DEVELOPMENT OF A NUTRITIONAL MODEL TO PREDICT DIGESTIBLE ENERGY REQUIREMENTS OF BROODMARES BASED ON BODY CONDITION CHANGES

A Thesis

by

VIVIANA VICTORIA CORDERO

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2011

Major Subject: Animal Science

Development of a Nutritional Model to Predict Digestible Energy Requirements of

Broodmares Based on Body Condition Changes

DEVELOPMENT OF A NUTRITIONAL MODEL TO PREDICT DIGESTIBLE ENERGY REQUIREMENTS OF BROODMARES BASED ON BODY CONDITION CHANGES

A Thesis

by

VIVIANA VICTORIA CORDERO

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Approved by:

Chair of Committee,	Clay A. Cavinder
Committee Members,	Dennis Sigler
	Luis O. Tedeschi
	Carolyn Arnold
Head of Department,	H. Russell Cross

May 2011

Major Subject: Animal Science

ABSTRACT

Development of a Nutritional Model to Predict Digestible Energy Requirements of Broodmares Based on Body Condition Changes. (May 2011)

Viviana Victoria Cordero, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Clay A. Cavinder

Nutritional models have been developed for beef and dairy cattle to estimate energy balance based on changes in body condition score. These models have not been developed or fully evaluated in horses to date. The objective of this study was to develop a model to predict changes in body weight (BW), rump fat (RF) thickness, and overall % body fat (BF) to maximize profitability and productivity by accurately predicting energy balance of mares. The evaluation of the model was performed using non-lactating Quarter Horse mares (n=20; 4 to 18 yr of age). The initial BW ranged from 376 to 553 kg, with an initial body condition score (BCS) of 3.5 to 7.0 (scale of 1 - 9; 1 = emaciated, 5 = moderate, and 9 = obese). The BCS, RF thickness, and BW were measured for each mare prior to the commencement of the feeding trial and once/wk thereafter for the duration of a 30 d feeding trial. The pre-trial BCS was used to assign mares to 1 of 4 treatment groups and fed to alter BCS by 1 unit as follows: Group 1, 4 up to 5; Group 2, 5 down to 4; Group 3, 6 up to 7; and Group 4, 7 down to 6. Initial BCS, target BCS, %BF, and BW data was collected from each mare and input into the model. Mares were individually fed according to the digestible energy (DE) suggestions

proposed by the model in order to achieve the targeted BCS change within 30 d. Results showed a 79.8% correlation between BCS and BF in which for every change in 1 BCS (either increasing or decreasing) a change in the same direction of 1.054 percentage units of BF can be expected. All mares' observed final %BF values finished with less than a 20% variation from the model-predicted values, less than 10% variation from BCS values, and less than 32kg variation from final EBW values. An equine nutritional model will enhance feeding management and also reduce the costs of unnecessary over-feeding while maintaining broodmares at a nutritional level to achieve optimum reproductive efficiency.

DEDICATION

I would like to dedicate this manuscript to my parents- Carlos and Vivian. With their insight and wisdom, I was able to achieve beyond what I believed to be capable of. Their hard work allowed me the support I needed to reach my goals and attain greater success. They believed in me in times when I doubted my own capabilities, and they provided me with constructive criticism as they edged me in the right direction with my studies while allowing me to create my own path at the same time. My parents provided me with new outlooks and opportunities when I felt all others had been lost or closed. Most importantly, without my parents' love and dedication to both my future and well-being I would not be half the person I am today. I also would like to dedicate this manuscript to my younger brother, Kristian. It was his voice I longed to hear after a long day's work, for his words always managed to refresh my mind and keep my heart young. My family completes me in everything I do, and because of them I am a strong, happy, and healthy individual.

ACKNOWLEDGEMENTS

There are many people that I would like to thank and acknowledge for making this research possible. First and foremost, Dr. Clay Cavinder - his teachings and guidance aided me in every step of this adventure. I would like to thank my research committee: Dr. Dennis Sigler, who assisted in the application period of the study and provided insight throughout all stages of the development, Dr. Luis O. Tedeschi who was the mastermind behind the development of the model and shared his expertise on animal nutrition modeling, and Dr. Carolyn Arnold for providing insight on fat deposition in the horse from her experience in the large animal surgery room. I would also like to thank Mr. Dave Golden and the Texas A&M University Horse Center who provided both research mares and the housing facility, as well as overseeing the maintenance of the facility and the hay and feed supply. Also from the Horse Center is Mrs. Krissy Johnson Schroeder whom I would like to thank for her assistance and guidance during my years as a Graduate Student. Drs. Martha and Stephen Vogelsang not only provided research mares as well, but contributed their time to overseeing the transportation of the mares to and from the research housing facility. I would like to thank the Parsons Mounted Cavalry for also assisting with mare transport. Special thanks to the Texas A&M Horse Center workers who provided daily assistance with numerous activities. I would also like to give a special thanks to the three people who worked next to me day in and day out, assisting with the daily care of the research mares and aiding with the weekly measurements: Rachel Slovak, Jennifer Rosenberg, and Daniel Olson. I would like to thank the individuals that performed the body condition scoring and aided with the weekly collection of data: Dr. Clay Cavinder, Dr. Dennis Sigler, Dr. Martha Vogelsang, Teri Antilley, Jessica Lucia, Kelly Winsco, and Jeannette Mawyer. Several individuals I would like to recognize that shared invaluable guidance and insight during my time at Texas A&M as a Graduate student include Dr. Josie Coverdale, Dr. Bret Scott, Dr. Mike Martin, and Dr. Thomas. Most importantly, my studies at Texas A&M University would not have been possible without the financial support from the Texas A&M Equestrian team, specifically Tana McKay, Linzy Woolf, Beth Bass, and Steve Cannon. The assistantship they provided not only allowed me to continue my studies but provided me with invaluable experience and insight in equine management.

TABLE OF CONTENTS

Page

ABSTRACT.. iii

DEDICATION…... v

ACKNOWLEDGEMENTS…... vi

TABLE OF CONTENTS….. viii

LIST OF FIGURES…... xi

LIST OF TABLES…... xii

CHAPTER

I INTRODUCTION.. 1

II LITERATURE REVIEW.. 4

The Body Condition Score System... 4
Nutrition and Reproductive Efficiency... 5

CHAPTER Page

Effects on Ovulation 7
Effects on Hormone Levels 8
Effects on Gestation Length and Parturition 9
Effects During Lactation 12
Leptin as a Metabolic Signal 14
Dietary Energy 14
Nutrition Models 19
Body Composition 20
Determination of Body Fat Content.... 21
Determination of Body Water Content.... 22
Determination of Body Protein and Ash Contents.... 23
Body Weight Measurements and Adjustments.... 24
Total Energy (TE) 25
Energy Efficiencies.... 26

III MATERIALS AND METHODS.... 27

Data Used for Model Development.... 27
Model Development 27
Body Composition 27
Body Weight Measurements and Adjustments 28
Predicting Changes in Body Weight 29
Total Energy Determination 29
Energy Efficiencies 30
Model Application 31
Physical Measurements 32
Treatments 33
Diet 34
Model Evaluation 35

IV RESULTS 37

Model Evaluations 41

CHAPTER Page

Evaluating BCS ….. 41
Evaluating BF …... 47
Evaluating BW …... 48
Comparative Analysis……………………………………….. 50
Correlations …... 52
Body Condition Score and Body Fat % Correlation 52
Digestible Energy Changes per BCS ….................................. 53

V DISCUSSION …... 57

Model Predictability…………………………………………….. 55
Implications and Advantages…………………………………… 59
Further Model Development…………………………………….. 60
Usability………………………………………………………... 60
Factors Affecting Diet Digestibility …................................... 61

VI CONCLUSIONS …... 64

LITERATURE CITED.. 65

APPENDIX ….. 78

VITA …... 92

LIST OF FIGURES

FIGURE		Page
1	BCS values: observed vs model-predicted …..	43
2	BF values: observed vs model-predicted …...	48
3	EBW values: observed vs model-predicted …..	50

LIST OF TABLES

TABLE		Page
1	Results of studies on water content in equines …................................	23
2	Results of studies on protein and ash content in equines …...................	24
3	Body composition …...	28
4	Initial body condition score groups for mares fed to achieve a targeted body condition …..	33
5	Placement of research mares into treatment groups according to initial body condition scores (BCS) per mare…………………………………	38
6	Digestible energy (DE) intake changes per mare as predicted by model …..	40
7	Model Evaluation System (MES) statistic results for final BCS model predictions …..	42
8	Model Evaluation System (MES) statistic results for increasing-BCS model predictability…………………………………………………	44
9	Model Evaluation System (MES) statistic results for decreasing-BCS model predictability…………………………………………………	45
10	Model Evaluation System (MES) statistic results for final BCS model predictions (n = 18) …………………………………………………	46

TABLE Page

11 Model Evaluation System (MES) statistic results for final body fat model predictions 47

12 Model Evaluation System (MES) statistic results for final empty body weight model predictions 49

13 Comparative analysis of all statistics per evaluation 52

14 Digestible energy change required to increase one body condition score 55

15 Digestible energy change required to decrease one body condition score 56

CHAPTER I

INTRODUCTION

Mares have long gestation periods (approximately 340 days), leaving a relatively short amount of time for re-breeding in order to produce a foal the following year. It is imperative for an equine breeder to ensure the mare enters the breeding season as healthy as possible in order to maximize her reproductive efficiency. Research has documented that over- and under- nutrition can result in reproductive problems such as prolonged intervals from parturition to ovulation, reduced conception rates, and increased number of cycles per conception in cows (Fitzgerald et al., 2003), sows (Hartz et al., 1979), mares (Henneke et al., 1981; Henneke, 1984) and humans (Ottinger, 2010). Nutrition and dietary energy intake play an important role in the efficiency of reproduction in all species including humans; therefore, any tools that can be used to aid equine breeders in maintaining their broodmares at an optimum level of nutrition and decrease the potential for reproductive problems will prove beneficial.

Many factors play a role in the amount of dietary energy required by an animal. In the beef and dairy cattle industries, nutritional models have been developed to estimate the animal's energy requirements. Such models allow owners to maintain cattle at an appropriate BCS by providing an adequate amount of dietary energy, thus ensuring cows maximize reproductive efficiency. Cattle models have proved successful and reliable, and have led to the development of computer programs specifically designed to

---

This thesis follows the style of *Journal of Animal Science*.

assist producers in maintaining an efficient herd at the least cost possible. To date, no such models or computer programs have been developed for use in horses so the actual amount of DE required to change BCS is not known but rather estimated. Today, if a horse owner desires to alter a horse's BCS they simply increase, or decrease, the dietary intake the horse is receiving, thus adjusting DE intake. A more accurate assessment of this dietary adjustment is warranted in order to more precisely change BCS in the horse.

In order to aid equine breeders in establishing an appropriate body condition for their respective mares, this study seeks to develop an acceptable nutritional model to predict DE intake amounts that will result in an overall change to a desired body condition and composition. This system will be based on the concepts used in cattle models, but will incorporate equine information available from the NRC (2007) for horses and data (BCS, RF, BW, and % BF) collected from broodmares in an earlier study (Cavinder et al., 2009). Additionally, our model would predict estimated changes in BW, RF thickness, and overall % BF. Ultimately, the objective of this model will be more accurate and reliable than visual appraisal alone and provide a much needed tool to the equine industry to assist in maximizing profitability and production on the farm by accurately predicting feeding requirements of mares in order to adjust the current fat status of the animal. It will also minimize the amount of resources spent on a mare not yet at an optimum body condition for reproduction. Through development of this model, mare owners will be able to precisely maintain mares in a desired BCS, proving to minimize feed costs at each stage of pregnancy and lactation that may stem from unnecessary overfeeding. The economic benefit the mare owner will gain due to more precise feeding regimen will lead to greater profit and business potential.

With the above ideas in mind, the objectives of this study are to:

1. develop a nutritional model able to predict proper dietary intake needed to adjust BCS in mares and,

2. analyze the effectiveness and accuracy of the developed model in predicting changes in energy status.

CHAPTER II

LITERATURE REVIEW

The Body Condition Score System

Throughout the past 40 years, much has been learned about the role nutrition and body condition play in the reproductive function of farm animals. The relationship between nutritional status, body condition, and reproductive efficiency has been studied in the horse (Henneke et al., 1984; Hines et al., 1985; Kubiak et al., 1989), cow (Rutter and Randel, 1984), and sow (Randel, 1990). Initial research in cattle demonstrated that body condition, the amount of stored fat in an animal's body, is positively related to reproductive performance (Donaldson, 1969; Lamond, 1969; Whitman, 1975; Croxton and Stollard, 1976; Dunn and Kaltenbach, 1980). Research has concluded that females that are too thin, due to inadequate nutrition, may suffer reproductive inefficiencies manisfested as longer interovulatory periods, decreased pregnancy rates, and decreased ovarian activity (Dunn et al., 1969; Kubiak et al., 1989). Similar studies have also been conducted in sheep (Polliott and Kilkenny, 1976) and other mammals (Frisch, 1980), providing evidence that a minimum level of body fat is needed for successful reproductive performance.

Henneke et al. (1984) is responsible for initiating body condition research in horses and established the BCS system. While several BCS systems have been proposed, including one by Suagee et al. (2008) who derived a BCS system from judging only 4 body areas (neck, shoulders, ribs and tailhead), Henneke's BCS system is the current system still in place today. This system was developed to subjectively measure the amount of stored body fat in horses and is analogous to the scoring system used in beef cattle. The BCS system used with horses utilizes a numerical scale from 1 to 9 (1 = emaciated; 9 = obese) with half-point increments acceptable. The BCS system is based on palpable fat cover and visual appraisal of a horse by an individual at 6 body areas- neck, withers, shoulders, ribs, loin, and tailhead. This system has been utilized as an assessment of stored energy (fat) in many studies and proven to be a useful tool in equine management to achieve maximum performance. However, the basis of the BCS system is highly subjective and differing results for the same horse are sometimes attained, depending on the individual performing the scoring. A more objective standard is needed to accurately measure a horse's energy status; however, one is currently not in place.

Energy deficiencies and excesses are easily identified by weight loss or gain, but the difficulty still remains for horse owners to regularly and accurately weigh horses. The use of a BCS system helps to determine whether a horse is gaining or losing weight (NRC, 2007).

Nutrition and Reproductive Efficiency

Studies vary in their definition of reproductive efficiency. However, efficiency has routinely been measured by the number of cycles per conception, pregnancy rates at 30 d post-ovulation, and d to onset of first estrus and ovulation after parturition (NRC, 2007). Reproductive rates, such as conception and pregnancy rates, have been noted to increase with a positive energy balance due to higher ovarian activity (Van Niekerk and Van Heerden, 1972) and an earlier onset of the breeding season (Ginther, 1974). Mares entering the breeding season in a moderate BCS require fewer cycles for conception and have higher conception rates than mares entering the breeding season in thin condition (Kubiak et al., 1987). Henneke et al. (1984) found similar results in mares and concluded that breeding efficiency is enhanced in mares entering the breeding season at a BCS of 5.0 (moderate body condition) or above. Mares entering the breeding season in a low BCS (<5) had prolonged postpartum intervals, reduced conception rates, and required more cycles per conception than mares entering the breeding season in fatter condition (Henneke et al., 1981). Mares that enter the breeding season in thin condition and remain thin have longer initial estrus periods than mares above a BCS of 5.0, and in fact tend to have an extended anovulatory period (Kubiak et al., 1987). Open mares maintained in moderately fat to fat body condition (BCS of 6.5 to 8) during the fall and winter mo often continue to cycle throughout the winter. Such results confirm the hypothesis that nutritional restriction leading to low body condition would intensify the depth and/or length of the seasonal anovulatory period in mares (Gentry et al., 2002).

Research on feeding females to excess fat levels and the effect on postpartum reproductive performance is contradictory among various species. While Fitzgerald et al. (2003) found that excessive fatness was related to an abnormally long estrous cycle due to a lengthened luteal phase in cows, Kubiak et al. (1989) found that mares possessing a large amount of BF during gestation did not adversely affect reproductive performance postpartum. Cavinder et al. (2005) evaluated mares in fat vs. moderate body condition and concluded there was no significant difference in conception rates between the 2 groups, and that maintaining broodmares in a fat body condition (BCS = 7 to 8) does not impair or improve reproductive efficiency. Additionally, these researchers determined that mares maintained at a high BCS are not prone to reproductive dysfunction or lowered levels of fertility (Cavinder et al., 2005). Rutter and Randel (1984) demonstrated a decrease in the postpartum interval to estrus with increasing levels of nutrient intake. Results from this study suggest that females maintaining body condition after parturition have an enhanced pituitary function and reproductive potential. This is similar to results found in other farm animals, including cattle in which an inadequate nutrition impairs reproductive function by prolonging the postpartum anestrus period (Selk et al., 1988). Selk et al. (1988) concluded that pre-calving BCS and BCS at the beginning of the breeding season, along with BW changes between 2 and 4 mo before parturition are major factors influencing the pregnancy rate in beef cows.

Effects on Ovulation

Henneke and Kreider (1979) and Van Niekerk and Van Heerden (1972) reported an earlier ovulation related to the improvement of mare energy balance. This was later confirmed by Kubiak et al. (1987) who concluded that mares entering the breeding season with a mean BCS of 5.0 ovulate sooner when compared to mares at a BCS below 5.0. It was also noted that high energy intakes were effective in decreasing time to ovulation mares that were already thin (BF <11.5%) but not for mares who were moderate (BF 11.5-15%) or fat (BF >15%) since they were already at an adequate BCS

(BCS 5 or above)(Kubiak et al., 1987). The period from parturition to first ovulation was not significantly influenced by nutritional status, but rather the period from foaling to second ovulation, which was lengthened in mares foaling in thin- vs fat- condition (Henneke et al., 1981). The threshold BCS for mares to maximize reproductive efficiency was reported by Cavinder at al. (2009) as these researchers concluded there was no significant difference between moderate and high BCS mares (BCS 5 to BCS 6 vs BCS 7 to BCS 8) in the average time from parturition to foal heat ovulation and foal heat ovulation to second postpartum ovulation.

Effects on Hormone Levels

Sudden or chronic energy restriction can also affect reproductive efficiency. Research has shown that when mares in moderate or fat body condition were fed energy-restricted diets all mares became anovulatory within 12 wk of the onset of restriction and remained anovulatory for an extended period of time (Gentry et al., 2002). All mares in a low BCS had low progesterone concentrations, lacked significant follicular activity, and were anovulatory for 6 to 7 mo. Mares had a reduced luteinizing hormone (LH) response to gonadotropin-releasing hormone (GnRH) and a reduced prolactin response to thyroid releasing hormone (TRH)(Gentry et al., 2002). Under-nutrition inhibits pulsatile secretion of LH by reducing luteinizing hormone releasing hormone (LHRH) secretion by the hypothalamus, thus suppressing follicular ovulation (Schillo, 1992). In a study by Hines et al. (1987), serum LH concentrations for thin mares were greater in the second estrous cycle than the first estrous cycle. Serum LH concentration patterns in thin mares tended to be similar to serum LH concentration patterns found in mares during seasonal transition. Also, the interval from parturition to ovulation was random in thin mares when compared to mares in the control group (moderate BCS). Control mares had equivalent concentrations of serum LH in both the first and second estrous cycles, and had predictable intervals from parturition to ovulation, with serum LH concentration patterns similar to those commonly reported in the middle of the breeding season.

Effects on Gestation Length and Parturition

During pregnancy, energy is used for maintenance of the dam, deposition of fetal and placental tissue, mammary development, and maintenance of the fetus and placenta (Morgan, 1998; NRC, 2007). Thus, adequate energy intake during gestation is very important. While Henneke et al. (1981) concluded that varying nutritional treatments did not significantly influence gestation length, more recent research found nutrition level in the mare can affect gestation length, independent of seasonal variation. Howell and Rollins (2009) determined that "well fed" mares kept inside a stable had gestation lengths averaging 4 d shorter than mares kept on a "maintenance ration" out on pasture and calculated the level of nutrition to account for 5% of the total variance in gestation length. Hines et al. (1987) also found that mares foaling in a thin BCS (<4.5) had a longer mean gestation length than the control (<6). Longer gestation lengths, in turn, decrease the amount of time available for re-breeding.

In addition, Belonje and Van Niekerk (1975) and Potter et al. (1985) have shown that an energy deficit frequently results in pregnancy termination and embryonic re-absorption during the first 90 d of gestation. It has been hypothesized the associated stresses of weight loss may alter progesterone levels resulting in the loss of pregnancy (Potter et al., 1985). Caloric intake greatly influences both pregnancy rate and maintenance of pregnancy to 90 d, both of which were reduced in thin mares when compared to fat mares (Henneke et al., 1981).

In order to ensure that a mare will enter the breeding season at an adequate body condition, energy intake level must be increased during late gestation. Coenen and Meyer (1986) have shown a positive effect of energy level in late pregnancy on reproduction. Mares entering the breeding season in thin condition and gain weight during the breeding season remain less reproductively efficient than mares that begin the season already at a BCS above 5.0. This leads to the conclusion that establishing a moderate body condition prior to the commencement of the breeding season is more important than increasing energy intake to a mare in thin condition during the breeding season (Henneke et al., 1984). Evans (1989) indicated that when the increase in BW during gestation is less than 10%, mares will convert body stores to meet the nutrient demands of fetal and placental development. Most of foal growth occurs during late gestation and a large amount of metabolic activity is present during this time (Powell et al., 1989; Hintz and Cymbaluk, 1994; Fowden et al., 2000). Total weight gain during gestation averaged 16% of the mares' initial BW in one study (Lawrence et al., 1992). Fowden et al. (2000) found significant uptakes of glucose and oxygen by the gravid uterus, fetus, and uteroplacental tissues to be 2 to 3 times higher in late gestation than mid-gestation. Lawrence (1992) found that the majority of weight gain occurred in the second, rather than third trimester of gestation and it was hypothesized that mares might increase fat storage during mid-gestation followed by mobilization of those stores during late gestation, which coincides with the period of rapid fetal growth. Powell et al. (1989) conducted similar research to evaluate the body store changes in broodmares during the second and third trimesters of gestation. Fat stores increased from the beginning of the study through d 215 of gestation. Stores then remained constant through d 305, at which point they began to decline. Similar results were seen by Hintz and Cymbaluk (1994), in which the data showed a trend towards increasing fat accretion through the initial part of the third trimester, followed by a mobilization of fat during late gestation. Current NRC (2007) recommendations dictate a mare should enter mid-gestation in at least moderate body condition (BCS > 5). Mares that are in an inadequate body condition (BCS < 5) in early or mid-gestation should be fed additional energy to reach a BCS of at least 5 by the 9th mo of gestation. Additional DE should also be provided to mares kept in environmentally stressful conditions during gestation. It is important to note that foal BW is not affected greatly by mare energy restriction during the last 90 d of gestation, but rather the consequences are at the expense of the mare herself (Banach and Evans, 1981; Martin-Rossett et al., 1994).

Although catabolism of body stores may not pose a problem to mares entering the breeding season with a BCS above 6, the consequence to mares at a lower BCS may be greater (Evans, 1989). Similar results were seen by Cavinder et al (2009) who found that mares foaling in a BCS of 7 - 8 lost a lower percentage of BF at foaling as compared to mares foaling in a BCS of 5 - 6. Thus, it was recommended mares be foaled in at least a BCS of 6 so as to prevent a drop in body condition below a BCS of 5 at time of re-breeding and to prevent excess weight loss during early lactation (Cavinder et al., 2009) which could adversely affect fertility (Mangus, 1986). Unlike cattle, mares in fat body condition at time of parturition have foaling characteristics similar to mares in moderate body condition at parturition (Kubiak et al., 1988), suggesting that maintaining broodmares at a high BCS (7 - 8) neither impairs nor improves reproductive efficiency. The duration of Stages II and III of parturition, all intermediate times, the interval from birth of the foal to standing and nursing, as well as the degree of cervical and vaginal bruising incurred during parturition were not different between the mares in low vs high body condition (Kubiak et al., 1988). Mares in moderate or fat body condition had similar intervals from parturition to foal heat ovulation, and from parturition to the second postpartum ovulation. Therefore, it is recommended that mares used for breeding be maintained at a BCS of at least 5.0 (Henneke et al., 1984; Cavinder et al., 2005). Excessive BF stored during gestation is not detrimental to the parturition process (Kubiak et al., 1988).

Effects During Lactation

The effects of nutritional deficiency are greatest during early lactation. Milk production greatly increases a mare's energy output and an increased level of energy intake is required. Additionally, the first month of lactation corresponds to the re-breeding period. Energy requirements of lactating mares must be met in order to maintain a constant weight and prevent negative effects on foal growth, milk yield, milk energy content, and re-breeding (Doreau et al., 1992). The DE requirements for lactation are calculated as the sum of the DE utilized for milk production and the DE utilized for maintenance and the efficiency of DE use for lactation has been estimated at 60% (NRC, 2007). Review of studies suggests that mares will produce about 3 kg milk/100 kg of BW in early lactation and 2 kg milk/100 kg of BW in late lactation (NRC, 1989). Mares receiving an adequate amount of energy during lactation produce milk with higher concentrations of fat and energy in contrast to mares that are fed under the lactation requirements (Doreau et al., 1992). Negative energy balance can also cause the mobilization of body reserves of the mare, which in turn will decrease re-breeding efficiency (Doreau et al., 1988). Henneke et al. (1981) found that mares foaling in low body condition (BCS < 5.0) had impaired reproductive efficiency even when the energy requirements for lactation were met. While increasing the caloric intake during lactation slightly improved re-breeding efficiency of the mares foaling in thin condition, it was noted that mares foaling in a high level of condition are not impaired reproductively when lactation requirements are not met and instead can utilize stored BF as energy for reproduction and efficient foal growth without detrimental effects to body condition body condition (Henneke et al., 1981; Doreau and Boulot, 1989).

Leptin as a Metabolic Signal

Leptin is a satiety hormone secreted by the adipocyte, and is suggested to be a signal between BF and the hypothalamus. Therefore, the more fat an animal has the more leptin is secreted in order to signal the body that enough fat covering is available (Houseknecht et al., 1998). Mares with less BF also have lower leptin concentrations and leptin is thought to regulate nutritional status effects on reproductive function (Fitzgerald and McManus, 2000). In some species, leptin concentrations vary directly with percentage of BF (Prolo et al., 1998; Chilliard et al., 2000). The awareness the body has to “proper” fat covering through mediators such as leptin indicates that the body dictates whether or not it can sustain a pregnancy. In order to achieve and maintain proper nutrition and ensure mares are receiving an adequate amount of energy intake, it is important to understand how energy requirements are formulated, what factors can alter the requirements, and how to measure the amount of energy consumed.

Dietary Energy

The horse is a monogastric, nonruminant herbivore naturally apt to digesting diets high in fiber via microbial fermentation. The diet of horses has gone from a natural forage-based diet to a diet including cereal grains and by-products and supplemental fat due to the increased demand in performance of domesticated horses (Harris, 1997). The need for increases in the amount of energy intakes in horses has led to an increasing interest in the research of energy partitioning within the equine body.

Energy systems have been developed to define and quantify the energy content of feeds and the energy utilization in the horse. A feed's energy content can be separated into that which will be utilized by the animal and that which will be lost as a product of digestion. The chemical composition of a feed will affect the amount of energy that can be provided by the feed and thus the amount of feed that must be consumed by the horse in order to meet their respective energy requirements (NRC, 2007). The heat given off by a feed after it has been burned to its final oxidative products is the heat of combustion, also known as gross energy (GE). The GE is the total amount of intake energy of a feed consumed by the animal. For GE to be an accurate indicator of energy available for digestion, energy losses from the processes of digestion must be accounted for. To obtain DE, the amount of GE in the feces is subtracted from the intake energy (Pagan, 1997). The amount of energy that is metabolized (ME) as a product of digestion can then be calculated by subtracting urinary and gaseous energy losses from DE. Generally, urinary and gaseous losses are less than the fecal energy losses; however, gaseous losses may be higher if the majority of the feed is digested in the large intestine, such as feeds high in fiber (NRC, 1989). The amount of ME is then partitioned into energy that is recovered (RE) and into energy given off as heat (HE). Heat energy includes the total amount of heat production that is lost to the environment, while RE includes the energy that is stored in tissues, such as in moments of weight gain, and also includes energy that will be secreted in a product, such as energy content of milk during lactation. Recovered energy is commonly termed Net energy (NE) and may be partitioned further into specific categories of energy distribution (for example, NE_M, NE_L, NE_R).

Energy content of feeds was originally measured in units of TDN, however, the equine NRC (1989) adopted the DE system as the unit to describe the energy content of horse feeds, and is the system still in place today (Cuddeford, 2004). A unit of TDN can be converted to DE since 1 kg of TDN is equivalent to 4.4 Mcal of DE, or 18.4 MJ of DE. It is important to note that DE is also known as “apparent” DE because some of the material in the feces is not from the feed itself but from endogenous products. If endogenous losses are known, only then can the “true” DE content of a feed be calculated. However, most DE values represent apparent DE and not true DE. Both the GE content of a feed and its digestibility by the animal affect the amount of DE provided by the feed. Several equations have been formulated to estimate DE content from a feed’s chemical composition, as demonstrated below (Fonnesbeck, 1981), where ADF = acid detergent fiber and CP = crude protein:

Dry Forages and Roughages, Pasture, Range Plants, and Forages Fed Fresh:

$$DE \text{ x } (Mcal/kg) = 4.22 - 0.11 \text{ x } (\%ADF) + 0.0332 \text{ x } (\%CP) + 0.00112 \text{ x } (\%ADF)$$

Energy Feeds and Protein Supplements:

$$DE \text{ x } (Mcal/kg) = 4.07 - 0.055 \text{ x } (\%ADF)$$

These equations were based on work by Fonnesbeck (1981), who developed regression equations from chemical and biological data for estimating DE and TDN for horses via chemical analysis of feeds. Using data from 30 different diets, Pagan et al. (1998) reported that DE could be estimated from the following equation, where hemicelluloses = ADF – neutral detergent fiber (NDF) and nonstructural carbohydrate = (100 - %NDF - %fat - %ash - %CP):

$$DE \times (\text{kcal/kg DM}) = 2118 + 12.18 \times (\%CP) - 9.37 \times (\%ADF) - 3.83 \times (\%\text{hemicellulose}) + 47.18 \times (\%\text{fat}) + 20.35 \times (\%\text{nonstructural carbohydrate}) - 26.3\ (\%\text{ash});\ R2 = 0.88$$

Zeyner and Kienzle (2002) derived the following equation:

$$DE\ (\text{MJ/kg DM}) = -3.6 + 0.211 \times (\%CP) + 0.421 \times (\%AEE) + 0.015 \times (\%CF) + 0.189 \times (\%NFE)$$

Nutrient supply of feeds of similar DE varies depending on its chemical composition (for example, starch versus cell-wall carbohydrates) and varies depending on the site and type of digestion (for example, enzymatic digestion in the small intestine versus fermentation in the large intestine). Therefore, it has been noted the DE system overestimates the DE value of forages and protein-rich feeds, while it underestimates the DE value of starch-rich feeds (Vermorel and Martin-Rossett, 1997). Such discrepancies led to the development of a NE system. While the DE system of estimating energy content is based on digestibility as the discriminating factor between feeds, the NE system is based on the usage-ability of the end-product, as it takes into consideration the energy costs of mastication, movement of ingesta through the digestive tract, and heat of fermentation (Cuddeford, 2004).

The NE system has the potential to predict energy content and requirements more accurately, however, it requires more information and therefore is more complicated than DE systems (NRC, 2007). NE systems have been established for use in cattle, however, work on an NE system for horses was not initiated until the early 1980s in France. The French system (Vermorel et al., 1984) is the most developed NE system for horses to date. Also known as the Unite Fourragere Cheval (UFC) system, it relates NE requirements to a standard horse feed unit derived from the NE value of 1 kg of barley (1 UFC = NE of 1 kg barley). The UFC value of a particular feed is calculated by dividing its NE content (in kcal) by that of barley (2250 kcal)(Vermorel et al., 1984). Since the nutritive value of 1 kg of barley is better understood than 1 kg of TDN, or a Mcal, or a MJ, some consider a feed unit system to be more practical (Vermorel and Martin-Rossett, 1997). However, a feed unit system based on barley as the reference unit would only be practical to those who commonly use barley in their horse diet and may not be accepted as the standard horse feed in other parts of the world (Martin-Rossett et al., 1994; Martin-Rossett, 2000; Martin-Rossett and Vermorel, 2004). Another drawback to the DE system is that it does not account for differences in energy efficiency of use for different purposes, such as for NE_M, NE_R, and NE_L (NRC, 2007).

In order to truly compare both energy systems, numerous feeding trials involving different classes of horses and different types of feeds would be needed. Few authors have compared the 2 systems theoretically. Even fewer studies have compared the 2 systems in practice, and the results have been inconclusive (NRC, 2007). While Hintz and Cymbaluk (1994) found the calculated amount of feed required by broodmares as estimated by the French NE system was similar to that estimated by the DE system, others found that DE requirements exceeded the NE requirements by 19% (Martin-Rossett and Vermorel, 2004).

While the French NE system is most popular in Europe, the DE system in horses has been retained in the USA because barley is not as commonly used as the standard horse feed. Although the NE system is more detailed and is currently used in other areas of the livestock industry, the DE system is more practical and easier to use in horses. More information has been acquired about estimating the DE content of horse feeds as compared to their NE content since most feeding experiments have based DE as the unit of measure of dietary energy content of feeds (Cuddeford, 2004). Thus, the DE system is more widely accepted and will serve as the unit of caloric intake in this study.

Nutrition Models

As noted above, many factors play a role in the amount of DE required by the equine body. In order to maintain an appropriate BCS by providing an adequate amount of dietary energy to maintain reproductive efficiency, nutritional models have been developed to aid in estimating energy requirements in both beef and dairy cattle (Tedeschi, 2002). Such models have proved successful and reliable, and have spurred the creation of other computer programs, including Bo Vision and the Cornell Net

Carbohydrate and Protein System (CNCPS), specifically designed to aid producers in maintaining an efficient herd at the least cost possible. To date, no such models or computer programs have been developed for use with horses. In order to create a model that will predict changes in the total energy content of the animal, information on body composition, BW, and energy efficiency values must be taken into consideration.

Body Composition

Information on the body composition of horses is scarce. The most variable component of the body is fat, while the fat-free body composition remains relatively constant over an animal's lifetime. Coefficients of variation are normally greater than 16% for fat while only 6% for water and protein (Lohman, 1971). The relative consistency in fat-free body composition has spurred research in the estimation of whole-body composition thru indirect methods (Lohman, 1971). Variability in BF content has been correlated to both genetics and environmental factors and such differences amongst breeds, planes of nutrition, age, gender and type of diet affect fat deposition in every horse (Lohman, 1971; Kearns et al., 2002a).

The majority of variation in fat-free body composition takes place in the animal's early years of life. During development, decreases in body water (BWa) and increases in body protein (BP) and body ash (BA) occur simultaneously until a plateau is reached, after which point the fat-free body composition remains relatively constant for the duration of the animal's life (Lohman, 1971). This concept of "chemical maturity" was first defined by Moulton in 1923 as "the point at which the concentration of water, proteins, and salts becomes comparatively constant in the fat-free cell." Moulton (1923) estimated the point of chemical maturity to be about 4.5% of total life expectancy. Therefore, while different animals reach chemical maturity at different ages, the ages are relative to a part of the total life cycle (Moulton, 1923).

Determination of Body Fat Content

Among total BWa, BF, BP, and BA, BF is the composition compartment that has received the most attention in horses. Ultrasonic rump fat thickness was found to be highly correlated ($r = 0.85$) with actual rump fat thickness (Westervelt et al., 1976). The relationship between ultrasonic measurements and total BF as developed by Westervelt et al. (1976) is predicted by Equation [1] ($r^2 = 0.86$, $n = 15$); where Y is the percent of ether extractable fat and X is ultrasonically measured rump fat thickness, cm.

$$Y = 8.64 + 4.70 \bullet X \qquad [1]$$

Westervelt et al. (1976) concluded that ultrasonography is a reliable tool in the estimation of fat cover in horses and ponies and ultrasonic rump fat measurement can aid in the prediction of total BF. The model is still commonly used today. Westervelt's conclusions were supported by the work of Kane (1987), who confirmed that rump fat thickness is related to total BF using real-time ultrasonography. However, Kane (1987) determined variations in rump fat thickness exist and are dependent on ultrasound probe placement on the horse's hip. The greatest deposits of fat were located 6 cm anterior to the tailhead approximately 10 cm off the midline and the least amount of fat located near the top of the croup. It was concluded that a standardized location for sampling rump fat thickness must be implemented for estimating body condition.

Determination of Body Water Content

Several methods have been developed to estimate BWa content in horses. The most commonly used method is based on isotope-indicator dilution techniques (Julian et al., 1955; Elser et al., 1983; al., Lawrence et al., 1986; Andrews et al., 1997; Forro et al., 2000). Isotope-indicator dilution techniques involve the estimation of BWa based on the elimination of the isotope after administration via the jugular artery. Another method used in the estimation of BWa content in horses is bioelectrical impedance analysis (BIA) (Forro et al., 2000; Fielding et al., 2004). The BIA technique is comprised of sending small electrical currents through the body via electrodes placed at various anatomic areas of the horse. A bioimpedance analyzer then records the resistance and reactance at varying frequencies. The resistance to electricity varies between different types of tissues and their water content. Because water is a good conductor of electrical current, the higher the amount of water, the lesser the resistance will be; and therefore, standard equations can be developed and used to assess BWa based on resistance. The results from studies on water content in equines along with the methods used are summarized in Table 1.

Table 1. Results of studies on water content in equines

Reference	Method[1]	n	Breed[2]	TBW[3]	Weighted Avg[4]
Andrews (1997)	D_2O	6	Mixed-breeds	62.3 ± 2.2	7.788
Forro (2000)	BIA and D_2O	8	Horses[5] and Ponies	67.7 ± 2.2	11.283
Julian (1955)	T_2O	6	Horses[6]	63.8	7.975
Elser (1983)	Ethanol dilution	10	Ponies	65.87 ± 1.07	13.723
Lawrence (1986)	Urea dilution	10	Horses and Ponies	58.5 ± 2.8	12.188
Deavers (1973)	T_2O	8	Ponies	67.7 ± 5.87	11.283
		48		AVG: 64.31	Total: 64.24

[1] D_2O = deuterium oxide dilution, T_2O = tritium oxide dilution.
[2] Equine breed used in study
[3] Total body water as a percent of body weight. Values are mean ± S. E. M.
[4] Weighted average of results from each study
[5] Standardbred, Thoroughbred, Percheron
[6] Thoroughbred, Quarter Horse, Arabian, American Saddlebred

Determination of Body Protein and Ash Contents

Two studies have provided information on equine BP and BA. Kane (1987) provided BF (13.03%), BP (18.5%), and BWa (61.05%) as percentages of empty body weight (EBW) after cadaver dissection and carcass evaluation of horses weighing 281 to 474 kg. Because no values for ash were provided, the amount of BA (7.42%) was calculated by difference (100 - 13.03 - 18.5 - 61.05). Similarly, Elser et al. (1983) performed cadaver dissection and carcass evaluation in ponies and concluded that protein and ash as a percent of EBW were 19.51% and 5.37%, respectively. The weighted average of the results from both studies indicated 19.13% of total BW was protein and 6.14% of total BW was ash. The results are summarized in Table 2.

Table 2. Results of studies on protein and ash content in equines

Reference	n	Breed[1]	TBP[2]	TBP Weighted Avg[3]	TBA[4]	TBA Weighted Avg[5]
Kane (1987)	6	Horses	18.5	6.94	7.42	2.78
Elser et al. (1983)	10	Ponies	19.51	12.19	5.37	3.36
	16		AVG: 19.01	Total: 19.13	AVG: 6.40	Total: 6.14

[1] Type of equine used in study
[2] Total body protein as a percent of body weight
[3] Weighted average of total body protein results from each study
[4] Total body ash as a percent of body weight
[5] Weighted average of total body ash results from each study

Body Weight Measurements and Adjustments

The model developed for the current research project is based on that published by Tedeschi et al. (2006) and the dairy NRC (2001) equations with modifications based on horse data. Shrunk body weight (SBW) is equivalent to an animal's weight after an overnight fast without feed or water and is typically estimated as 96% of full BW (FBW) by the beef cattle NRC (2000). Shrunk BW is used to compute NE_m requirements, which are measured as fasting heat production and used to determine the amount of NE available for growth in the diet and target SBW gain. Empty body weight is the FBW minus the weight of the ingesta and is typically computed as 89.1% of SBW or 85.5% of FBW in cattle (NRC, 2000). Both SBW and EBW are used to determine changes in BW that are associated with mobilization and repletion of body mass of the animal in support of physiological needs and status (growing, lactating, gestating, dry).

In dairy cattle, EBW has been used to develop the equations to predict the energy required for target SWG because NE requirements are a function of the proportion of fat and protein in the empty body tissue gain (NRC, 2001). The prediction of body reserves in dairy is obtained using Eq. [2] and Eq. [3].

$$SBW = FBW \cdot 0.96 \quad [2]$$

$$EBW = SBW \cdot 0.851 \quad [3]$$

where SWB is shrunk body weight, kg; EBW is empty body weight, kg; and FBW is full body weight, kg.

Total Energy (TE)

A negative energy balance (ΔTE value is negative) occurs when the intake of energy is lower than the energy required for reproductive and productive purposes and leads to a mobilization of reserve energy. On the other hand, in a positive energy balance (when the ΔTE value is positive), the intake of energy is greater than the energy intake required for reproduction and production, which leads to an addition to the energy reserves that would be available for later mobilization.

Energy Efficiencies

Moe et al. (1970) used a multiple regression analysis of data from 126 lactating dairy cows in a negative energy balance and 224 lactating dairy cows in a positive energy balance. The above study reported an 84% efficiency in the conversion of NE of reserves to NE available for lactation (NE_L), a 64.4% efficiency in the conversion of ME to NE_L, and a 72.6% efficiency in the conversion of ME to NE available for reproduction (NE_R).

At present, efficiency of utilization of dietary energy for milk production is difficult to determine accurately in horses. Differences in attempts to compute such efficiencies have been caused by either differences in the value chosen for efficiency of utilization or by differences in the estimation of milk energy output in horses. In the late 1970s, both Norway and the USA estimated a 60% efficiency of utilization (Nedkvitne, 1976; NRC, 1978), while France estimated a 66% efficiency (Meyer, 1979). These comparisons show that there are only small differences in lactating energy requirements formulated in different countries, and are also similar to the efficiencies derived for dairy cattle (Doreau, 1988). In addition, similar studies conducted around the same time in the United Kingdom estimated an 85% efficiency in the use of ME for DE (Abrams, 1984).

CHAPTER III

MATERIALS AND METHODS

Data Used for Model Development

Data collected in a previous project (Cavinder et al., 2009) utilizing 24 Quarter Horse mares was used in the creation of a model to predict DE requirements needed to alter BCS in mares. Measurements included BCS, BW, and RF thickness of gestating mares and were collected once every 2 wk over a 9 mo period (October, 2003 – June, 2004). In the 2009 project, mares ranged in age from 3 to 18 yr and were blocked by age and parity into 2 treatment groups: 1) fat-conditioned mares (BCS range of 7 to 8) and 2) moderately-conditioned mares (BCS range of 5 to 6). All mares were fed to reach and maintain desired body condition. Body condition scores were assigned by 3 independent appraisers on a scale of 1 to 9, including half-point increments (Henneke et al., 1983). Rump fat thickness was measured 5.08 cm from the midline and 10.16 cm from the point of the hip by ultrasonography. All gathered data was used in the formulation of regression equations for the development of this study's model as described below.

Model Development

Body Composition

The weighted average of total BWa for horses from previous research studies is 64.24% as listed in Table 1. This is the value used in the development of the current model and is within the range (62 – 68%) provided by the NRC (2007) for adult horses. When calculated as a percentage of fat-free matter (FFM), BWa, BP, and BA equal 71.8%, 21.4%, and 6.86%, respectively. This study uses the combined results of the information presented above for the development of the model (Table 3).

Table 3. Body composition

	Water	Protein	Ash	Total
% of EBW[1]	64.24	19.13	6.14	89.51
% of FFM[2]	71.77	21.37	6.86	100

[1] Empty body weight
[2] Fat-free matter

Body Weight Measurements and Adjustments

For mature lactating dairy cows, a change in BW does not always necessarily indicate changes in tissue reserves, and vice versa (Tedeschi et al., 2006). As much as 40% variation in energy with no change in BW has been reported in dairy cows. Because of the inconsistencies between actual changes in BW and energy reserves, the model in this study used actual FBW to compute EBW, using Eq. [2] and Eq. [3].

Predicting Changes in Body Weight

The information of FBW is not always available in practical conditions. Therefore, changes in BW associated with changes in BCS were used to assess changes in tissue reserves. The individual mare data collected by Cavinder et al. (2009) was used to describe the relationship between BCS and percentage of empty BF (EBF), EBW, and actual BW. The regression between BCS and EBW indicated that the mean EBW change associated with a BCS change was equivalent to 3.88% of the mean BW. Therefore, a weight adjustment factor (WAF) was computed from the BCS in order to compute an adjusted EBW (aEBW) associated with changes in BCS, as shown in Eq. [4] and Eq. [5]:

$$WAF_i = 1 - 0.0388 \cdot (5 - BCS_{[1\text{-}9]}) \qquad [4]$$

$$aEBW = (\text{initial EBW} \cdot WAF)/\text{initial WAF} \qquad [5]$$

where WAF is weight adjustment factor; $BCS_{[1\text{-}9]}$ is the BCS on a scale of 1 to 9; EBW is empty body weight, kg; aEBW is the adjusted EBW to a given BCS.

The initial EBW to initial WAF ratio (Eq. [5]) computes the expected BW at BCS 5. The aEBW for each period assesses the variation in tissue energy from that which would be provided by an animal at a BCS of 5.

Total Energy Determination

Total body energy (TE, Mcal) is computed by multiplying the amount of BF and the amount of BP by their respective heat of combustion. The heat of combustion of fat in cattle has been estimated at 9.367 Mcal/kg, while the heat of combustion of protein has been found to vary from 5.554 to 5.686 Mcal/kg (Blaxter and Rook, 1953). The growing animal heat of combustion values of 9.376 Mcal/kg for fat and 5.554 Mcal/kg for protein have been adopted by the beef cattle NRC (2000), and therefore, were the numbers used in development of this study's model as no values have been developed specifically for horses to date. The total energy computation is noted below:

$$TE = (9.367 \bullet TF) + (5.554 \bullet TP) \quad [6]$$

$$TF = aEBW \bullet BF \quad [7]$$

$$TP = aEBW \bullet BP \quad [8]$$

where TE is total body energy, Mcal; TF is the amount of body fat, kg; TP is the amount of body protein, kg; and aEBW is the adjusted empty body weight.

The changes in total body energy within a period is assessed by computing the TE of consecutive periods, as shown in Eq. [9].

$$\Delta TE_i = TE_i - TE_{i-1};\ i \geq 2 \quad [9]$$

where ΔTE_i is the change in total energy (Mcal), TE_i represents the TE during the *i*th time period, and TE_{i-1} represents the TE of the period before the *i*th time period. While the TE at the first time period remains constant, the subsequent period's TE is computed by using Eq. [9].

Energy Efficiencies

As scarce information is presently available for horses, the coefficients of energy interconversion proposed in the energy efficiencies section above will be used in this model. When the animal is lactating, a negative energy balance ($\Delta TE < 0$) indicates energy reserves are being used for milk production. As noted above there is an 84%

efficiency in the mobilization of NE_R into NE_L and a 64.4% efficiency in ME use for lactation, the milk able to be produced from the mobilization of reserves is computed using Eq. [10]. On the other hand, a positive energy balance ($\Delta TE > 0$) indicates that the intake energy exceeds the energy requirements, and therefore, the diet energy is used for deposition into reserves rather than milk production. As stated above, a 72.6% efficiency of ME use for to NE_R is assumed. The calculated amount of milk from a lactating animal in a positive energy balance is shown in Eq. [11]:

if $\Delta TE < 0$, then $\Delta Milk = (\Delta TE \bullet 0.84)/0.644$ [10]

if $\Delta TE > 0$, then $\Delta Milk = (\Delta TE)/0.726$ [11]

where ΔTE is variation in total tissue energy (Mcal NE/d), and $\Delta Milk$ is variation in milk production (kg/d).

When the animal is not lactating, a 60% efficiency of ME used for NE_R is assumed.

Model Application

Non-lactating Quarter Horse mares (n=20; 4 to 18 yr of age; mean = 7), with initial BW ranging from 376 kg to 553 kg (mean = 458 kg) and initial BCS of 3.5 to 7 (scale of 1 - 9; 1 = emaciated and 9 = obese; 5 = moderate) were used in this study. Mares were borrowed from local owners within the community and individually housed (3.6 X 4.3 m stalls) at the Texas A&M University Equestrian Center. Individual housing of each mare was needed to precisely manage dietary intake throughout the study; however, all mares were rotated to individual turn out pens every other day to provide free exercise. A 1 wk acclimation period was used to allow mare adaptation to the housing environment. All mares were treated with a 450 kg dose of broad-spectrum dewormer (Equimectrin Paste, 1.87% Ivermectin equine dewormer in oral syringe) before the start of the study. Use of animals for this study was approved by the Texas A&M University Institutional Agricultural Animal Care and Use Committee using guidelines set forth by the Federation of Animal Science Societies (2009).

Physical Measurements

Body condition score, RF thickness, and BW were measured for each mare once prior to the commencement of the feeding trial and once/wk thereafter for the duration of a 30 d feeding trial. Body condition scores were obtained for each mare by 3 experienced, independent appraisers and then averaged together to determine each mare's body condition. Body condition was assessed using the equine BCS system established by Henneke et al. (1983) with a 9-point scale including quarter-point increments (1 = emaciated and 9 = obese; 5 = moderate). Each judge conducted their scoring of body condition independently, but concurrently with the other judges so all horses were scored at the same time of day. Each of the 6 body areas (neck, withers, shoulders, ribs, loin, and tailhead) was assessed using both physical palpation and visual appraisal to evaluate the amount of fat present.

Rump fat thickness measurements were gathered via ultrasonic scanning equipment with a 5 MHz transducer (MicroMaxx Ultrasound System, SonoSite, Inc., Bothell, WA). Rump scanning site was determined by measuring 5.08 cm from the midline and 10.16 cm from the point of the hip. Body fat content was then calculated using Eq. [1] described above. Measurement points were consistent from week to week by taking ultrasonography pictures of rump fat measurement site each sampling time.

Mares were individually led onto and weighed on a livestock weighbridge scale (Paul Livestock Scale, Adrian J. Paul Co., Inc., Duncan, OK) to determine BW.

Treatments

Pre-trial body condition scores were used to assign mares to 1 of 4 treatment groups as follows:

Table 4. Initial body condition score groups for mares fed to achieve a targeted body condition

Group 1	**Group 2**	**Group 3**	**Group 4**
BCS 4	BCS 5	BCS 6	BCS 7
Fed to achieve BCS 5	Fed to achieve BCS 4	Fed to achieve BCS 7	Fed to achieve BCS 6

Upon initial scoring, each mare’s information was placed into the model. Mares were then fed according to the model predictions.

Diet

Hay samples were obtained randomly by core sampling and concentrate samples were obtained by random grab sampling. Hay samples were submitted for nutrient analysis to a commercial laboratory (Soil, Water, and Forage Testing Laboratory, Texas A&M University, College Station, Texas).

Each mare was individually fed forage and concentrate twice/d 12 h apart in individual stalls outfitted with hay and grain combo stall feeders. The forage was offered first with the concentrate being offered immediately afterward. The forage consisted of a Coastal Bermudagrass hay (95.3% DM; 9.7% CP; 36.3% ADF; 65.9% NDF; 57.1% estimated TDN; 0.18% P; 0.4% Ca; 1.3% K; 0.2% Mg; 82 ppm Na; 23 ppm Zn; 161 ppm Fe; 89 ppm Cu; 105 ppm Mn). The concentrate consisted of a 12% crude protein pelleted horse feed (Brazos County Producer's Co-Operative Association, Bryan, Texas). Clean water was available *ad libitum*. During the 1 wk acclimation period, mares were fed a 70:30 forage:concentrate intake ratio of 2.5% of BW in an attempt to maintain a constant energy status during the pre-trial period. Any refusals were collected daily after each feeding, weighed, and recorded.

Initial BCS, target BCS, %BF, and BW data collected from each mare was input into the proposed model. Feeding regimen was manipulated so that mares were individually fed according to the DE predicted by the model in order to achieve a gain or loss of 1 BCS within a 30 d period depending on the treatment protocol. Proposed DE intake values were calculated to maintain the 70:30 forage:concentrate intake ratio. At the conclusion of the application period, final BCS, %BF, and BW values will be compared to the model's predicted values and the results will be used in model accuracy analyses.

Model Evaluation

The Model Evaluation System (MES) designed by Tedeschi (2006) was used to evaluate the accuracy and predictability of the developed model. Analysis ran include linear regression analysis, mean square error of prediction, correlation coefficients, distribution analysis, deviation analysis, graphics, and histograms. The MB is one of the most common statistics used to evaluate model accuracy, and is based on the mean deviance between the observed and model-predicted values (Cochran and Cox, 1957). A positive MB statistic means the model under-predicted the final values, while a negative MB statistics means the model over-predicted the final values. SPSS (SPSS, Inc., 2007) was used to run regression models. Mean absolute error measures the mean absolute deviance between the observed and model-predicted values, where the lower the MAE, the more accurate the model is (Byers et al., 1989; Mayer and Butler, 1993). The modeling efficiency (MEF) is a statistic that determines the proportion of variation between the observed values from the model-predicted values that is explained by the linear regression. The closer to 1, the better the MEF is (Loague and Green, 1991; Mayer and Butler, 1993). The coefficient of model determination (CD) also relies on the principle in which the closer to 1, the better the model predictability. It explains the proportion of the total variance of the observed values explained by the predicted values

(Loague and Green, 1991). The mean square error of prediction (MSEP) is a common and reliable measure of the predictive accuracy of a model (Bibby and Toutenburg, 1977). Accuracy is a measure of how closely model-predicted values are to the observed values, while precision is a measure of how closely individual model-predicted values are within each other (Tedeschi, 2002).

CHAPTER IV

RESULTS

Table 5 below demonstrates how the 20 mares were divided amongst the 4 treatment groups. Because changes in BCS took place from the time the mares were first assessed for use in the study to the time the mares chosen arrived at the research housing facility, not all 5 mares within each group had uniform initial BCS (with the exception of Group 4 with all 5 mares having an initial BCS of 7). The mares in Groups 1, 2, and 3 were divided into what would create an average BCS per group that is relatively close to the target BCS of the pertinent group. For example, Group 1 was initially assigned to contain mares beginning at a BCS of 4 that would be fed to increase 1 BCS (BCS of 5). Only 1 out of the 5 mares in Group 1 was at an initial BCS of 4, however, the average of the group itself was 3.9, which was rounded up to 4. The same principle was used for Groups 2 and 3.

Table 5. Placement of research mares into treatment groups according to initial body condition scores (BCS) per mare

Treatment Groups								
	Group 1 (BCS 4 - 5)		**Group 2 (BCS 5 - 4)**		**Group 3 (BCS 6 - 7)**		**Group 4 (BCS 7 - 6)**	
	Mare ID#	*BCS*$_{initial - desired}$	*Mare ID#*	*BCS*$_{initial - desired}$	*Mare ID#*	*BCS*$_{initial - desired}$	*Mare ID#*	*BCS*$_{initial - desired}$
	15	3.5 - 4.5	73	5 - 4	112	5.5 - 6.5	140	7 - 6
	32	3.5 - 4.5	11	4.5 - 3.5	508	5.5 - 6.5	106	7 - 6
	35	3.5 - 4.5	5	5 - 4	137	6 - 7	109	7 - 6
	8	4 - 5	48	5 - 4	57	6.5 - 7.5	510	7 - 6
	24	5 - 6	36	5 - 4	63	5.5 - 6.5	105	7 - 6
Mean Group BCS:		3.9 - 4.9		4.9 - 3.9		5.8 - 6.8		7 - 6

Table 6 below shows the calculated initial DE intake along with the change in DE intake as predicted by the model for each individual mare. Since several of the mares used in this study were put out to pasture for free-range grazing before the commencement of the study, their exact initial dietary energy intake that was maintaining the animal at its initial BCS was not able to be measured. Therefore, a theoretical method for calculating approximate initial DE intake was developed. A mare at an initial BCS of 5 was said to be in optimal condition and therefore was receiving 100% of her maintenance DE requirements/d. However, it can hypothesized that a mare at a BCS below 5 was receiving less than 100% of her DE requirements, while a mare at a BCS above 5 was receiving more than 100% of her maintenance DE requirements. Therefore, a scale was used to estimate initial DE intake. Every change in 1 BCS is equivalent to a change of 10% in DE requirements in the corresponding direction. For example, according to the NRC (2007), mare ID 73 (Group 2) requires 15.2 Mcal of DE/d. Since she was initially at a BCS of 5, it can be estimated that she was receiving 100% required DE and it was assumed she was consuming the entire 15.2 Mcal of DE/d. Therefore, her estimated current DE intake was 15.2 Mcal/d. On the other hand, Mare ID 8 (Group 1) was in an initial BCS of 4, and her DE requirements per the NRC (2007) are 13.3 Mcal DE/d. However, since she is 1 full BCS below 5, it can be assumed that she is not consuming the entire 13.3 Mcal DE/d, but rather 10% less than 13.3 (11.97 Mcal DE/d). As seen in Table 5, this theory was applied to every mare, and each current DE intake was calculated. After each mare's data is inputted into the model, the model calculates a proposed change in DE intake/d. These amounts were then either subtracted from or added to the current DE intake for each mare, depending on whether she was assigned to a group that would decrease or increase BCS. The total DE intake (in Mcal/d) as proposed by the model was calculated and the amount represents the total dietary energy intake consumed by each mare during this study.

Table 6. Digestible energy (DE) intake changes per mare as predicted by model

Mare ID	Initial BCS	DE Maint Req	% DE Maint Req Met	Current DE Intake	Proposed DE Change	Proposed total DE Intake
		(Mcal)	*Estimated*[a]	*Mcal/d*	*(Mcal/d)*	
GROUP 1						
15	3.50	13.3	85	11.31	5.98	17.29
32	3.50	13.3	85	11.31	6.08	17.39
35	3.50	13.3	85	11.31	4.95	16.26
8	4.00	13.3	90	11.97	7.63	19.60
24	5.00	13.3	100	13.3	7.40	20.70
GROUP 2						
73	5.00	15.2	100	15.2	-4.23	10.97
11	4.50	13.3	100	13.3	-3.55	9.75
5	5.00	13.3	100	13.3	-2.46	10.84
48	5.00	13.3	100	13.3	-2.38	10.92
36	5.00	13.3	100	13.3	-2.37	10.93
GROUP 3						
112	5.50	15.2	105	15.96	7.46	23.42
508	5.50	15.2	105	15.96	3.88	19.84
137	6.00	12.1	110	13.31	9.16	22.47
57	6.50	15.2	115	17.48	8.03	25.51
63	5.50	13.3	100	13.3	6.02	19.32
GROUP 4						
140	7.00	15.2	120	18.24	-6.46	11.78
106	7.00	15.2	120	18.24	-5.92	12.32
109	7.00	12.1	120	14.52	-3.33	11.19
510	7.00	15.2	120	18.24	-4.16	14.08
105	7.00	15.2	120	18.24	-6.94	11.30

[a]Assuming BCS of 5 is a mare meeting 100% of maintenance DE requirements; change in 1 full BCS from a BCS of 5 is equivalent to a 10% deviation from 100% of maintenance DE requirements

Model Evaluations

Evaluating BCS

Three independently judged BCS were averaged to attain a mean BCS, which was then rounded up to the nearest 0.5 BCS. Appendix Table 1 shows each mare's scores/wk, as well as her rounded mean (final) BCS. The final BCS values (observed) were compared to the final BCS values (predicted) as proposed by the model. The coefficient of determination (r^2) is used in the evaluation of models whose main purpose is to predict a future outcome. It represents the proportion of variability in a given data set and provides a measure of the likelihood a future outcome can be predicted by the model. All 20 mare data points (n = 20) were used for the evaluation of the model's predictability in regards to BCS, and resulted in an r^2 of 0.907 (P = 0.00001) with a maximum error (ME) of 0.5. This means the model accounted for 90.7% of the observed BCS variation, with a maximum BCS variation of 0.5 of a BCS between final observed and model-predicted values. The BCS evaluation resulted in a mean bias (MB) of 0.025 BCS units. On the other hand, the mean absolute error (MAE) for this evaluation was 0.275. The MEF for this evaluation was 0.860, while the CD was 0.732. MSEP resulted in 0.138 BCS units. Table 7 below summarizes these results.

Table 7. Model Evaluation System (MES) statistic results for final BCS model predictions

Coefficient of determination (r^2)	0.907
Maximum error (ME)	0.5 BCS units
Mean bias (MB)	0.025 BCS units (model under-prediction)
Mean absolute error (MAE)	0.275 BCS units
Modeling efficiency (MEF)	0.860
Coefficient of model determination (CD)	0.732
Mean square error of prediction (MSEP)	0.138 BCS units

Figure 1 below shows the scatterplot of the final observed BCS values versus the final model-predicted values. Points above the Y = X line indicate under-predictions by the model while points lying below the Y = X line indicate model over-predictions.

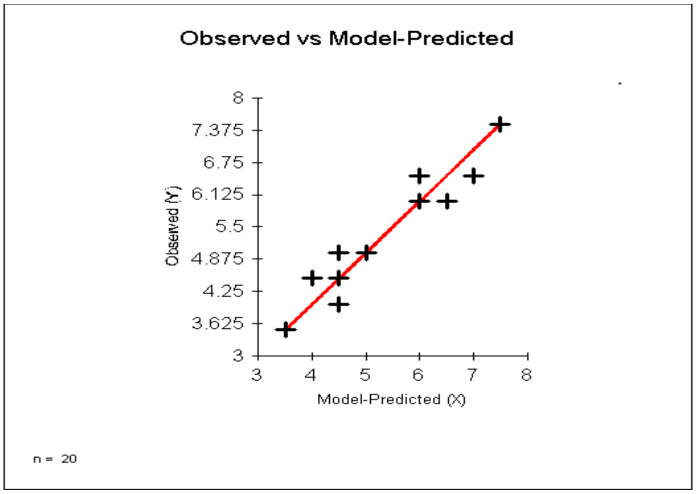

Figure 1. BCS values: observed vs model-predicted

In order to compare the predictability of the model at increasing a BCS versus decreasing a BCS, Group 1 and Group 3 (both the increasing BCS groups) data (n = 10) were combined and evaluated as 1 data set, while Group 2 and Group 4 (both decreasing BCS groups) data (n = 10) were combined and evaluated as well. The model's increasing-BCS predictability MES results are presented in Table 8, while the model's decreasing-BCS predictability MES results are presented in Table 9.

Table 8. Model Evaluation System (MES) statistic results for increasing-BCS model predictability

Coefficient of determination (r^2)	0.906 (P = 0.00002)
Maximum error (ME)	0.5 BCS units
Mean bias (MB)	-0.2 BCS units (model over-prediction)
Mean absolute error (MAE)	0.3 BCS units
Modeling efficiency (MEF)	0.843
Coefficient of model determination (CD)	0.799
Mean square error of prediction (MSEP)	0.15 BCS units

Table 9. Model Evaluation System (MES) statistic results for decreasing-BCS model predictability

Coefficient of determination (r^2)	0.950 (P = 0.00001)
Maximum error (ME)	0.5 BCS units
Mean bias (MB)	0.25 BCS units (model under-prediction)
Mean absolute error (MAE)	0.25 BCS units
Modeling efficiency (MEF)	0.863
Coefficient of model determination (CD)	0.768
Mean square error of prediction (MSEP)	0.125 BCS units

The allotted time to alter BCS in all 20 mares was 30 d. However, 2 of the mares did not receive the exact amount of DE as proposed by the model from day 1 due to the large change in consumption. Instead, feed intakes for the corresponding mares were gradually increased/decreased over a 1 wk period to prevent colic and/or health related issues. Therefore, it should be noted that those mares did not receive the total proposed DE intake over the 30 d period (Mare ID# 508 and Mare ID# 57). However, they consumed no less than 90% of the total proposed DE over the trial period, while the remaining mares received no less than 95% of the total proposed intake (including refusals). To evaluate if the results for the 2 mares skewed the overall model evaluation results when all 20 mares' data was included, further evaluations were conducted excluding the 2 mares (n = 18). The model evaluation for the remaining 18 mares results are presented in Table 10 below.

Table 10. Model Evaluation System (MES) statistic results for final BCS model predictions (n = 18)

Coefficient of determination (r^2)	0.917 (P = 0.00001)
Maximum error (ME)	0.5 BCS units
Mean bias (MB)	0.083 BCS units (model under-prediction)
Mean absolute error (MAE)	0.25 BCS units
Modeling efficiency (MEF)	0.881
Coefficient of model determination (CD)	0.780
Mean square error of prediction (MSEP)	0.125 BCS units

When compared to the results when all 20 mares were included in the data set (n = 20 vs n = 18), there was a 1.1% difference in the r^2 between the 20-mare and 18-mare evaluations, no change in ME, 2.38% difference in the MEF and a 6.15% difference in the CD. Due to the minimal differences in the results, it can be concluded that including all 20 mares in the evaluation still poses accurate results. Also, it can be expected that a horse owner using this model will run into a similar situation in which they will not be able to immediately feed their animal the entire proposed DE intake amount, and they too will have to decrease/increase intake in moderation.

Evaluating BF

Appendix Table 2 shows the rump fat measurements and extractable fat (BF%) results/mare/wk. The ability of the model to predict changes in BF was analyzed and the observed final BF values were compared to the model-predicted final BF values for all 20 mares (n = 20). This resulted in an r^2 of 0.607 (P = 0.00005) with an ME of 2.96 %BF units. Table 11 below shows the model evaluation results, while Figure 2 is the scatterplot of the observed final BF values versus the model-predicted final BF values on the Y = X line.

Table 11. Model Evaluation System (MES) statistic results for final body fat model predictions

Coefficient of determination (r^2)	0.607 (P = 0.00005)
Maximum error (ME)	2.96 %BF units
Mean bias (MB)	0.759 %BF units (model over-prediction)
Mean absolute error (MAE)	1.235 %BF units
Modeling efficiency (MEF)	0.376
Coefficient of model determination (CD)	0.355
Mean square error of prediction (MSEP)	2.182 %BF units

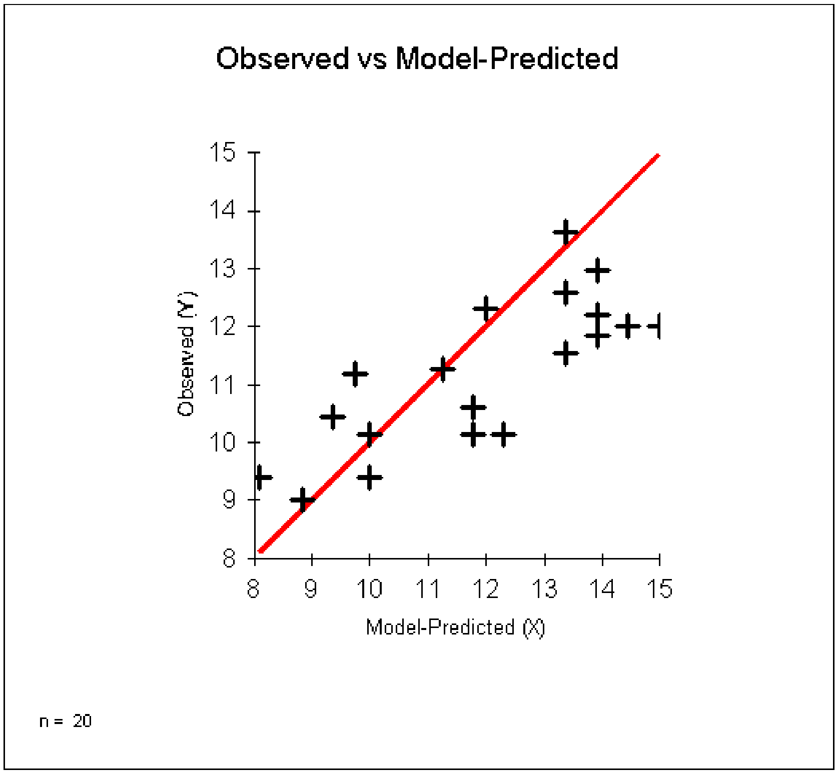

Figure 2. BF values: observed vs model-predicted

Evaluating BW

Body weight evaluations were conducted using EBW values so as to not include the weight of the ingesta. All mares' data were inputted and analyzed (n = 20) for model predictability of final EBW and is presented below in Table 12. Figure 3 represents a scatterplot of the observed final EBW values versus the model-predicted final EBW values on the Y = X line.

Table 12. Model Evaluation System (MES) statistic results for final empty body weight model predictions

Coefficient of determination (r^2)	0.944 (P = 0.00001)
Maximum error (ME)	31.88 kg
Mean bias (MB)	9.65 kg (model under-prediction)
Mean absolute error (MAE)	7.833 kg
Modeling efficiency (MEF)	0.927
Coefficient of model determination (CD)	0.824
Mean square error of prediction (MSEP)	10.96 kg

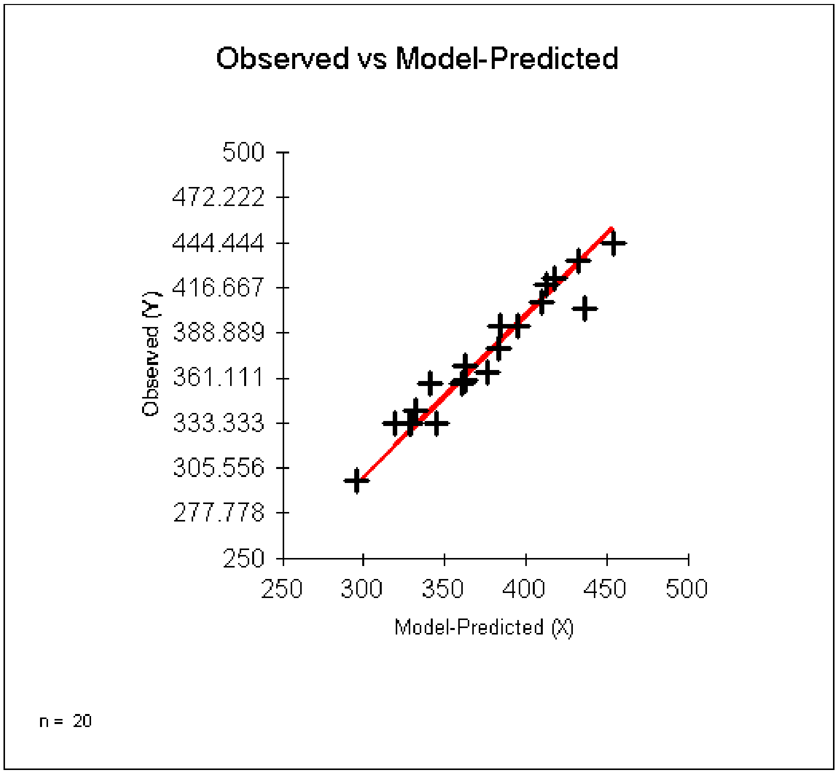

Figure 3. EBW values: observed vs model-predicted

Comparative Analysis

Table 13 provides a comparative analysis of all the model evaluations. The coefficient of determination is a statistic that provides information about the goodness-of-fit of a model, evaluating how well the regression line approximates the observed data points. An r^2 of 1.0 indicates a regression line that perfectly fits the data, which can be thought of as a representation of the percent variance that can be explained by the model.

Mean error represents the maximum amount by which the observed values differ from the model-predicted values. Mean bias is a calculation based on the mean deviance between the observed values and the model-predicted values (Cochran and Cox, 1957). It also aids in identifying under- and over-predictions of the model. A negative MB value represents a model over-prediction, while a positive MB value represents model under-prediction. Mean absolute error measures the mean absolute deviance between observed and model-predicted values, where the lower the MAE, the more accurate the model is (Byers et al., 1989; Mayer and Butler, 1993). The MEF statistic represents the proportion of variation explained by the line Y = X, where Y is the observed values and X is the model-predicted values (Mayer and Butler, 1993). The coefficient of model determination is a ratio of the total variance of the observed data to the squared difference between model values and the mean of the observed values. In other words, the CD statistic can explain the proportion of the total variance of the observed values that can be explained by the predicted data (Loague and Green, 1991).

Table 13. Comparative analysis of all statistics per evaluation

	BCS n = 20	BCS (inc) n = 20	BCS (dec) n = 20	BCS n = 18	%BF	BW
r^{2a}	0.907	0.906	0.95	0.917	0.607	0.94
ME[b]	0.5[i]	0.5[i]	0.5[i]	0.5[i]	2.96[j]	31.88[k]
MB[c]	0.025[i]	-0.2[i]	0.25[i]	0.083[i]	0.759[j]	9.65[k]
MAE[d]	0.275[i]	0.3[i]	0.25[i]	0.25[i]	1.235[j]	7.833[k]
MEF[e]	0.860	0.842	0.863	0.881	0.376	0.93
CD[f]	0.732	0.799	0.768	0.78	0.355	0.82
MSEP[g]	0.138[i]	0.15[i]	0.125[i]	0.125[i]	2.182[j]	10.967[k]
Prediction[h]	under	over	under	under	over	under

[a]coefficient of correlation
[b]mean error
[c]mean bias
[d]mean absolute error
[e]modeling efficiency
[f]coefficient of determination
[g]mean square error of prediction
[h]model over-prediction or under-prediction
[i]BCS units
[j]%BF units
[k]kg

Correlations

Body Condition Score and Body Fat % Correlations

Correlation analyses were run to determine the strength of correlation between BCS and BF. Precisely, what percent change in BF can be expected per 1 BCS change. Two sets of data were analyzed: initial BCS/%BF and final BCS/%BF. If there is a strong correlation between BCS and %BF, then in theory, both sets of data should reveal similar results. The initial set of data (n = 20) resulted in a Pearson correlation (r) of 0.808, while the final set of data (n = 20) had an r of 0.788. Both correlations were significant (*P* = 0.01; 2-tailed). Since both correlation statistics are less than 2.5% different, the mean correlation was calculated (0.798). It can be concluded that a 0.798 correlation exists between BCS and %BF, where for every change in 1 BCS (either increasing or decreasing), a change in the same direction of 1.054 percentage units of BF can be expected.

Digestible Energy Changes per BCS

From the results presented in Table 5, an average DE intake change can be deduced and analyzed per group. On average, it took an increase of 6.41 Mcal DE/d to the diet for a mare to increase 1 BCS; from a BCS 4 to BCS 5 (Group 1). The exact DE increase in Mcal/d for the mares in Group 1 ranged from 4.95 to 7.63 Mcal DE/d. Therefore, we can conclude that an increase of 5 to 7.5 Mcal of DE/d is needed for a mare to go from a BCS of 4 to 5. On the other hand, as seen by the model-proposed DE values for the mares in Group 3, it takes approximately 7.58 Mcal DE/d for a mare to decrease 1 BCS from a BCS 5 to a 4, ranging anywhere between 2.46 to 5.22 Mcal DE/d less (more practical, 2.5 to 5 Mcal DE/d decrease). Mares in Group 2 who were fed to increase BCS from a 6 to 7 required an average of a 7.58 Mcal DE/d increase. The range was 4.74 to 9.83 Mcal of DE/d, which can be rounded to 4.5 to 10 Mcal DE/d. Conversely, an average decrease of 4.69 Mcal DE/d was needed for mares in Group 4 to go from BCS 7 to 6. The range was 3.11 to 6.94 Mcal of DE/d decrease, which can be rounded to 3 to 7 Mcal DE/d.

Tables 14 and 15 demonstrate the approximate amount of DE change required to increase or decrease 1 BCS, depending on the initial BCS, BW and BF level. The tables may be used as a reference when the actual computerized model is not available for use. Initial BCS is represented on the table's left margin. A table containing every BF percentage would be hard to read and impractical. Therefore, the level of BF is separated into 2 groups- low and high BF level. The low BF level represents animals containing less than 10% BF, while the high BF level represents animals containing more than 10% BF. If the exact %BF is unknown or unable to be measured, the 2 levels of BF can instead be used as a range of DE required for BCS- the low BF level representing the lower limit and the high BF level representing the upper limit. The columns of both tables are divided into BW, starting at 800 lb in 50 lb increments.

Table 14. Digestible energy change required to increase one body condition score

Initial BCS	BF level[a]	Initial BW, lb								
		800	*850*	*900*	*950*	*1000*	*1050*	*1100*	*1150*	*1200*
	L	5.25	5.58	5.91	6.24	6.57	6.9	7.2	7.55	7.88
3	*H*	2.13	2.26	2.39	2.52	2.66	2.79	2.92	3.06	3.19
	L	6.94	7.38	7.81	8.24	8.68	9.11	9.55	9.98	10.41
4	*H*	3.81	4.05	4.29	4.53	4.77	5	5.24	5.48	5.72
	L	8.63	9.17	9.71	10.25	10.79	11.33	11.87	12.41	12.94
5	*H*	5.5	5.84	6.19	6.53	6.88	7.22	7.56	7.91	8.25
	L	10.32	10.96	11.61	12.25	12.9	13.54	14.19	14.83	15.48
6	*H*	7.19	7.64	8.09	8.54	8.99	9.44	9.88	10.33	10.78

[a] The low (L) BF level represents animals containing less than 10% BF; high (H) BF level represents animals containing more than 10% BF

Table 15. Digestible energy change required to decrease one body condition score

		Initial BW, lb								
Initial BCS	**BF level**[a]	*800*	*850*	*900*	*950*	*1000*	*1050*	*1100*	*1150*	*1200*
4	*L*	-3.28	-3.48	-3.69	-3.89	-4.1	-4.3	-4.51	-4.71	-4.92
	H	-2.86	-3.04	-3.22	-3.4	-3.58	-3.76	-3.94	-4.12	-4.29
5	*L*	-4.85	-5.15	-5.45	-5.75	-6.06	-6.36	-6.66	-6.97	-7.27
	H	-1.96	-2.08	-2.21	-2.33	-2.45	-2.57	-2.7	-2.82	-2.94
6	*L*	-6.42	-6.82	-7.23	-7.63	-8.03	-8.43	-8.83	-9.23	-9.63
	H	-3.53	-3.75	-3.97	-4.19	-4.41	-4.63	-4.85	-5.07	-5.29
7	*L*	-8.01	-8.51	-9.01	-9.51	-10.01	-10.51	-11.01	-11.51	-12.01
	H	-5.1	-5.42	-5.74	-6.06	-6.38	-6.7	-7.02	-7.34	-7.66

[a]The low (L) BF level represents animals containing less than 10% BF; high (H) BF level represents animals containing more than 10%

CHAPTER V

DISCUSSION

Model Predictability

Models are mathematical representations of natural events that cannot always be explained or understood, and have become useful in decision-making. The development of mathematical models requires that the objectives of the model be described, the assumed limits of the model be outlined, appropriate data be acquired, model structure be designed, evaluations designed to identify strengths and weaknesses be developed, and the results be analyzed to provide insight for future model development (Tedeschi, 2002).

When evaluating the predictability of a model, one must define both its precision and accuracy. As stated previously, accuracy is a measure of how closely model-predicted values are to the observed values and is usually measured by the CD, while precision is a measure of how closely individual model-predicted values are within each other which is usually measured by correlation coefficients (r; r_2) and the mean square error of prediction (MSEP)(Tedeschi, 2002). Mean square error of prediction evaluates the difference between observed values and model-predicted values, as opposed to comparing the observed values to regression-predicted values such as when using correlation coefficients. Other criteria have been used to discuss and compare mathematical models, however, no single statistic can completely evaluate the capabilities of model predictions (Green and Stephenson, 1986).

Table 13 illustrates that our model's predictability was most precise in predicting BW, then BCS, with the least predictable measurement being %BF; however, %BF still provides an r^2 of approximately 0.61. It was hypothesized that final %BF values would be difficult to predict, since BF deposition and metabolism trends vary per individual animal and rely heavily on genetics. However, it was noted that all mares' observed final %BF values finished with less than a 20% variation from the model-predicted values. Almost half of the mares' (n = 9) observed final BF percentage values varied less than 10% from the model-predicted values, and 5 mares' observed final %BF values varied less than 5% from model- predicted values.

In regards to BCS, all mares finished the model application period at a BCS that was at least 90% of the final model-predicted BCS. When comparing the model's ability to predict changes in increasing versus decreasing BCS (i.e. mares in group 1 vs those in group 2, etc.), it was noted that the model was able to more accurately predict the final BCS of mares that were decreasing a BCS as opposed to the mares that were increasing a BCS. Also, a larger amount of DE is needed to increase BCS above 5 as opposed to below 5, perhaps due to the fact that mares in a BCS below 5 are receiving less than 100% of the maintenance requirements for DE and any increase in DE, no matter how small, can greatly enhance the nutrition status for that animal as opposed to an animal that is already at an acceptable state of nutrition.

In regards to BW, the ME was 31.88 kg, meaning that all mares' observed final EBW values veered no more than approximately 32kg from the model-predicted final values. Thirty-two kg accounts for an 8% difference from model-predicted values. Eighteen mares had observed final values with less than a 5% difference (< 17kg), 16 mares had less than 3% difference (< 12kg), 12 mares had less than 2% difference (< 6kg), and 7 mares had less than 1% difference (< 3kg) from predicted final values. This means that, of the data inputted into the model, 90% of the mares inputted into the model will end with observed final values that differ no more than 5% from the model-predicted final values in regards to BW.

Implications and Advantages

The developed model is more accurate and reliable than visual appraisal alone and can be used by any horse owner, breeder, trainer, equine nutrition specialist, or farm owner seeking to maximize profitability and production. This model can enhance animal feeding systems and provide insight on nutrition status of the animal, providing a much needed tool to the equine industry. The economic benefit the mare owner will gain due to more precise feeding regimens will lead to greater profit and business potential. The developed model will also provide a foundation on which to build more complex equine models in the future, including models tailored to growing or working horses, lactating broodmares, breeding stallions, geriatric horses, etc. This model can also be used by rescue facilities to calculate more precise costs of feeding abused and malnourished horses in hopes of being able to house a larger number of animals. Due to the nation's current economic status, most horse owners are more focused on the costs and expenses of horse ownership than animal welfare, as seen in the ongoing unwanted horse and horse slaughter debates. Using more precise ways to calculate feeding costs can aid in decreasing the number of potential horse buyers that are deterred from owning a horse due to inflated estimated ownership costs. Along with the economic benefits possible with the use of the developed model, other benefits to the equine industry include the ability to minimize the amount of resources (such as trained personnel and equipment) spent on a mare not yet at an optimum state for reproduction.

Further Model Development

Usability

It is important to note there are several weaknesses to the model developed at this point. First and foremost, this model is limiting in its usability, as it is only meant to be applied to Quarter Horse broodmares that are non-lactating. Further models need be developed that can apply to horses in various stages of production (ie. lactating, working, growing). Incorporation of a feed list, where the user can enter specifically which forages to use when calculating intake, and the ability to calculate exact feed costs per item can provide users an even easier way of choosing which forages and grains to feed based on the amounts that must be fed to meet requirements. However, the current model does serve as a foundation for accurate assessment of DE required to alter BCS of non-lactating mares and with further research can extend to horses with other demands (performance, stallions, etc.).

Factors Affecting Diet Digestibility

When developing future models, it will be imperative that factors that may influence diet digestibility be taken into consideration, for ignoring such factors may present discrepancies in results. There are several known factors affecting diet digestibility, including individual animal variation, body composition, age, gender, voluntary exercise and temperament, nutrition level, diet composition, effective ambient temperature, and others (Martin-Rossett et al., 1994; Harris, 1997; Pagan, 1997). Accurate prediction of feed intake by animals requires a sufficient description of the animal and the feed (Tolkamp et al., 2006). The current research project took into account the majority of the above factors when developing the study.

All mares used in this study were of the same breed and, in theory, were of relatively similar genetic makeup. Previous research is clear that energy digestibility of a specific feed can be affected by differences among horses, with differences ranging from 58.8 to 65.8% digestibility between individuals (Pagan and Hintz, 1986). Furthermore, metabolic differences stemming from genetic variation in body composition have been found for animals who are fed the same diet (Kearns et al., 2002a). Within a breed, there are clear individual variations related to differences in size, such as length and height at withers (Doreau and Boulot, 1989). There also appears to be a breed-related difference in fat and muscle distribution in horses, possibly due to the fact that different breeds have been bred and developed for different functions (Kearns et al., 2002a). Digestible energy intake was found to be 6.9 Mcal/d greater when horses were in fleshy condition as compared to when in moderate condition, concluding that more energy is required by fleshier horses (Webb et al., 1990).

Due to the restricted availability of mares for this study, age was not uniform among all mares. Future studies should take into consideration age effects and use a group of mares that is homogenous in age. However, contradicting information has been found on the effect of age on energy requirements. Martin-Rossett and Vermorel (1991) determined that energy requirements were lower for horses approximately 11 yr old than for horses approximately 4 yr old. In contrast, the NRC (2007) states the amount of DE required per kg of gain typically increases with maturity, but Huesner (1993) stated that mature horses require approximately 24 Mcal of DE above maintenance per kg of gain. No information is yet available for the effects of gender on composition of gain, but it is thought to have some degree of influence (NRC, 2007).

The amount of time available for free exercise was equal for all mares, however, the amount of additional voluntary activity due to individual temperament is difficult to control. Individual variations in horse temperament and voluntary activity can affect the amount of DE required for maintenance. The NRC (2007) suggests a daily intake of 30.3 kcal DE/kg BW for horses at minimum maintenance (horses with a sedentary lifestyle), 33.3 kcal DE/kg BW for horses with moderate voluntary activity and alert temperaments, and 36.3 kcal DE/kg BW for elevated maintenance (horses with nervous and overly active temperaments).

Ambient temperature can affect diet digestibility as it poses physical stresses on the animal's body, as stresses occur at temperatures below and above the thermoneutral zone (TNZ). The TNZ is the temperature range when metabolic heat production does not need to be increased to maintain thermostability. To maintain thermostability, a horse will increase its heat production whenever ambient temperatures fall below the lower critical temperature (LCT), and evaporative heat loss will occur when temperatures are above the upper critical temperature (UCT) of the TNZ (NRC, 1981). While both processes of heat production and evaporative heat loss affect the amount of dietary energy required by the horse, more energy is required for maintenance during the hot season as compared to the temperate season. This is due to the fact that energy digestibility during the hot season is less (51.1%) than the energy digestibility during the temperate season (63.5%)(Webb et al., 1990). Cymbaluk (1994) established LCT of 5^{o}C and UCT of 25^{o}C. Effective ambient temperatures may have affected diet digestibility of mares in the current study since it was conducted in the summer months and temperatures above the UCT of the TNZ occurred. During the experimental period, there was an average high temperature of 34^{o}C (range = 25^{o}C to 41^{o}C) and an average low temperature of 23^{o}C (range = 21^{o}C to 27^{o}C). Average daily precipitation was 0.25 cm (range = 0 to 8.1 cm) and average humidity of 75% (range = 67% to 82%) was seen (Weather Underground, Inc., 2011).

CHAPTER VI

CONCLUSIONS

Knowledge of equine composition, intake, and digestion can be used to develop mathematical models that will aid in estimating nutrient requirements. Up until the development of this study's model, no such program had been previously created. This study developed a model to predict DE needed to support changes in BCS, and provides a starting point for equine nutritional models that will not only enhance equine feeding systems, but will reduce the costs of unnecessary over-feeding while maintaining broodmares at an optimum level of reproductive efficiency.

LITERATURE CITED

Abrams, J. T. 1984. Foods and feeding. Pages 93 – 151 in Horse Management. J. Hickman, ed. Academic Press, London, UK.

Andrews, F. M., J. A. Nadeau, L. Saabye, and A. M. Saxton. 1997. Measurement of total body water content in horses using deuterium oxide dilution. Am. J. of Vet. Res. 58(10):1060-1064.

Banach, M. A., and J. W. Evans. 1981. Effects of inadequate energy during gestation and lactation on the estrous cycle and conception rates of mares and on their foal weights. Pages 97-100 in Proc. 7th Eq. Nutr. and Physiol. Symp. Davis, CA.

Belonje, P. C. and C. H. can Niekerk. 1975. A review of the influence of nutrition upon the oestrous cycle and early pregnancy in the mare. J. Reprod. Fertil. Suppl. 23:167-169.

Bibby, J. and H. Toutenburg. 1977. Prediction and improved estimation in linear models. John Wiley & Sons, Berlin, Germany.

Blaxter, K. L., and J. A. F. Rook. 1953. The heat of combustion of the tissues of cattle in relation to their chemical composition. Br. J. Nutr. 7:83-91.

Byers, F. M., G. T. Schelling, and L. W. Greene. 1989. Development of growth functions to describe energy density of growth in beef cattle. Pages 195-198 in Proceedings of Energy Metabolism of Farm Animals, 11, Lunteren. Pudoc.

Cavinder, C. A., M. M. Vogelsang, D. W. Forrest, P. G. Gibbs, T. L. Blanchard. 2005. Reproductive parameters of fat vs moderately conditioned mares following parturition. Proc. 19th Equine Sci Soc., Tuczon, AZ.

Cavinder, C. A., M. M. Vogelsang, P. G. Gibbs, D. W. Forrest, and D. G. Schmitz. 2009. Variances in reproductive efficiency of mares in fat and moderate body conditions following parturition. Prof. Ani. Sci. 25(3):250-255.

Chilliard, Y., A. Ferlay, Y. Faulconnier, M. Bonnet, J. Rouel, and F. Bocquier. 2000. Adipose tissue metabolism and its role in adaptations to undernutrition in ruminants. Proc. Nutr. Soc. 59:127-134.

Cochran, W. G. and G. M. Cox. 1957. Experimental Design. John Wiley & Sons, NY.

Coenen, M. and H. Meyer. 1986. Feeding during late pregnancy and the importance for health of mare and foal. Page 17 of Proc. 37th Annu. Meet. E.A.A.P., Budapest.

Croxton, D. and R. J. Stollard. 1976. Use of body condition scoring as a management aid in dairy and beef herds. Anim. Prod. 4:146.

Cuddeford, D. 2004. A comparison of energy feeding systems for horses. Pgs 79-88 in Nutrition of the Performance Horse, V. Julliand and W. Martin-Rosset, eds. EAAP Publication No. 111.

Cymbaluk, N. F. 1994. Thermoregulation of horses in cold, winter weather: a review. Livest. Prod. Sci. 40(1):65-71.

Donaldson, L. E. 1969. Relationships between body condition, lactation, and pregnancy in beef cattle. Aust. Vet. J. 45:577.

Doreau, M., W. Martin-Rosset, and S. Boulot. 1988. Energy requirements and the feeding of mares during lactation: a review. Livest. Prod. Sci. 20:53-68.

Doreau, M., and S. Boulot. 1989. Recent knowledge on mare milk production: a review. Livest. Prod. Sci. 22:213-235.

Doreau, M., S. Boulot, D. Bauchart, J. P. Barlet, and W. Martin-Rosset. 1992. Voluntary intake, milk production, and plasma metabolites in nursing mares fed two different diets. J. Nutr. 122(4):992-999.

Dunn, T G., J. E. Ingalls, D. R. Zimmerman, and J. N. Wiltbank. 1969. Reproductive performance of 2-year-old Hereford and Angus heifers as influences by pre- and postcalving energy intake. J. Anim. Sci. 29:719-726.

Dunn, T. G. and C. C. Kaltenbach. 1980. Nutrition and postpartum interval of the ewe, sow, and cow. J. Anim. Sci. Suppl. II. 51:29-38.

Elser, A. H., S. G. Jackson, J. P. Lew, and J. P. Baker. 1983. Comparison of estimated total body in the equine from ethanol dilution and from carcass analysis. Pages 61-66 in Proc. 8th Eq. Nutr. Physiol. Symp. Lexington, KY.

Evans, J. W. Horses: A Guide to Selection, Care, and Enjoyment. W. H. Freeman and Co: New York, NY. Pp. 187. 1989.

Fielding, L. C., K. G. Magdesian, D. A. Elliot, L. D. Cowgill, and G. P. Carlson. 2004. Use of multifrequency bioelectrical impedance analysis for estimation of total body water and extracellular and intracellular fluid volumes in horses. Am. J. Vet. Res. 65(3): 320-326.

Fitzgerald, B. P., and C. J. McManus. 2000. Photoperiodic versus metabolic signals as determinants of seasonal anestrus in the mare. Biol. Reprod. 63(1):335-340.

Fitzgerald, B. P., S. E. Ready, D. R. Sessions, M. M. Vick, and B. A. Murphy. 2003. Obesity disrupts the duration of the estrous cycle in the mare. J. Anim. Sci. Suppl. 81:102 (Abstr.).

Fonnesbeck, P. V. 1981. Linear models for calculating digestible energy for sheep diets. J. Anim. Sci. 52(5):1183-1196.

Forro, M., S. Cieslar, G. L. Ecker, A. Walzak, J. Hain, and M. I. Lindinger. 2000. Total body water and ECFV measured using bioelectrical impedance analysis and indicator dilution in horses. J. Appl. Physiol. 89:663-671.

Fowden, A. L., A. J. Forhead, K. L. White, and P. M. Taylor. 2000. Equine uteroplacental metabolism at mid- and late gestation. Exp. Physiol. 85(5):539-545.

Frisch, R. E. 1980. Pubertal adipose tissue: is it necessary for normal sexual maturation? Evidence from the rat and human female. Fed. Proc. 39:2395.

Gentry, L. R., D. L. Thompson Jr., G. T. Gentry Jr., K. A. Davis, R. A. Godke, and J. A. Cartmill. 2002. The relationship between body condition, leptin, and reproductive and hormonal characteristics of mares during the seasonal anovulatory period. J. Anim. Sci. 80:2695-2703.

Ginther, O. J. 1974. Occurrence of anestrus, estrus, diestrus, and ovulation over a 12-month period in mares. Am. J. Vet. Res. 35:1173-1179.

Green, I. R. A. and D. Stephenson. 1986. Criteria for comparison of single event models. J. Hydrol. Sci. 31:395-411.

Harris, P. 1997. Energy sources and requirements of the exercising horse. Annu. Rev. Nutr. 17:185-210.

Henneke, D. R. and J. L. Kreider. 1979. Effects of restrictive suckling on postpartum reproductive performance in mares. Am. J. Vet. Res. 40:1281-1284.

Henneke, D. R., G. D. Potter, and J. L. Kreider. 1981. Rebreeding efficiency in mares fed different level sof energy during late gestation. Pages 101-104 in Proc. 7th Eq. Nutr. and Physiol. Symp., Petersburg, VA.

Henneke, D. R., G. D. Potter, J. L. Kredider, and B. F. Yeates. 1983. Relationship between condition score, physical measurements and body fat percentage in mares. Equine Vet. J. 15(4):371-371.

Henneke, D. R. 1984. Body condition during pregnancy and lactation and reproductive efficiency of mares. Equine Vet. J. 21:897-909.

Heusner, G. L. 1993. Ad libitum feeding of mature horses to achieve rapid weight gain. Pages 86-87 in Proc. 13th Equine Nutr. and Physiol. Symp. Gainesville, FL.

Hines, K. K. 1985. Reproductive efficiency and endocrine status of postpartum mares at different levels of body condition. Ph. D. Dissertation, Texas A&M Univ., College Station.

Hines, K. K., S. L. Hodge, J. L. Kreider, G. D. Potter, and P. G. Harms. 1987. Relationship between body condition and levels of serum luteinizing hormone in postpartum mares. Therio. 28(6):815-825.

Hintz, H. F., and N. F. Cymbaluk. 1994. Nutrition of the horse. Annu. Rev. Nutr. 14:243-267.

Houseknecht, K. L., C. A. Baile, R. L. Matteri, and M. E. Spurlock. 1998. The biology of leptin: a review. J. Anim. Sci. 76(5):1405-1420.

Howell, C. E., and W. C. Rollins. 2009. Environmental sources of variation in the gestation length of the horse. J. Anim. Sci. 10:789-796.

Julian, L. M., J. H. Lawrence, N. I. Berlin, and G. M. Hyde. 1955. Blood volume, body water, and body fat of the horse. J. Appl. Physiol. 8(6):651-653.

Kane, R. A., M. Fisher, D. Parrett, and L. M. Lawrence. 1987. Estimating fatness in horses. Pages 127-131 in Proc. 10th Eq. Nutr. and Physiol. Symp. Urbana, IL.

Kearns, C. F., K. H. McKeever, and T. Abe. 2002a. Overview of horse body composition and muscle architecture: implications for performance. Vet. J. 164:224-234.

Kienzle, E., S. Fehrle, and B. Opitz. 2002. Interactions between the apparent energy and nutrient digestibilities of a concentrate mixture and roughages in horses. J. Nutr. 132:1778S-1780S.

Kubiak, J. R., B. H. Crawford, E. L. Squires, R. H. Wrigley, and G. M. Ward. 1987. The influence of energy intake and percentage of body fat on the reproductive performance of nonpregnant mares. Therio. 28(5): 587-598.

Kubiak, J. R., J. W. Evans, G. D. Potter, P. G. Harms, and W. L. Jenkins. 1988. Parturition in the multiparous mare fed to obesity. Equine Vet. J. 8(2):135-140.

Kubiak, J. R., J. W. Evans, G. D. Potter, P. G. Harms, and W. L. Jenkins. 1989. Postpartum reproductive performance in the multiparous mare fed to obesity. Therio. 32(1):27-36.

Lamond, R. D. 1969. Sources of variation in reproductive performance in selected herds of beef cattle in north eastern Australia. Aust. Vet. J. 45:50.

Lawrence, M. L., R. A. Kane, P. A. Miller, A. Reece, and C. Hartman. 1986. Urea space determination and body composition in horses. J. Anim. Sci. 63(Suppl. 1):233.

Lawrence, L. M., J. DiPietro, K. Ewert, D. Parrett, L. Moser, and D. Powell. 1992. Changes in body weight and condition of gestating mares. Equine Vet. J. 12(6):355-358.

Loague, K. and R. E. Green. 1991. Statistical and graphical methods for evaluating solute transport models: Overviewa and application. Journal of Contaminant Hydrology. 7:51-73.

Lohman, T. G. 1971. Biological variation in body composition. J. Anim. Sci. 32:647-653.

Mangus, D. 1986. The Standard Horse Book. Page 296. Werner Co., Chicago, IL.

Martin-Rosset, W., and M. Vermorel. 1991. Maintenance energy requirement variations determined by indirect calorimetry and feeding trials in light horses. Equine Vet. J. 11:42-45.

Martin-Rosset, W., M. Vermorel, M. Doreau, J. L. Tisserand, and J. Andrieu. 1994. The French horse feed evaluation systems and recommended allowances for energy and protein. Livest. Prod. Sci. 40:37-56.

Martin-Rosset, W. 2000. Feeding standards for energy and protein for horses in France. Pp. 31-94 in Proc., 2000 Equine Nutr. Conf. for Feed Manufacturers, Kentucky Equine Research Inc., Versailles, KY.

Martin-Rossett, W. and M. Vermorel. 2004. Evaluation and expression of energy allowances and energy value of feeds in the UFC system for the performance horse. Pages 29-60 in Nutrition of the Performance Horse, V. Julliand and W. Martin-Rossett, eds. EAAP Publication No. 111. Netherlands: Wageningen Academic Publishers.

Mayer, D. G. and D. G. Butler. 1993. Statistical validation. Ecol. Model. 68:21-32.

Meyer, H. 1979. Ernährung des Pferdes. Pages 262 – 397 in Pferdezucht and Pferdefütterung. H. Lowe and H. Meyer, eds. Eugen Ulmer, Stuttgart.

Moe, P. W., H. F. Tyrrell, and W. P. Flatt. 1970. Partial efficiency of energy use for maintenance, lactation, body gain and gestation in the dairy cow. Pages 65-68 in Proc. Energy Metabolism of Farm Animals, 5. European Association for Animal Production, Juris Verlag, Zurich, Switzerland.

Morgan, K. 1998. Thermoneutral zone and critical temperatures of horses. J. Thermal Biol. 23(1):59-61.

Moulton, C. R. 1923. Age and chemical development in mammals. J. Biological Chem. 57:79-97.

Nedkvitne, J. J. 1976. Pages 91 – 129 in Forelesningar om fóring av hestar. Agric. Univ. Norway.

NRC. 1978. Nutrient Requirements of Horses. 4th ed., Natl. Acad. Sci., Washington, DC.

NRC. 1981. Effect of environment on nutrient requirements of domestic animals. Washington, DC: National Academy Press.

NRC. 1989. Nutrient Requirements of Horses, 5th rev. ed. Washington, DC: National Academy Press.

NRC. 2000. Nutrient Requirements of Beef Cattle. 7th ed., Natl. Acad. Press., Washington, DC.

NRC. 2001. Nutrient Requirements of Dairy Cattle. 7th ed., Natl. Acad. Press., Washington, DC.

NRC. 2007. Nutrient Requirements of Horses. 6th rev. ed. Natl. Acad. Press., Washington, DC.

Ottinger, M. A. 2010. Mechanisms of reproductive aging: conserved mechanisms and environmental factors. Ann. NY Acad. Sci. 1204 (1):73-81.

Pagan, J. D. 1997. Measuring the digestible energy content of horse feeds. Pages 51-52 in Proc. Equine Nutr. Conf., Lexington, KY.

Pagan, J. D., and H. F. Hintz. 1986. Equine energetics. I. relationship between body weight and energy requirements in horses. J. Anim. Sci. 63:816-822.

Pagan, J. D., P. Harris, T. Brewster-Barnes, S. E. Duren, and S. G. Jackson. 1998. Exercise affects digestibility and rate of passage of an all forage and mixed diets in Thoroughbred horses. J. Nutr. 128:2074s-2707s.

Polliott, G. E., and J. B. Kilkenny. 1976. A note on the use of condition scoring in commercial sheep flocks. Anim. Prod. 23:261.

Potter, J. T., J. L. Kreider, G. D. Potter, D. W. Forrest, and W. L. Jenkins. 1985. Embryo survival durgin early gestation in energy deprived mares. Pages 392-397 in Proc. 9th Eq. Nutr. and Physiol. Symp., East Lansing, MI.

Powell, D. M., L. M. Lawrence, D. F. Parrett, J. DiPietro, L. R. Moser, M. G. Fisher, and K. D. Bump. 1989. Body composition changes in broodmares. Pages 91-94 in Proc. 11th Eq. Nutr. Physiol. Symp., Stillwater, OK.

Prolo, P., M. L. Wong, and J. Licinio. 1998. Leptin. Int. J. Biochem. Cell. Biol. 30:1285-1290.

Randel, R. D. 1990. Nutrition and postpartum rebreeding in cattle. J. Anim. Sci. 68:853-862.

Rutter, L. M., and R. D. Randel. 1984. Postpartum nutrient intake and body condition: effect on pituitary function and onset of estrus in beef cattle. J. Anim. Sci. 58:265-274.

Schillo, K. K. 1992. Effects of dietary energy on control of luteinizing hormone secretion in cattle and sheep. J. Anim. Sci. 70(4):1271-1282.

Selk, G. E., R. P. Wettemann, K. S. Lusby, J. W. Oltjen, S. L. Mobley, R. J. Rasby, and J. C. Garmendia. 1988. Relationships among weight change, body condition and reproductive performance of range beef cows. J. Anim. Sci. 66:3153-3159.

Suagee, J. K., A. O. Burk, R. W. Quinn, E. D. Petersen, T. G. Hartsock, and L. W. Douglass. 2008. Effects of diet and weight gain on body condition scoring in thoroughbred geldings. Equine Vet. J. 28:156-166.

Tedeschi, L. O. 2002. Assessment of the Adequacy of Mathematical Models. Department of Animal Science. Cornell University, Ithaca, NY.

Tedeschi, L. O., S. Seo, D. G. Fox, and R. Ruiz. 2006. Accounting for energy and protein reserve changes in predicting diet-allowable milk production in cattle. J. Dairy Sci. 89:4795-4807.

Tolkamp, B. J., G. C. Emmans, and I. Kyriazakis. 2006. Body fatness affects feed intake of sheep at a given body weight. J. Anim. Sci. 84:1778-1789.

Van Niekerk, C. H. and J. S. Van Heerden. 1972. Nutrition and ovarian activity of mares early in the breeding season. J. S. Afr. Vet. Assoc. 43:351-360.

Vermorel, M., R. Jarrige, and W. Martin-Rosset. 1984. Metabolisme et besoins energetiques du cheval. Le systeme des UFC. 273-276. In: R. Jarrige et, W. Martin-Rosset (Editors). “Le Cheval” Reproduction – Selection – Alimentation – Exploitation. INRA Publications, Route de St Cyr, 78000 Versailles.

Vermorel, M. and W. Martin-Rosset. 1997. Concepts, scientific bases, structure and validation of the French horse net energy system (UFC). Livest. Prod. Sci. 47:261-275.

Weather Underground, Inc. 2011. Past weather information. http://www.wunderground.com.

Webb, S. P., G. D. Potter, J. W. Evans, G. W. Webb. 1990. Influence of body fat content on digestible energy requirements of exercising horses in temperate and hot environments. Equine Vet. J. 10(2):116-120.

Westervelt, R. G., J. R. Stouffer, H. F. Hintz, and H. F. Schryver. 1976. Estimating fatness in horses and ponies. J. Anim. Sci. 43:781-785.

Whitman, R. W. 1975. Weight change, body condition and beef cow reproduction. Ph.D. thesis. Colorado State University, Fort Collins.

Zeyner, A., and E. Kienzle. 2002. A method to estimate digestible energy in horse feed. J. Nutr. 132:1771S-1773S.

APPENDIX

Appendix Table 1. Body Condition Score (BCS) results per mare

Mare ID	Day	BCS			Mean BCS	BCS_a
		Judge 1	*Judge 2*	*Judge 3*		
GROUP 1						
15	**Initial**	**4**	**3**	**3**	**3.33**	**3.50**
	Week 1	4.25	4	3.5	3.92	4.00
	Week 2	3	3	3	3.00	3.00
	Week 3	3.5	4	4.5	4.00	4.00
	Final	4	3.5	4	3.83	4.00
	Targeted Final BCS					**4.50**
32	**Initial**	**4**	**3.75**	**3**	**3.58**	**3.50**
	Week 1	4.5	4.75	3.5	4.25	4.50
	Week 2	4	4.5	4.25	4.25	4.50
	Week 3	4.75	4.5	4.5	4.58	4.50
	Final	5	4.5	4.5	4.67	4.50
	Targeted Final BCS					**4.50**
35	**Initial**	**3.75**	**3**	**3**	**3.25**	**3.50**
	Week 1	4.5	4.25	4.5	4.42	4.50
	Week 2	4.5	4.5	4.5	4.50	4.50
	Week 3	4.75	4.5	5	4.75	5.00
	Final	5	5	5	5.00	5.00
	Targeted Final BCS					**4.50**
8	**Initial**	**4.25**	**3.5**	**3.5**	**3.75**	**4.00**
	Week 1	4.75	4.5	4.5	4.58	4.50
	Week 2	4	5	4.5	4.50	4.50
	Week 3	5	5.5	4.75	5.08	5.00
	Final	5.5	5	5	5.17	5.00
	Targeted Final BCS					**5.00**
24	**Initial**	**5.25**	**5**	**5**	**5.08**	**5.00**
	Week 1	4.75	4.75	5.5	5.00	5.00
	Week 2	5	5	6	5.33	5.50
	Week 3	5.5	5.5	5.75	5.58	5.50
	Final	6	5.5	6	5.83	6.00
	Targeted Final BCS					**6.00**

GROUP 2						
73	**Initial**	**5.5**	**5**	**4.5**	**5.00**	**5.00**
	Week 1	5	4.5	4.5	4.67	4.50
	Week 2	4	5	5	4.67	4.50
	Week 3	4	5	4.75	4.58	4.50
	Final	4.5	4.5	4.5	4.50	4.50
	Targeted Final BCS					**4.00**
11	**Initial**	**4.25**	**5**	**4.5**	**4.58**	**4.50**
	Week 1	4.75	4.75	4	4.50	4.50
	Week 2	4	4	3.5	3.83	4.00
	Week 3	4	4	4.5	4.17	4.00
	Final	4	3.5	3.5	3.67	3.50
	Targeted Final BCS					**3.50**
5	**Initial**	**5**	**5.5**	**5**	**5.17**	**5.00**
	Week 1	4.75	4.75	5	4.83	5.00
	Week 2	5	4.5	4.5	4.67	4.50
	Week 3	4.5	4.5	5	4.67	4.50
	Final	5	4.5	4.5	4.67	4.50
	Targeted Final BCS					**4.00**
48	**Initial**	**5**	**5**	**5**	**5.00**	**5.00**
	Week 1	5	5.5	5	5.17	5.00
	Week 2	4.5	5	5.5	5.00	5.00
	Week 3	5	5	5.5	5.17	5.00
	Final	4.5	4.5	5	4.67	4.50
	Targeted Final BCS					**4.00**
36	**Initial**	**5.5**	**4.5**	**5**	**5.00**	**5.00**
	Week 1	4.75	4.75	5	4.83	5.00
	Week 2	4.5	5.5	5	5.00	5.00
	Week 3	4.5	5	4.5	4.67	4.50
	Final	4.5	4	4.5	4.33	4.50
	Targeted Final BCS					**4.00**
GROUP 3						
112	**Initial**	**5.5**	**6**	**5**	**5.50**	**5.50**
	Week 1	5.5	5.25	5	5.25	5.50
	Week 2	5	5.5	6	5.50	5.50
	Week 3	6.5	5.5	6.5	6.17	6.00
	Final	6	5.5	6	5.83	6.00

	Targeted Final BCS					**6.50**
508	**Initial**	**5.5**	**6**	**5**	**5.50**	**5.50**
	Week 1	5.75	5.5	5.5	5.58	5.50
	Week 2	5	5.5	5.5	5.33	5.50
	Week 3	6.5	5.5	6	6.00	6.00
	Final	6	6	5.5	5.83	6.00
	Targeted Final BCS					**6.50**
137	**Initial**	**6**	**6**	**5.5**	**5.83**	**6.00**
	Week 1	6	5.75	5.5	5.75	6.00
	Week 2	5.75	6	7	6.25	6.50
	Week 3	6.5	6	7.25	6.58	6.50
	Final	6.5	6	7	6.50	6.50
	Targeted Final BCS					**7.00**
57	**Initial**	**6.5**	**6.75**	**6**	**6.42**	**6.50**
	Week 1	6.75	6.75	6	6.50	6.50
	Week 2	5.5	6.5	7.5	6.50	6.50
	Week 3	7	6.5	7.75	7.08	7.00
	Final	7.5	7	7.5	7.33	7.50
	Targeted Final BCS					**7.50**
63	**Initial**	**4.75**	**6**	**5**	**5.25**	**5.50**
	Week 1	5.75	4.75	5	5.17	5.00
	Week 2	5	5.5	5.25	5.25	5.50
	Week 3	5	5.5	5.5	5.33	5.50
	Final	5.5	6	6	5.83	6.00
	Targeted Final BCS					**6.50**
GROUP 4						
140	**Initial**	**7.25**	**7**	**7.25**	**7.17**	**7.00**
	Week 1	7	6	6.5	6.50	6.50
	Week 2	5.5	6.5	7	6.33	6.50
	Week 3	5	6.5	7	6.17	6.00
	Final	6	6	6.5	6.17	6.00
	Targeted Final BCS					**6.00**
106	**Initial**	**7**	**6.5**	**7**	**6.83**	**7.00**
	Week 1	6.5	6.5	6.25	6.42	6.50
	Week 2	5.5	5.75	6	5.75	6.00
	Week 3	6	5	6.25	5.75	6.00
	Final	6	5.5	6	5.83	6.00
	Targeted Final BCS					**6.00**

109	**Initial**	**7.25**	**7**	**6.5**	**6.92**	**7.00**
	Week 1	7	7	5.5	6.50	6.50
	Week 2	6	5.5	6.5	6.00	6.00
	Week 3	6	5.5	7	6.17	6.00
	Final	6	6	6.5	6.17	6.00
	Targeted Final BCS					**6.00**
510	**Initial**	**7.5**	**7**	**7**	**7.17**	**7.00**
	Week 1	7	7	5.5	6.50	6.50
	Week 2	6	6	6	6.00	6.00
	Week 3	6.25	6	6.25	6.17	6.00
	Final	6.5	6.5	6	6.33	6.50
	Targeted Final BCS					**6.00**
105	**Initial**	**7.5**	**7.5**	**6.5**	**7.17**	**7.00**
	Week 1	6	6.75	6.5	6.42	6.50
	Week 2	5.5	5.5	6	5.67	5.50
	Week 3	5.5	5.5	7	6.00	6.00
	Final	5.5	6.5	6.5	6.17	6.00
	Targeted Final BCS					**6.00**

[a] Mean BCS rounded to nearest 0.5 BCS

Appendix Table 2. Body fat (%BF) results per mare

Mare ID	Day	%BF	
		Rump Fat (cm)	Extractable Fat (%)
GROUP 1			
15	**Initial**	**0.24**	**9.77**
	Week 1	0.26	9.86
	Week 2	0.34	10.24
	Week 3	0.34	10.24
	Final	0.32	10.14
	Targeted Final %BF		**11.78**
32	**Initial**	**0.20**	**9.58**
	Week 1	0.30	10.05
	Week 2	0.28	9.96
	Week 3	0.30	10.05
	Final	0.32	10.14
	Targeted Final %BF		**11.78**
35	**Initial**	**0.28**	**9.96**
	Week 1	0.30	10.05
	Week 2	0.32	10.14
	Week 3	0.36	10.33
	Final	0.42	10.61
	Targeted Final %BF		**11.78**
8	**Initial**	**0.14**	**9.30**
	Week 1	0.28	9.96
	Week 2	0.30	10.05
	Week 3	0.30	10.05
	Final	0.32	10.14
	Targeted Final %BF		**12.31**
24	**Initial**	**0.34**	**10.24**
	Week 1	0.36	10.33
	Week 2	0.46	10.80
	Week 3	0.50	10.99
	Final	0.62	11.55
	Targeted Final %BF		**13.38**

GROUP 2			
73	**Initial**	**0.22**	**9.67**
	Week 1	0.18	9.49
	Week 2	0.20	9.58
	Week 3	0.16	9.39
	Final	0.16	9.39
	Targeted Final %BF		**8.10**
11	**Initial**	**0.24**	**9.77**
	Week 1	0.18	9.49
	Week 2	0.20	9.58
	Week 3	0.16	9.39
	Final	0.08	9.02
	Targeted Final %BF		**8.82**
5	**Initial**	**0.66**	**11.74**
	Week 1	0.62	11.55
	Week 2	0.62	11.55
	Week 3	0.56	11.27
	Final	0.56	11.27
	Targeted Final %BF		**11.25**
48	**Initial**	**0.42**	**10.61**
	Week 1	0.36	10.33
	Week 2	0.36	10.33
	Week 3	0.32	10.14
	Final	0.32	10.14
	Targeted Final %BF		**9.98**
36	**Initial**	**0.42**	**10.61**
	Week 1	0.32	10.14
	Week 2	0.28	9.96
	Week 3	0.16	9.39
	Final	0.16	9.39
	Targeted Final %BF		**9.98**
GROUP 3			
112	**Initial**	**0.60**	**11.46**

	Week 1	0.6	11.46
	Week 2	0.62	11.55
	Week 3	0.64	11.65
	Final	0.68	11.84
	Targeted Final %BF		**13.91**
508	**Initial**	**0.92**	**12.96**
	Week 1	0.92	12.96
	Week 2	0.94	13.06
	Week 3	0.96	13.15
	Final	0.92	12.96
	Targeted Final %BF		**13.91**
137	**Initial**	**0.50**	**10.99**
	Week 1	0.50	10.99
	Week 2	0.56	11.27
	Week 3	0.66	11.74
	Final	0.72	12.02
	Targeted Final %BF		**14.44**
57	**Initial**	**0.64**	**11.65**
	Week 1	0.64	11.65
	Week 2	0.64	11.65
	Week 3	0.62	11.55
	Final	0.72	12.02
	Targeted Final %BF		**14.98**
63	**Initial**	**0.46**	**10.80**
	Week 1	0.47	10.85
	Week 2	0.52	11.08
	Week 3	0.64	11.65
	Final	0.76	12.21
	Targeted Final %BF		**13.91**
GROUP 4			
140	**Initial**	**1.08**	**13.72**
	Week 1	0.90	12.87
	Week 2	0.90	12.87
	Week 3	0.90	12.87

	Final	0.84	12.59
	Targeted Final %BF		**13.38**
106	**Initial**	**0.62**	**11.55**
	Week 1	0.56	11.27
	Week 2	0.54	11.18
	Week 3	0.54	11.18
	Final	0.54	11.18
	Targeted Final %BF		**9.73**
109	**Initial**	**0.86**	**12.68**
	Week 1	0.84	12.59
	Week 2	0.84	12.59
	Week 3	0.80	12.40
	Final	0.78	12.31
	Targeted Final %BF		**11.99**
510	**Initial**	**1.18**	**14.19**
	Week 1	1.10	13.81
	Week 2	1.06	13.62
	Week 3	1.08	13.72
	Final	1.06	13.62
	Targeted Final %BF		**13.38**
105	**Initial**	**0.58**	**11.37**
	Week 1	0.54	11.18
	Week 2	0.46	10.80
	Week 3	0.46	10.80
	Final	0.38	10.43
	Targeted Final %BF		**9.35**

Appendix Table 3. Body weight (BW) results per mare

Mare ID	Day	Full BW		Empty BW	
		lbs	*kg*	*lbs*	*kg*
GROUP 1					
15	**Initial**	**975.00**	**442.25**	**796.54**	**361.30**
	Week 1	975	442.25	796.54	361.30
	Week 2	970	439.98	792.45	359.45
	Week 3	975	442.25	796.54	361.30
	Final	985	446.79	804.71	365.01
	Targeted Final BW	**1015.2**	**460.49**	**829.38**	**376.20**
32	**Initial**	**935.00**	**424.11**	**763.86**	**346.48**
	Week 1	960	435.45	784.28	355.74
	Week 2	945	428.64	772.03	350.19
	Week 3	950	430.91	776.11	352.04
	Final	965	437.72	788.37	357.60
	Targeted Final BW	**973.55**	**441.59**	**795.36**	**360.77**
35	**Initial**	**860.00**	**390.09**	**702.59**	**318.69**
	Week 1	900	408.23	735.26	333.51
	Week 2	905	410.50	739.35	335.36
	Week 3	905	410.50	739.35	335.36
	Final	920	417.30	751.60	340.92
	Targeted Final BW	**895.46**	**406.17**	**731.55**	**331.83**
8	**Initial**	**940.00**	**426.38**	**767.94**	**348.33**
	Week 1	965	437.72	788.37	357.60
	Week 2	975	442.25	796.54	361.30
	Week 3	975	442.25	796.54	361.30
	Final	995	451.32	812.88	368.71
	Targeted Final BW	**977.97**	**443.60**	**798.96**	**362.40**
24	**Initial**	**885.00**	**401.43**	**723.01**	**327.95**
	Week 1	930	421.84	759.77	344.63
	Week 2	935	424.11	763.86	346.48
	Week 3	955	433.18	780.20	353.89
	Final	965	437.72	788.37	357.60
	Targeted Final BW	**919.36**	**417.02**	**751.08**	**340.69**

GROUP 2					
73	**Initial**	**1075.00**	**487.61**	**878.23**	**398.36**
	Week 1	1035	469.47	845.55	383.54
	Week 2	1035	469.47	845.55	383.54
	Week 3	1030	467.20	841.47	381.68
	Final	1025	464.93	837.38	379.83
	Targeted Final BW	**1033.26**	**468.68**	**844.13**	**382.89**
11	**Initial**	**970.00**	**439.98**	**792.45**	**359.45**
	Week 1	950	430.91	776.11	352.04
	Week 2	925	419.57	755.69	342.77
	Week 3	915	415.04	747.52	339.07
	Final	900	408.23	735.26	333.51
	Targeted Final BW	**931.59**	**422.56**	**761.07**	**345.22**
5	**Initial**	**830.00**	**376.48**	**678.08**	**307.57**
	Week 1	825	374.21	673.99	305.72
	Week 2	815	369.68	665.82	302.01
	Week 3	815	369.68	665.82	302.01
	Final	805	365.14	657.65	298.31
	Targeted Final BW	**797.77**	**361.86**	**651.75**	**295.63**
48	**Initial**	**925.00**	**419.57**	**755.69**	**342.77**
	Week 1	925	419.57	755.69	342.77
	Week 2	910	412.77	743.43	337.22
	Week 3	910	412.77	743.43	337.22
	Final	900	408.23	735.26	333.51
	Targeted Final BW	**889.09**	**403.28**	**726.35**	**329.47**
36	**Initial**	**920.00**	**417.30**	**751.60**	**340.92**
	Week 1	920	417.30	751.60	340.92
	Week 2	920	417.30	751.60	340.92
	Week 3	905	410.50	739.35	335.36
	Final	900	408.23	735.26	333.51
	Targeted Final BW	**884.28**	**401.10**	**722.42**	**327.68**
GROUP 3					
112	**Initial**	**1065.00**	**483.08**	**870.07**	**394.66**

	Week 1	1085	492.15	886.40	402.07
	Week 2	1085	492.15	886.40	402.07
	Week 3	1090	494.42	890.49	403.92
	Final	1100	498.95	898.66	407.62
	Targeted Final BW	**1105.56**	**501.48**	**903.21**	**409.69**
508	**Initial**	**1180.00**	**535.24**	**964.01**	**437.27**
	Week 1	1200	544.31	980.35	444.68
	Week 2	1205	546.58	984.44	446.53
	Week 3	1215	551.11	992.61	450.24
	Final	1200	544.31	980.35	444.68
	Targeted Final BW	**1224.94**	**555.62**	**1000.73**	**453.92**
137	**Initial**	**1000.00**	**453.59**	**816.96**	**370.57**
	Week 1	1045	474.00	853.72	387.24
	Week 2	1045	474.00	853.72	387.24
	Week 3	1050	476.27	857.81	389.10
	Final	1060	480.81	865.98	392.80
	Targeted Final BW	**1037.38**	**470.55**	**847.49**	**384.42**
57	**Initial**	**1125.00**	**510.29**	**919.08**	**416.89**
	Week 1	1135	514.83	927.25	420.59
	Week 2	1145	519.36	935.42	424.30
	Week 3	1165	528.44	951.76	431.71
	Final	1170	530.70	955.84	433.56
	Targeted Final BW	**1166.28**	**529.01**	**952.80**	**432.18**
63	**Initial**	**830.00**	**376.48**	**678.08**	**307.57**
	Week 1	855	387.82	698.50	316.83
	Week 2	865	392.36	706.67	320.54
	Week 3	875	396.89	714.84	324.25
	Final	900	408.23	735.26	333.51
	Targeted Final BW	**861.61**	**390.82**	**704.40**	**319.51**
GROUP 4					
140	**Initial**	**1170.00**	**530.70**	**955.84**	**433.56**
	Week 1	1150.00	521.63	939.50	426.15
	Week 2	1150.00	521.63	939.50	426.15
	Week 3	1135.00	514.83	927.25	420.59

	Final	1140.00	517.10	931.33	422.45
	Targeted Final BW	**1140.00**	**517.10**	**931.33**	**422.45**
106	**Initial**	**1105.00**	**501.22**	**902.74**	**409.48**
	Week 1	1105.00	501.22	902.74	409.48
	Week 2	1085	492.15	886.40	402.07
	Week 3	1060	480.81	865.98	392.80
	Final	1060	480.81	865.98	392.80
	Targeted Final BW	**1065.19**	**483.16**	**870.22**	**394.72**
109	**Initial**	**1015.00**	**460.40**	**829.21**	**376.13**
	Week 1	980	444.52	800.62	363.16
	Week 2	975	442.25	796.54	361.30
	Week 3	980	444.52	800.62	363.16
	Final	970	439.98	792.45	359.45
	Targeted Final BW	**978.43**	**443.81**	**799.34**	**362.57**
510	**Initial**	**1155.00**	**523.90**	**943.59**	**428.00**
	Week 1	1140	517.10	931.33	422.45
	Week 2	1135	514.83	927.25	420.59
	Week 3	1130	512.56	923.16	418.74
	Final	1130	512.56	923.16	418.74
	Targeted Final BW	**1113.39**	**505.02**	**909.59**	**412.58**
105	**Initial**	**1220.00**	**553.38**	**996.69**	**452.09**
	Week 1	1185	537.51	968.10	439.12
	Week 2	1180	535.24	964.01	437.27
	Week 3	1175	532.97	959.93	435.42
	Final	1090	494.42	890.49	403.92
	Targeted Final BW	**1176.04**	**533.44**	**960.78**	**435.80**

NOMENCLATURE

ADF	Acid detergent fiber
aEBW	Adjusted empty body weight
BA	Body ash
BCS	Body condition Score
BF	Body fat
BP	Body protein
BW	Body weight
BWa	Body water
CD	Coefficient of determination
CP	Crude protein
DE	Digestible energy
EBF	Empty body fat
EBW	Empty body weight
FBW	Full body weight
FFM	Fat free matter
GE	Gross energy
GnRH	Gonadotropin-releasing hormone
HE	Heat energy
LCT	Lower critical temperature
LH	Luteinizing hormone
LHRH	Luteinizing hormone-releasing hormone
MAE	Mean absolute error
MB	Mean bias
ME	Metabolizable energy
MEF	Model efficiency
MSEP	Mean standard error of prediction
NDF	Neutral detergent fiber
NE	Net energy
NE_L	Net energy for lactation
NE_M	Net energy for maintenance
NE_R	Net energy for reproduction
R^2	coefficient of correlation
RE	Recoverable energy
SBW	Shrunk body weight
TDN	Total digestible nutrients
TE	Total energy
TF	Total fat
TNZ	Thermo-neutral zone
TP	Total protein
TRH	Thyroid-releasing hormone
UCT	Upper critical temeprature

WAF	Weight adjustment factor
ΔTE	Change in total energy

VITA

Name:	Viviana Victoria Cordero
Address:	Texas A&M University, Animal Science Department, 2471 TAMU, College Station, TX
Email Address:	Shelsea101@neo.tamu.edu
Education:	B.S., Animal Science, Texas A&M University, 2008 M.S., Animal Science, Texas A&M University, 2011