<th></th>
<th>UMS</th>
<th>UBF, cm</th>
<th>BW, kg</th>
<th>DMI, kg/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>UMS</td>
<td>1.00</td>
<td>1.00</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>UBF, cm</td>
<td>0.219</td>
<td>0.496</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>BW, kg</td>
<td>0.531</td>
<td></td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>0.292</td>
<td>0.118</td>
<td>0.548</td>
<td>1.00</td>
</tr>
</tbody>
</table>

\textsuperscript{1}UMS = Ultrasound Marbling Score where 500=small, 600= moderate, 700=modest; BF=backfat; UBF = Ultrasound Backfat
Table 3. Marbling score prediction models\(^1\) developed from 1,761 animals with serial ultrasound carcass measurement.

<table>
<thead>
<tr>
<th></th>
<th>Intercept</th>
<th>Day</th>
<th>UBF(^2)</th>
<th>BW</th>
<th>DMI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Linear</td>
<td>Quadratic</td>
<td>Linear</td>
<td>Quadratic</td>
</tr>
<tr>
<td>Full</td>
<td>382.92</td>
<td>-1.2583</td>
<td>0.0104</td>
<td>48.1491</td>
<td>-11.6671</td>
</tr>
<tr>
<td>P-value</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Full – no BW</td>
<td>433.00</td>
<td>-0.8818</td>
<td>0.1096</td>
<td>58.8000</td>
<td>-13.4375</td>
</tr>
<tr>
<td>P-value</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Full – no DMI</td>
<td>386.29</td>
<td>0.0559</td>
<td>0.0029</td>
<td>38.7815</td>
<td>-12.4579</td>
</tr>
<tr>
<td>P-value</td>
<td>&lt;0.01</td>
<td>0.454</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Year 4 Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>437.84</td>
<td>-0.6992</td>
<td>0.0095</td>
<td>43.7147</td>
<td>-9.7087</td>
</tr>
<tr>
<td>P-value</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>B</td>
<td>345.50</td>
<td>-0.0558</td>
<td>0.0025</td>
<td>21.7566</td>
<td>-8.8367</td>
</tr>
<tr>
<td>P-value</td>
<td>&lt;0.01</td>
<td>0.521</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>C</td>
<td>395.66</td>
<td>0.6510</td>
<td>0.0019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P-value</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>D</td>
<td>382.36</td>
<td>0.4354</td>
<td>0.0035</td>
<td>34.8866</td>
<td>-10.9051</td>
</tr>
<tr>
<td>P-value</td>
<td>0.0005</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>E</td>
<td>377.96</td>
<td></td>
<td></td>
<td>64.6671</td>
<td>-7.8476</td>
</tr>
<tr>
<td>P-value</td>
<td>0.01</td>
<td></td>
<td></td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>F</td>
<td>321.92</td>
<td>-0.0376</td>
<td>0.0020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P-value</td>
<td>&lt;0.01</td>
<td>0.662</td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>338.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P-value</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>452.84</td>
<td>-0.4878</td>
<td>0.0086</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P-value</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>479.54</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P-value</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Prediction models to evaluate influence of parameter from all 4 yr of data = Full, Full-no BW, and Full-no DMI; prediction models derived from 3 yr of data to be tested against yr 4 to determine accuracy and precision = A – I.

\(^2\)UBF = Ultrasound Backfat.
Table 4. Average ultrasound marbling score\(^1\) compared to predicted ultrasound marbling scores from model derived from animals fed during yr 1, 2, and 3 and tested against animals fed during yr 4.

<table>
<thead>
<tr>
<th>Day of Measurement</th>
<th>0</th>
<th>42</th>
<th>84</th>
<th>120</th>
<th>(B_1) (^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg UMS(^3)</td>
<td>397</td>
<td>425</td>
<td>456</td>
<td>531</td>
<td>1.064</td>
</tr>
<tr>
<td>Model(^d)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>492</td>
<td>405</td>
<td>435</td>
<td>486</td>
<td>0.007</td>
</tr>
<tr>
<td>B</td>
<td>396</td>
<td>425</td>
<td>465</td>
<td>515</td>
<td>0.978</td>
</tr>
<tr>
<td>C</td>
<td>396</td>
<td>426</td>
<td>463</td>
<td>500</td>
<td>0.873</td>
</tr>
<tr>
<td>D</td>
<td>394</td>
<td>423</td>
<td>462</td>
<td>508</td>
<td>0.947</td>
</tr>
<tr>
<td>E</td>
<td>402</td>
<td>413</td>
<td>422</td>
<td>443</td>
<td>0.327</td>
</tr>
<tr>
<td>F</td>
<td>398</td>
<td>426</td>
<td>463</td>
<td>507</td>
<td>0.900</td>
</tr>
<tr>
<td>G</td>
<td>398</td>
<td>429</td>
<td>463</td>
<td>504</td>
<td>0.875</td>
</tr>
<tr>
<td>H</td>
<td>453</td>
<td>490</td>
<td>521</td>
<td>572</td>
<td>0.964</td>
</tr>
<tr>
<td>I</td>
<td>480</td>
<td>449</td>
<td>453</td>
<td>458</td>
<td>-0.154</td>
</tr>
</tbody>
</table>

\(^1\)Ultrasound Marbling Score = UMS, 500=small, 600=moderate, 700=modest.  
\(^2\)\(B_1\) = slope of marbling scores from d 0 to d 120 for correlating model.  
\(^3\)Avg UMS = actual average ultrasound marbling score for animals in yr 4 across d.  
\(^d\)Models tested against yr 4 data and derived from yr 1, 2, and 3. Listed in Table 3.  
\(^5\)DMI Models  

\(^5\)D 0 UMS excluded from models containing DMI as an independent variable because DMI is not available on d 0. Slopes improve.
Table 5. Prediction equation within day mean absolute bias\textsuperscript{a} of ultrasonic-measured marbling versus predicted marbling calculated from yr 4 data.

<table>
<thead>
<tr>
<th>Day</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>101.14</td>
<td>45.76</td>
<td>44.09</td>
<td>43.51</td>
<td>44.32</td>
<td>46.43</td>
<td>46.82</td>
<td>68.52</td>
<td>88.45</td>
</tr>
<tr>
<td>42</td>
<td>52.62</td>
<td>44.89</td>
<td>44.95</td>
<td>43.89</td>
<td>42.49</td>
<td>45.21</td>
<td>46.13</td>
<td>78.66</td>
<td>52.48</td>
</tr>
<tr>
<td>84</td>
<td>56.14</td>
<td>52.83</td>
<td>52.65</td>
<td>51.73</td>
<td>54.36</td>
<td>52.49</td>
<td>53.33</td>
<td>81.76</td>
<td>51.29</td>
</tr>
<tr>
<td>120</td>
<td>72.74</td>
<td>62.22</td>
<td>64.25</td>
<td>63.08</td>
<td>94.76</td>
<td>62.75</td>
<td>64.59</td>
<td>74.47</td>
<td>82.72</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Mean absolute bias = |Observed UMS – predicted mean UMS|/hd per DOM within model.

\textsuperscript{b}Models tested against yr 4 data and derived from yr 1, 2, and 3. Listed in Table 3.
Table 6. R-squared values\(^1\) for ultrasonic-measured marbling versus predicted ultrasound marbling calculated from Year 4 data.

<table>
<thead>
<tr>
<th>Day</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.837</td>
<td>0.956</td>
<td>1.000</td>
<td>0.996</td>
<td>0.974</td>
<td>0.951</td>
<td>0.937</td>
<td>0.999</td>
<td>0.999</td>
</tr>
<tr>
<td>42</td>
<td>0.770</td>
<td>0.927</td>
<td>1.000</td>
<td>0.995</td>
<td>0.955</td>
<td>0.932</td>
<td>0.897</td>
<td>0.966</td>
<td>0.982</td>
</tr>
<tr>
<td>84</td>
<td>0.878</td>
<td>0.909</td>
<td>1.000</td>
<td>0.996</td>
<td>0.958</td>
<td>0.924</td>
<td>0.870</td>
<td>0.968</td>
<td>0.979</td>
</tr>
<tr>
<td>120</td>
<td>0.906</td>
<td>0.901</td>
<td>1.000</td>
<td>0.996</td>
<td>0.945</td>
<td>0.923</td>
<td>0.854</td>
<td>0.972</td>
<td>0.979</td>
</tr>
</tbody>
</table>

\(^1\)\(R^2 = 1 - \left[\frac{\sigma_{res}^2}{\sigma_{obs}^2}\right]\).

\(^2\)Models tested against yr 4 data and derived from yr 1, 2, and 3. Listed in Table 3.
Figure 1. Bias of ultrasonic measured marbling score versus predicted ultrasound marbling score from prediction model on Day 0 of Year 4.
Figure 2. Bias of ultrasonic measured marbling score versus predicted ultrasound marbling score from prediction model on Day 42 of Year 4.
Figure 3. Bias of ultrasonic measured marbling score versus predicted ultrasound marbling score from prediction model on Day 84 of Year 4.
Figure 4. Bias of ultrasonic measured marbling score versus predicted ultrasound marbling score from prediction model on Day 120 of Year 4.
Marketing strategy influences optimum marketing date of steers in relation to corn price and days on feed

M. F. Wilken*1, PAS, J. C. MacDonald1, PAS, G. E. Erickson1, PAS, T. J. Klopfenstein1, C. J. Schneider1, K. M. Luebbe1, and S. D. Kachman2

1Department of Animal Sciences, University of Nebraska-Lincoln, Lincoln, NE 68583
2Department of Statistics, University of Nebraska-Lincoln, Lincoln, NE 68583

ABSTRACT: Seven trials conducted at the University of Nebraska-Lincoln fed similar diets were used to evaluate carcass weight change over the feeding period and to determine the influence of corn price on profit potential on a live- (LW) and carcass-weight (CW)-basis. Regression analysis of dressing percent change over the feeding period was used to calculate CW gain and CW transfer in relation to LW gain.

Economics were calculated with diet costs at $3.50, $5.50, and $7.50/25.4 kg corn price and cattle marketed at 75, 100 (1.2 cm backfat), and 125 percent days on feed on both a LW and CW-basis. Results of the analysis demonstrate CW increased quadratically (P < 0.01) at an increasing rate while LW increased quadratically at decreasing rate (P < 0.01). Transfer of LW to CW increased linearly (P < 0.01) reaching 90 percent at final days on feed. Because DMI increased linearly (P < 0.01) and ADG decreased for both LW (linearly; P < 0.01) and CW (quadratically; P < 0.01), LW G:F decreased in a linear (P < 0.01) fashion, whereas CW G:F decreased in a quadratic (P < 0.01) manner. Economic analysis showed, regardless of marketing scheme, cattle received similar returns when marketing at 1.2 cm backfat for all corn prices. Feeding cattle longer and marketing on a CW-basis observed the greatest returns and minimized losses. Overall, feeding cattle longer increased CW gain and profit potential when selling on a CW-basis which provides a biological explanation for the incentive to feed cattle longer.

Keywords: Feedlot cattle, carcass weight change, profitability, market factors
INTRODUCTION

Average profitability in the cattle feeding industry has been essentially zero over the last 40 years (Walter and Hale, 2011). Factors influencing profitability have long been studied and HCW has been deemed one of the most important (Langmeier et al., 1992; Fuez, 2002; Pyatt et al., 2005; Walter and Hale, 2011; Tatum et al., 2012). Other factors related to variation in profitability include initial calf price (Wilken et al., 2012), Choice-Select spread (Pyatt et al., 2005; Wilken et al., 2012), and fed cattle price (Walter and Hale, 2011). Additional influencers have been corn price (Langmeier et al., 1992) or total feed costs (Pyatt et al., 2005; Tatum et al., 2012).

Because cattle are marketed on both a live and carcass-weight-basis, profit potential from each scenario has been evaluated by several groups. Walter and Hale (2011) noted that feeding for longer periods of time benefits both schemes but efficiency of gain limits the profit potential for selling cattle on a live-basis more quickly than marketing in the beef. Still, Streeter et al. (2012) noted that optimum marketing date can change with the marketing scenario since cattle marketed on a carcass-weight-basis should be fed longer compared to those marketed live. Feeding cattle longer is more profitable with increased Choice-Select spread making marbling score a greater influence of profitability (Fuez, 2002; Wilken et al., 2012). The additional weight and increased quality grades can potentially overcome the discounts from overweight carcasses and YG 4 and 5 (Fuez, 2002; Streeter et al., 2012).

While it is assumed that G:F decreases over the feeding period because gain is composed of fat rather than lean tissue, fat gain as a proportion of empty BW gain remains relatively constant (Brethour, 2004). Weight transfer from live to carcass gain
has been shown to increase over the feeding period to the point of 86 percent or more at finishing (Walter and Hale, 2011; Streeter et al, 2012). Therefore, the objective of this analysis was to demonstrate the impact of diet costs on cost of gain on a live- or carcass-weight-basis for profit potential.

**MATERIALS and METHODS**

**Data Collection**

All animal care procedures were approved by the University of Nebraska’s Institute for Animal Use and Care committee for the five years of data compiled from feeding trials conducted at the University of Nebraska – Lincoln to evaluate the change in animal performance and carcass performance over the feeding period. Trials for the dataset were selected for similar experimental diets or where dietary treatments had no significant differences in animal performance resulting in seven research experiments that included 298 pens with 2380 steers. Criteria for trial selection also included 4 to 5 interim weights collected throughout the feeding period at approximately 30-day intervals (Stock et al., 1983). Initial BW for all trials required 2- to 3- day consecutive weights averaged after a limit-feeding period to minimize the influence of gut fill (Watson et al., 2013). Additionally, interim weights were subjected to a 4 percent pencil shrink to account for gut fill.

Average initial live BW (LW) was 348 kg (SD = 21 kg) with days on feed ranging from 117 to 159 and fed between May and October. All cattle were marketed for a projected industry average endpoint of 1.2 cm backfat and averaged 1.3 cm backfat across trials. Trial averages are shown in Table 1. Shrunken LW and carcass weight (CW) were used to calculate changes in BW, ADG, G:F, and transfer of LW gain to CW gain for each of the interim period measurements.
Change in dressing percentage over the feeding period was predicted from a regression equation based off of previously derived equations from serial slaughter analysis (May et al., 1992; Bruns et al., 2004). May et al. (1992; Eq. 1) observed carcass changes with calf-fed steers while Bruns et al. (2004; Eq. 2) observed yearling changes and equations are below, respectively:

\[ \text{Eq. 1} \quad y = 0.09x + 55.5; \quad R^2 = 0.93 \]

and

\[ \text{Eq. 2} \quad y = 0.105x + 53.9; \quad R^2 = 0.99 \]

where the dependent variable (y) is the resulting dressing percentage and the independent variable (x) is days as a percent of days on feed. Because the regression response is different for calf-feds versus yearlings (Owens et al., 1995), the dependent variables on the final day of the feeding period were set to 100 percent days on feed rather than observed days. By calculating the days on feed as a percent of the feeding period, the adjusted equations responded by essentially matching with equal slopes and intercepts, and the resulting equation was then used to calculate dressing percent and change in carcass weight over the feeding period for the compiled dataset used for this analysis.

The regression equation is shown:

\[ y = 0.097x + 54.7; \quad R^2 = 0.94. \]

Days on feed differed between trials included in this analysis. Therefore, variation in days on feed between trials was corrected by regressing dressing percentage on days on feed and extrapolating the data to the intercept at day 0 in order to achieve dressing percent equivalent as percent days on feed. This allowed for the comparison of trial results on a 100 percent days-on-feed-basis like that of the regression equation.
development for the dressing percent calculation discussed earlier. Thus, all results will
be reported on a percent days-on-feed-basis.

**Economic Analysis**

The influence of feed efficiency change over the feeding period on both a LW and
CW-basis was evaluated through changes in cost of gain as subjected to three different
diet-cost scenarios. Varying diet cost was assessed because corn price can influence
profitability by up to 22 percent (Langmeier et al., 1992) and can explain cost of gain
variability to a large extent (Albright et al, 1993). Diet costs were considered equivalent
to $5.26/25.4 kg (± $1.55, 5-year average; CattleFax, Englewood, CO). For the
profitability analysis, assumptions were: feeder calf price (340 kg or 750 lbs) =
$116.36/45.4 kg (5-year average; CattleFax, Englewood, CO); yardage + interest =
$0.45/head/day; miscellaneous charges = $40/head; live cattle price = $101.82/45.4 kg
(5-year average; CattleFax, Englewood, CO); and carcass price assuming 63 percent
dressed = $161.62/45.4 kg. Both live and carcass-based pricing were used to calculate
profit/loss from the difference of total costs and total revenue per steer.

Price variability was analyzed by first observing monthly average price trends for
feeder calf price (750/45.4 kg), live slaughter price, and corn price over 5 years as shown
in Figure 1. Historically, a relationship between live cattle price and corn price was
determined and found to influence the price slide of feeder cattle negatively (Dhuyvetter
et al., 2002). However, current market conditions may not be representative of previous
analyses. Therefore, correlations between live slaughter, feeder calf and corn prices were
tested with live and calf prices moving together at 0.9686 and corn price being highly
related but to a lesser extent at 0.8604 and 0.8056 for live and calf prices, respectively.
These correlations are similar to those more recently calculated by Schulz (2013) where live and calf prices were more similar at 0.9751 and lesser to corn at 0.8733 and 0.8209, respectively. Therefore, live slaughter and feeder calf prices used in each scenario are those prices averaged during periods in which corn averaged one of the three applied prices. Due to increased relevancy in the industry, corn prices were analyzed at $3.50, $5.50, and $7.50 per 25.4 kg and applied to diet cost. With methodology in accordance with Dhuyvetter et al. (2002) and using 5-year monthly data (Figure 1; CattleFax, Englewood, CO), live and calf price was averaged during months when corn was $3.50, $5.50, and $7.50 per 25.4 kg (+/-$0.50 at each price level). Live slaughter price was adjusted to $87.35, $98.23, and $118.14 per 45.4 kg and feeder calf price was set at $98.97, $109.79, and $135.73 per 45.4 kg for changing corn prices, respectively. This allowed for the use of numbers related to current market conditions on an averaged 5-year basis. Additionally, yardage and interest applied to input costs were collectively assumed to be $0.45 per head per day.

To illustrate the ideal marketing strategy on a LW or CW-basis, three corn price scenarios were generated to analyze corn price influence on ideal marketing date. The three corn prices were applied to diet costs on a DM-basis equating costs of $158.96, $249.79, and $340.63 per 907 kg DM, respectively. Marketing dates chosen to illustrate effects of varying market date were selling early at 75 percent of normal (105 days on feed), at industry average of 100 percent (1.2 cm backfat; 140 days on feed), and selling late for additional weight at 125 percent of normal (175 days on feed). Parameter estimates to predict performance with longer feeding were extrapolated from the seven-trial dataset through regression analysis.
Statistical Analysis

Trial selection was conducted in accordance with Alemayehu (2011). Trials were regressed for linear and quadratic coefficients with pen as the experimental unit using the GLM procedures of SAS (SAS Inst. Inc., Cary, NC). To estimate parameter response, a pooled analysis of trials was conducted where the response variable was regressed to percent days on feed. Linear and quadratic parameter estimates were determined using the GLM procedures of SAS by obtaining intercept and regression coefficients for each pen within trial for each parameter (intercept, linear coefficient, quadratic coefficient). A pooled analysis was used since experimental unit parameters and responses were available, rather than only treatment averages that are generally used in meta-analysis studies (Berman and Parker, 2002). Regression parameter estimates were then centered across trials using the MIXED procedures of SAS by including experiment in the model. Significance of linear and quadratic parameters was determined by first including the quadratic term in the model, and removing it if not significant ($P < 0.05$). Based on regression response of feed efficiency, economic analysis was conducted to observe changes in cost of gain on a LW and CW-basis in relation to $3.50, 5.50$ and $7.50/25.4$ kg corn price.

RESULTS AND DISCUSSION

Results of the LW and CW changes over the feeding period as a percent of days on feed revealed that both LW and CW increase in a quadratic fashion and are shown in Figure 2. Because the quadratic term is slightly negative for LW, it can be concluded that
LW increased at a decreasing rate ($P < 0.01$); whereas, CW increased at an increasing rate because of the slight positive response in its quadratic term ($P < 0.01$). Daily weight gain over the feeding period decreased linearly ($P < 0.01$; Figure 3) for LW while daily CW gain increased at an decreasing rate quadratically ($P < 0.01$) illustrated by the negative quadratic term, similar to that of regression analysis conducted by May et al. (1992) and Bruns et al. (2004). From serial slaughter analysis, both May et al. (1992) and Bruns et al. (2004) observed LW and dressing percent to increase linearly ($P < 0.01$) as slaughter group increased and noted ADG decreased over the feeding period. For the current analysis, Figure 3 shows the response of carcass ADG increasing more sharply in the beginning of the feeding period and then slowly plateauing towards the conclusion. Live weight feed efficiency declined linearly ($P < 0.01$; Figure 4) and CW feed efficiency observed a positive quadratic response that decreased at the end of the feeding period after experiencing an optimum G:F at 50 percent days on feed. Results from the current analysis were similar to several other studies (Vasconcelos et al., 2008; Streeter et al., 2012) with HCW increasing linearly and ADG and G:F decreasing linearly over the feeding period when calculated from LW. Carcass feed efficiency has not been widely reported.

The DMI response in Figure 5 increased in a quadratic manner ($P < 0.01$) by reaching maximum intake at the end of the feeding period. Even though animals eat to an energy level to meet maintenance and gain requirements resulting in increased intake as weight increases during growth (Owens et al., 1995; Johnson et al., 2003), the observed increase in DMI at feeding conclusion is counterintuitive since rate of weight gain tends to slow towards the end of the feeding period like that seen in the current
analysis. Additionally, previous research has demonstrated increased DMI at the
beginning of the feeding period followed by a plateau and then a decrease towards final
days on feed (Hicks et al., 1990a; Hicks et al., 1990b). Therefore, the increase intake
noted here could be a response to environmental conditions as yearlings experiencing
cooler fall temperatures tend to consume more energy because of reduced heat stress
compared to the summer months (Young, 1981; NRC, 2000). Therefore, the increased
rate of intake response was considered to be a function of environment and not biology.

As illustrated by Figure 6, a linear increase ($P < 0.01$) was observed for transfer
of LW gain to CW gain resulting in approximately 90 percent transfer by the end of the
feeding period, suggesting that 90 percent of every additional kg of LW gain was being
deposited in the carcass. Animals fed high energy diets like those used in this dataset
often have a lower visceral organ weight to LW ratio than those that may have been
restricted in energy (Johnson et al., 2003; Hersom et al., 2004). This transfer in weight
gained could ultimately alter the current paradigm that the price difference between LW
and CW is based on dressing percent at an industry average of 63 percent. To be more
analytical, 0.454 kg (1 pound) of gain added to LW would correspond to 0.409 kg (0.90
pounds) of weight gained in the carcass. Additionally, if market price for steers is
$115/45.4$ kg (100 pounds) on a live-basis and $160/45.4$ kg on a carcass-basis at 63
dressing percentage, $1.15$ would be gained per extra 0.454 kg gained live while $1.44
(0.409 kg at $160/45.4$ kg) would be added per 0.454 kg if selling in the beef. The
additional gain to the carcass and selling on a carcass-basis generates $0.29 per 0.454 kg
more revenue than on a live-basis.
Figures 7 and 8 show the response curve for the change in cost of gain on a live and carcass-basis, respectively, when corn is $3.50, $5.50, and $7.50 per 25.4 kg (1 bushel). As animals consume more feed and relative feed efficiency declines over the feeding period, it was expected that cost of gain would increase on both a LW and CW-basis. However, the response from live to carcass differed. Cost of gain on a LW-basis (Figure 7) was significant at both the linear and quadratic term with positive responses ($P < 0.01$) demonstrating that cost of gain increases at an increasing rate over the feeding period. However, carcass cost of gain (Figure 8) was negative for the linear term and positive for the quadratic slope ($P < 0.01$) noting an initial decrease in cost of gain with an increase at trial conclusion. These differing responses exhibits the incremental increase in cost of gain is greater on a LW-basis versus a CW-basis.

Hypothetical cost/benefit analysis was conducted with steer performance projected at 75, 100, and 125 percent of actual marketing date (1.2 cm backfat) from trial data in Table 1 in response to 5-year average corn, feeder calf, and live slaughter prices. Predicted average performance for steers marketed at 75, 100, and 125% of actual marketing date are shown in Table 2. For both LW and CW, the result of feeding cattle additional days is an increase in salable weight, but a decline in the average (closeout) gain, and feed efficiency. However, the apparent decline in closeout performance from additional days may lead to improved profitability. Using 5-year average prices for corn, feeder calves, and live cattle (Table 3), the greatest returns ($\$31.33$ per head) were from steers marketed at 125% days on feed on a CW-basis compared to all other marketing schemes. When steers were marketed at industry average fat depth, similar returns were observed whether on a LW or CW-basis, losing -29.03 and -29.23, respectively. Losses
were observed for steers marketed at 75% days on feed with $15.46 on a LW-basis and $90.99 lost per head when sold in the beef. These results illustrate the potential for increased returns when marketing cattle on a CW-basis, but additional days on feed are needed with this strategy since feeding until 100% days on feed or less inflates the loss potential for carcass-based pricing compared to selling on a LW-basis.

In order to analyze the impact of changing corn price at $3.50, $5.50, and $7.50 per 25.4 kg (Table 4, Table 5, and Table 6, respectively) industry trends in price fluctuations were maintained by adjusting feeder calf and live slaughter prices in relationship to corn price as explained earlier and depicted in Figure 1. Profit was maximized at 125% days on feed when corn price was $3.50/25.4 kg earning $108.44 per head (Table 4). Returns for steers sold live at 125% days on feed were $58.93 per head. When steers were sold at 100% days on feed, returns were $38 per head regardless of marketing scheme. However when steers were only fed for 75% of industry average, profits were only observed for those sold live at $8.99 per head whereas, those sold in the beef lost $31.34 per head.

When corn was $5.50/25.4 kg, the only positive returns of $6.38/25.4kg were observed for cattle sold on a CW-basis at 125% days on feed (Table 5). However, steers sold on a LW-basis at 125% days on feed lost $49.28 per head at $5.50 corn price. When cattle were marketed at 75% days on feed, losses were minimized by selling on a live-basis compared to a CW-basis as $48.63 and $93.98 were lost per head, respectively.

Losses were observed across the board regardless of marketing time and scheme when corn was analyzed at $7.50/25.4 kg (Table 6). Losses were increased with additional days on feed when marketed on a LW-basis while the inverse was observed
when selling steers on a CW-basis. Still, losses were minimized by feeding cattle past industry average and marketing on a CW-basis with negative returns of $76.82 per head compared to the $143.77 lost per head when steers were sold live at 75% days on feed.

The overall results of the comparison of varying corn price mirrored that of Streeter et al. (2012) where returns from LW marking strategies continually decreased with increased days fed while returns increased with increased days when sold on a CW-basis. Carcass weight has been shown to be the most important variable for profitability with increasing feed costs (Pyatt et al., 2005; Wilken et al., 2012). Instead, the Choice-Select (Ch-Se) spread offers more importance in profit variation concluding it is more beneficial to feed cattle for longer periods of time as HCW and USDA Quality Grade premiums will cover the discounts from overweight carcasses and USDA YG 4 and 5 from additional fat deposition (Fuez, 2002; Streeter et al., 2012). The impact of overweight carcasses can be minimized to a certain extent by sorting and therefore, minimizing the variation in final HCW at sale (Wilken et al., 2012).

Profitability for LW or CW based marketing is virtually the same at 100 percent feeding period (industry average backfat) because carcass price is based on a 63 percent dress. From a producer perspective, selling steers at 1.2 cm backfat results in similar returns regardless if marketing on a LW-basis, or a CW-basis. Therefore, the profit potential of feeding cattle longer should be considered due to the increased return at lower feed costs and minimized loss during higher corn price scenarios. It should be noted that cost of gain decreased on a CW-basis as days increased, whereas cost of gain on a LW-basis increased with additional days across all market schemes in the current analysis.
The profitability response illustrates the increased transfer of weight to the carcass as cattle are fed for longer periods of time. By feeding cattle longer, input costs are then distributed over the additional mass which is the reason cost of gains decreased with additional days over all corn price comparisons on a CW-basis. Carcass weight gain (final CW – initial CW; Table 2) was 64, 69, and 73 percent of the live weight gain (final LW- initial LW) for 75, 100, and 125 percent of the feeding period, respectively. The increased percentage of carcass weight gain relative to live weight gain depicts the increased proportional distribution of cost in relationship to weight. The additional cost of gain by feeding longer is diluted over more weight in the carcass than that of LW. An example is explained using the averages in Table 2. When applied to initial steer price, $15/45.4 kg must be returned at a cost of gain lower than $1.15/0.45 kg due to initial cost of $115/45.5 kg and live market price of $100/45.5 kg. Steers averaging 349 kg upon entry require a compensation of $192.18 per head to overcome the negative margin (349 * $15/45.4 kg). If steers are marketed at the average 1.3 cm backfat, the LW gain is 249 kg with a negative margin of $35/45.4 kg of gain. Now, if those steers were fed 25 percent longer resulting in a LW gain of 304 kg, the negative margin is adjusted to $29/45.4 kg from the purchase price because the cost is covered by more weight.

The complexity of feeding for longer periods is increased when animals are fed past the industry average of 1.2 cm. The current analysis only carried the additional backfat measurement to 1.4 cm by extrapolation of the dataset. Understanding feed efficiency and carcass quality changes past this measurement is fairly uncertain because protein accretion and fat deposition rates have been difficult to measure separately although they are highly correlated (Owens et al., 1995). Later in the feeding period,
there is a greater efficiency of dietary energy for gain to be used for laying down fat rather than depositing protein (Old and Garrett, 1987) since protein accretion is related to mature body size of an animal and fat deposition is influenced by energy intake (Carstens et al., 1991; Owens et al., 1995). Longissimus muscle area continues to increase with HCW as reported by Bruns et al. (2004) until skeletal maturity is reached. However when measured in respect to HCW, LM area decreases through time (Streeter et al., 2012). Even though the additional weight and quality grade premiums have been shown to overshadow the discounts from overweight and YG 4 and 5 (Walter and Hale, 2011; Streeter et al., 2012), Fuez (2002) noted the profit potential from more days on feed would decrease with lower Ch-Se spreads showing a reward for YG-based marketing. Wilken et al. (2012) found similar responses at lower Ch-Se spread values with a greater potential for profit with increased importance found for feed efficiency, especially at higher corn prices. Therefore, it is inappropriate to guarantee improved profitability when feeding for longer periods of time and selling on a CW-basis. Still, greater final CW can increase the potential for additional weight at lower backfat measurements (Fuez, 2002) and can be achieved by delaying entrance into the feedlot for concentrate feeding and thereby, delaying skeletal maturity (Owens et al., 1995) like that of yearlings versus calf-feds. Additionally, CW can be increased by increasing energy intake (Owens et al., 1995; Ferrell and Jenkins, 2008), administering hormonal implants (Duckett et al., 1997; Trenkle, 1997; Roeber et al., 2000; Smith et al., 2007), and feeding beta-adrenergic agonists (Kellermeier et al., 2009; Bryant et al., 2010, Scramlin et al., 2010). These approaches have tended to increase skeletal maturity (Owens et al., 1995) which allows for the potential of increased feed efficiency (Bruns et al., 2005), increased protein
accretion (Duckett et al., 1997; Roeber et al., 2000; Smith et al., 2007) and delayed intramuscular fat deposition until later in the finishing period (Hutcheson et al., 1997; Bruns et al., 2005). Because of these potential alterations in carcass weight gain over the feeding period, days on feed will vary in relationship to this analysis.

It is well understood that increased duration of feeding periods increases yield grades, quality grades and carcass weight which emphasizes the impact of sorting (Brethour, 2004). However, discounts are often applied to each parameter as the industry threshold is met. Discounts for YG 4 and 5 carcasses may be compensated for by the premiums received for quality grades of high Choice or even Prime with additional fat deposition (Fuez, 2002; Walter and Hale, 2011) since marbling scores increase with additional days on feed (Bruns et al., 2004). Carcass weight limits have been increased and few discounts have been observed recently (Hoffman et al., 2010) increasing the opportunity for producers to sell more weight for profit.

The addition of weight at the end of the feeding period has been highly discussed because of the greater correlation between feeder calf and live slaughter prices than those to corn price. Feeder calf prices have been shown to be less responsive to changes in corn prices (Anderson and Trapp, 2000) than live slaughter prices (Dhuyvetter et al., 2002) and thus changing feeding programs only minimally influence profit potential. The additional energy and lower cost of ethanol byproducts as priced 90% relative to corn can allow producers to maintain or increase gains and efficiency by feeding up to 40% of the diet (Klopfenstein et al., 2008). Trials included in this analysis contained byproducts and results illustrate that corn price and therefore, diet costs are less of a factor in profitability than that of feeder calf price.
Overall, optimum marketing date is dependent upon the marketing strategy employed. As observed in time of high feed costs, feeding for longer periods and marketing on a carcass-weight-basis may minimize losses. Even so, selling cattle at the industry standard will result in similar returns if marketed on a live or carcass-weight-basis but profitability may be increased from selling in the beef after a longer feeding period especially with increased dressing percentage potential with administration of beta-adrenergic agonists. The limited availability of research on feeding cattle past industry average requires further investigation.

**IMPLICATIONS**

Even though the profit potential is documented here, the optimum additional time on feed in a literal sense cannot be derived from this report because this analysis is based from extrapolated data of yearling steers. Instead, cattle type (calf-fed versus yearling, steer versus heifer) and subsequent growth rate would need to be taken into consideration. Since cattle are rarely fed to maturity (Owens et al., 1995; Ferrell and Jenkins, 2008), the point at which cattle weight gain plateaus is hardly realized which limits the opportunity to understand true CW transfer value. Further research of applied feeding trials of steers, heifers, calf-feds, and yearlings marketed at greater than 1.2 cm backfat is needed.
LITERATURE CITED


Table 1. Performance parameter\textsuperscript{a} averages by trial.

<table>
<thead>
<tr>
<th>Trial</th>
<th>LW, kg</th>
<th>SE</th>
<th>CW, kg</th>
<th>SE</th>
<th>DMI, kg/d</th>
<th>SE</th>
<th>ADG, kg/d</th>
<th>SE</th>
<th>cADG, kg/d</th>
<th>SE</th>
<th>G:F</th>
<th>SE</th>
<th>cG:F</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>578</td>
<td>2.1</td>
<td>364</td>
<td>1.3</td>
<td>11.5</td>
<td>0.07</td>
<td>1.74</td>
<td>0.04</td>
<td>1.35</td>
<td>0.02</td>
<td>0.152</td>
<td>0.003</td>
<td>0.117</td>
<td>0.002</td>
</tr>
<tr>
<td>2</td>
<td>570</td>
<td>2.2</td>
<td>359</td>
<td>1.4</td>
<td>11.3</td>
<td>0.06</td>
<td>1.67</td>
<td>0.03</td>
<td>1.37</td>
<td>0.02</td>
<td>0.147</td>
<td>0.003</td>
<td>0.121</td>
<td>0.002</td>
</tr>
<tr>
<td>3</td>
<td>579</td>
<td>2.4</td>
<td>365</td>
<td>1.5</td>
<td>11.6</td>
<td>0.06</td>
<td>1.78</td>
<td>0.03</td>
<td>1.34</td>
<td>0.02</td>
<td>0.153</td>
<td>0.003</td>
<td>0.115</td>
<td>0.001</td>
</tr>
<tr>
<td>4</td>
<td>616</td>
<td>1.8</td>
<td>388</td>
<td>1.1</td>
<td>11.4</td>
<td>0.05</td>
<td>1.83</td>
<td>0.02</td>
<td>1.41</td>
<td>0.01</td>
<td>0.162</td>
<td>0.002</td>
<td>0.123</td>
<td>0.001</td>
</tr>
<tr>
<td>5</td>
<td>598</td>
<td>3.1</td>
<td>380</td>
<td>2.0</td>
<td>10.9</td>
<td>0.08</td>
<td>1.86</td>
<td>0.04</td>
<td>1.41</td>
<td>0.02</td>
<td>0.172</td>
<td>0.004</td>
<td>0.130</td>
<td>0.002</td>
</tr>
<tr>
<td>6</td>
<td>625</td>
<td>2.9</td>
<td>394</td>
<td>1.8</td>
<td>11.2</td>
<td>0.06</td>
<td>1.62</td>
<td>0.03</td>
<td>1.25</td>
<td>0.02</td>
<td>0.145</td>
<td>0.003</td>
<td>0.111</td>
<td>0.002</td>
</tr>
<tr>
<td>7</td>
<td>606</td>
<td>2.7</td>
<td>382</td>
<td>1.7</td>
<td>11.2</td>
<td>0.06</td>
<td>1.65</td>
<td>0.03</td>
<td>1.25</td>
<td>0.02</td>
<td>0.148</td>
<td>0.003</td>
<td>0.113</td>
<td>0.002</td>
</tr>
</tbody>
</table>

\textsuperscript{a}LW = Live Weight; CW = Carcass Weight; ADG = ADG on LW-basis; G:F= LW G:F (kg ADG/kg DMI); cADG = ADG on CW-basis; cG:F= CW G:F (kg cADG/ kg DMI). SE= Standard Error of the Means.
Table 2. Predicted average performance\textsuperscript{a} of steers marketed at 75, 100, or 125% of expected days on feed\textsuperscript{b}.

<table>
<thead>
<tr>
<th>Item\textsuperscript{c}</th>
<th>75%</th>
<th>100%</th>
<th>125%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days on Feed</td>
<td>105</td>
<td>140</td>
<td>175</td>
</tr>
<tr>
<td>DMI, kg/day</td>
<td>10.88</td>
<td>11.12</td>
<td>11.41</td>
</tr>
</tbody>
</table>

**Live**

<table>
<thead>
<tr>
<th>Item</th>
<th>75%</th>
<th>100%</th>
<th>125%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial BW, kg</td>
<td>349</td>
<td>349</td>
<td>349</td>
</tr>
<tr>
<td>Final BW, kg</td>
<td>540</td>
<td>598</td>
<td>653</td>
</tr>
<tr>
<td>ADG, kg/day</td>
<td>1.81</td>
<td>1.77</td>
<td>1.73</td>
</tr>
<tr>
<td>G:F, kg/kg</td>
<td>0.168</td>
<td>0.161</td>
<td>0.154</td>
</tr>
</tbody>
</table>

**Carcass**

<table>
<thead>
<tr>
<th>Item</th>
<th>75%</th>
<th>100%</th>
<th>125%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial CW, kg</td>
<td>204</td>
<td>204</td>
<td>204</td>
</tr>
<tr>
<td>Final HCW, kg</td>
<td>327</td>
<td>377</td>
<td>428</td>
</tr>
<tr>
<td>cADG, kg/day</td>
<td>1.26</td>
<td>1.23</td>
<td>1.12</td>
</tr>
<tr>
<td>cG:F, kg/kg</td>
<td>0.123</td>
<td>0.121</td>
<td>0.117</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Performance estimated by pen within experiment from regression of equation developed from the combination of May et al. (1992) and Bruns et al. (2004) to calculate dressing percent change over the feeding period for carcass parameter changes as a percent of days on feed. \( y = 0.097 x + 54.7; \ R^2 = 0.94 \)

\textsuperscript{b}Days on feed calculated as percent days on feed in relation to optimum marketing date at 1.2 cm backfat.

\textsuperscript{c}LW = Live Weight; CW = Carcass Weight; ADG = ADG on LW-basis; G:F = LW G:F (kg ADG/kg DMI); cADG = ADG on CW-basis; cG:F = CW G:F (kg cADG/kg DMI)
Table 3. Predicted profit/loss\textsuperscript{a} and cost of gain of steers fed corn priced at $5.26/25.4 kg and marketed at 75, 100, or 125% of expected days on feed\textsuperscript{b}.

<table>
<thead>
<tr>
<th>Item\textsuperscript{c}</th>
<th>Marketing Date, % of normal to achieve 1.2 cm backfat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>75%</td>
</tr>
<tr>
<td>Days on Feed</td>
<td>105</td>
</tr>
<tr>
<td>Costs</td>
<td></td>
</tr>
<tr>
<td>Steer cost, $</td>
<td>894.82</td>
</tr>
<tr>
<td>Diet cost, $</td>
<td>272.29</td>
</tr>
<tr>
<td>Yardage, $</td>
<td>47.25</td>
</tr>
<tr>
<td>Miscellaneous, $</td>
<td>40.00</td>
</tr>
<tr>
<td>Total Costs, $</td>
<td>1226.36</td>
</tr>
</tbody>
</table>

Live Marketing

|                          | 75% | 100% | 125% |
| Revenue, $               | 1210.90 | 1340.75 | 1464.21 |
| Cost of Gain, $/0.45 kg  | 0.86 | 0.87 | 0.89 |
| Profit, $                | (43.98) | (29.03) | (26.38) |

Carcass Marketing

|                          | 75% | 100% | 125% |
| Revenue, $               | 1163.89 | 1340.55 | 1521.91 |
| Cost of Gain $/0.45 kg   | 1.33 | 1.25 | 1.21 |
| Profit, $                | (90.99) | (29.23) | 31.33 |

\textsuperscript{a}Profit/Loss = Revenue − Total Costs; Profit reported in () indicates a net Loss.

\textsuperscript{b}Days on feed calculated as percent days on feed in relation to marketing date at 1.2 cm backfat.

\textsuperscript{c}Total Costs = Steer cost ($116.36/45.4 kg) + Diet cost ($238.44/907 kg/day) + Yardage, including interest ($0.45/day) + Miscellaneous, including health ($40.00/head); Live Marketing = Revenue ($101.82/45.4 kg); Carcass Marketing = Revenue ($101.82/45.4 kg/0.63 dressing percent); Cost of Gain = (Diet costs + Yardage + Miscellaneous)/(Final weight - Initial weight).
Table 4. Predicted profit/loss\(^a\) and cost of gain of steers fed corn priced at $3.50/25.4 kg and marketed at 75, 100, or 125% of expected days on feed\(^b\).

<table>
<thead>
<tr>
<th>Item(^c)</th>
<th>Marketing Date, % of normal to achieve 1.2 cm backfat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>75%</td>
</tr>
<tr>
<td>Days on Feed</td>
<td></td>
</tr>
<tr>
<td>Steer cost, $</td>
<td>761.10</td>
</tr>
<tr>
<td>Diet cost, $</td>
<td>181.53</td>
</tr>
<tr>
<td>Yardage, $</td>
<td>47.25</td>
</tr>
<tr>
<td>Miscellaneous, $</td>
<td>40.00</td>
</tr>
<tr>
<td>Total Costs, $</td>
<td>1029.88</td>
</tr>
</tbody>
</table>

Live Marketing

- **Revenue, $**: 1038.87, 1150.27, 1256.19
- **Cost of Gain, $/0.45 kg**: 0.64, 0.64, 0.65
- **Profit, $**: 8.99, 38.67, 58.93

Carcass Marketing

- **Revenue, $**: 998.54, 1150.10, 1305.69
- **Cost of Gain $/0.45 kg**: 0.99, 0.92, 0.89
- **Profit, $**: (31.34), 38.50, 108.44

\(^a\)Profit/Loss = Revenue – Total Costs; Profit reported in () indicates a net Loss.

\(^b\)Days on feed calculated as percent days on feed in relation to marketing date at 1.2 cm backfat.

\(^c\)Total Costs = Steer cost ($98.97/45.4 kg) + Diet cost ($158.96/907 kg/day) + Yardage, including interest ($0.45/day) + Miscellaneous, including health ($40.00/head); Live Marketing = Revenue ($87.35/45.4 kg); Carcass Marketing = Revenue ($87.35/45.4 kg /0.63 dressing percent); Cost of Gain = (Diet costs + Yardage + Miscellaneous)/(Final weight - Initial weight).
Table 5. Predicted profit/loss\(^a\) and cost of gain of steers fed corn priced at $5.50/25.4 kg and marketed at 75, 100, or 125% of expected days on feed\(^b\).

<table>
<thead>
<tr>
<th>Item(^c)</th>
<th>Marketing Date, % of normal to achieve 1.2 cm backfat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>75%</td>
</tr>
<tr>
<td>Days on Feed</td>
<td>105</td>
</tr>
<tr>
<td>Costs</td>
<td></td>
</tr>
<tr>
<td>Steer cost, $</td>
<td>844.29</td>
</tr>
<tr>
<td>Diet cost, $</td>
<td>285.26</td>
</tr>
<tr>
<td>Yardage, $</td>
<td>47.25</td>
</tr>
<tr>
<td>Miscellaneous, $</td>
<td>40.00</td>
</tr>
<tr>
<td>Total Costs, $</td>
<td>1216.80</td>
</tr>
<tr>
<td>Live Marketing</td>
<td></td>
</tr>
<tr>
<td>Revenue, $</td>
<td>1168.17</td>
</tr>
<tr>
<td>Cost of Gain, $/0.45 kg</td>
<td>0.89</td>
</tr>
<tr>
<td>Profit, $</td>
<td>(48.63)</td>
</tr>
<tr>
<td>Carcass Marketing</td>
<td></td>
</tr>
<tr>
<td>Revenue, $</td>
<td>1122.82</td>
</tr>
<tr>
<td>Cost of Gain $/0.45 kg</td>
<td>1.37</td>
</tr>
<tr>
<td>Profit, $</td>
<td>(93.98)</td>
</tr>
</tbody>
</table>

\(^a\)Profit/Loss = Revenue – Total Costs; Profit reported in () indicates a net loss.

\(^b\)Days on feed calculated as percent days on feed in relation to marketing date at 1.2 cm backfat.

\(^c\)Total Costs = Steer cost ($109.79/45.4 kg) + Diet cost ($249.79/907 kg/day) + Yardage, including interest ($0.45/day) + Miscellaneous, including health ($40.00/head); Live Marketing = Revenue ($98.23/45.4 kg); Carcass Marketing = Revenue ($98.23/45.4 kg /0.63 dressing percent); Cost of Gain = (Diet costs + Yardage + Miscellaneous)/(Final weight - Initial weight).
Table 6. Predicted profit/loss\(^a\) and cost of gain of steers fed corn priced at $7.50/25.4 kg and marketed at 75, 100, or 125% of expected days on feed\(^b\).

<table>
<thead>
<tr>
<th>Item(^c)</th>
<th>Marketing Date, % of normal to achieve 1.2 cm backfat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>75%</td>
</tr>
<tr>
<td>Days on Feed</td>
<td>105</td>
</tr>
<tr>
<td>Costs</td>
<td></td>
</tr>
<tr>
<td>Steer cost, $</td>
<td>1043.78</td>
</tr>
<tr>
<td>Diet cost, $</td>
<td>388.99</td>
</tr>
<tr>
<td>Yardage, $</td>
<td>47.25</td>
</tr>
<tr>
<td>Miscellaneous, $</td>
<td>40.00</td>
</tr>
<tr>
<td>Total Costs, $</td>
<td>1520.02</td>
</tr>
</tbody>
</table>

Live Marketing

| Revenue, $ | 1405.00 | 1555.67 | 1698.91 |
| Cost of Gain, $/0.45 kg | 1.13 | 1.16 | 1.19 |
| Profit, $ | (115.02) | (121.47) | (143.77) |

Carcass Marketing

| Revenue, $ | 1350.46 | 155.43 | 1765.86 |
| Cost of Gain $/0.45 kg | 1.76 | 1.66 | 1.62 |
| Profit, $ | (169.56) | (121.70) | (76.82) |

\(^a\)Profit/Loss = Revenue – Total Costs; Profit reported in ( ) indicates a net loss.

\(^b\)Days on feed calculated as percent days on feed in relation to marketing date at 1.2 cm backfat.

\(^c\)Total Costs = Steer cost ($135.73/45.4 kg) + Diet cost ($340.63/907 kg/day) + Yardage, including interest ($0.45/day) + Miscellaneous, including health ($40.00/head); Live Marketing = Revenue ($118.14/45.4 kg); Carcass Marketing = Revenue ($118.14/45.4 kg/0.63 dressing percent); Cost of Gain = (Diet costs + Yardage + Miscellaneous)/(Final weight - Initial weight).
Figure 1. Five-year average feeder calf (dotted line), live slaughter (dashed line) and corn (solid line) prices per month from 2008 to 2012.
Figure 2. Change in BW of yearling steers on a live weight (solid line) and carcass weight (dashed line)-basis throughout the feeding period.

\[ y = 349 \pm 1 + 2.715x \pm 0.02 - 0.00228x^2 \pm 0.0002; \quad (P < 0.01) \]

\[ y = 186 \pm 1 + 1.800x \pm 0.01 + 0.001057x^2 \pm 0.0011; \quad (P < 0.01) \]
Figure 3. Change in ADG of yearling steers on a live weight (solid line) and carcass weight (dashed line)-basis throughout the feeding period.
Figure 4. Change in feed efficiency of yearling steers on a live weight (solid line) and carcass weight (dashed line)-basis throughout the feeding period.
Figure 5. Dry matter intake of yearling steers throughout the feeding period.
Figure 6. Percentage of live weight gain transferred to carcass weight gain throughout the feeding period of yearling steers.

\[ y = 61.9 \pm 1.2 + 0.276x \pm 0.017; \quad (P < 0.01) \]
Figure 7. Change live weight cost of gain at three different corn prices ($ / 25.4 kg) throughout the feeding period of yearling steers.
Figure 8. Change in carcass weight cost of gain at three different corn prices ($ / 25.4 kg) throughout the feeding period of yearling steers.