MAINTENANCE ENERGY REQUIREMENTS, RUMINAL TEMPERATURE, WALKING ACTIVITY, AND PLASMA CONCENTRATIONS OF IGF-I, THYROXINE, AND TRIIODOTHYRONINE OF GESTATING BEEF COWS

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TIMOTHY A. PYE

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Thesis Approved:

Dr. Robert P. Wettemann

Thesis Adviser

Dr. Leon J. Spicer

Dr. Gerald W. Horn

Dr. Mark E. Payton

Dean of the Graduate College

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CHAPTER I

INTRODUCTION

Profitability of cattle production could be increased by reducing maintenance energy requirements and feed costs for cows. Since feed is the greatest cost in cattle production, any improvement in efficiency could improve profitability. Maintenance energy requirement (MR) of cows accounts for approximately 50% of the total energy required for beef production from birth to slaughter (Ferrell and Jenkins, 1984) and is moderately heritable (Benyshek and Marlowe, 1973; Carstens et al., 1989; Hotovy et al., 1991). It is not practical to feed cows individually to estimate MR and it does not simulate normal management conditions. Metabolic hormones regulate biological processes and concentrations may be related to some of the variation in MR. Energy homeostasis and body temperature are influenced by thyroid hormones. Plasma concentrations of thyroxine and IGF-I are related to nutrient intake in cattle (Richards et al., 1995; Ciccioli et al., 2003; Lents et al., 2005). Technologies, such as ruminal boluses that measure body temperature, allow real time data collection without an increase in animal handling. Body temperature is influenced by physiological functions. Body temperature decreases prior to parturition in cattle (Wrenn et al., 1958; Aoki et al., 2005;

Prado-Cooper et al., 2011) and sheep (Ewbank, 1969), and body temperature is increased at estrus (Wrenn et al., 1958; Clapper et al., 1990; Prado-Cooper et al., 2011). Sickness increases body temperature (Prado-Cooper et al., 2010; Rose-Dye et al., 2010). Maintenance energy requirements of mice (Kgwatalala et al., 2004) and cattle (Derno et al., 2005) are related to body temperature.

A practical method to evaluate MR of cows has not been developed. Use of technology such as radioimmunoassay of hormones or ruminal temperature boluses may allow determination of specific biomarkers for efficiency of energy use by cows. The long-term goal of this research is to identify biomarkers that can be used to identify animals that are more efficient and require less energy for maintenance of BW. Identification of cows that are energetically more efficient could improve the profitability of beef production.

CHAPTER II

REVIEW OF LITERATURE

FEED EFFICIENCY OF BEEF COWS

Philosophers, such as Antoine-Laurnet Lavoisier (1743-1794), have long believed that life is primarily a combustion process (Johnson et al., 2003). Many new ideas and devices were invented to determine the use and combustion of feedstuffs. Metabolisms of proteins, fats, and carbohydrates are different, so Baron Justus Von Liebig (1803-1873) decided composition of feedstuffs should be partitioned (Johnson et al., 2003). Lavoisier's ice calorimeter was used to determine calories by measuring the amount of water collected from the heat from the test material. Pierre Eugene Berthelot's development of the adiabatic bomb calorimeter allowed for reproducible and accurate assessments of the chemical energy of an organic substance (Armsby, 1903; Johnson et al., 2003). Max von Pettenkofer (1818-1901) developed the open-circuit respiration apparatus to determine the composition of expelled gases (Armsby, 1903). In 1965, the Brouwer equation used oxygen consumption, respiration, urinary nitrogen, and methane production to calculate heat production, which led to the end of the open-circuit respiration apparatus (Johnson et al., 2003). Much of the chemical energy of feed is loss by the body and therefore metabolizable energy is defined as the gross energy of feed minus the gross energy of excreta (Armsby, 1917) or as heat production plus retained energy since metabolizable energy can appear in only those two forms (NRC, 1996).

Maintenance energy (MR) is defined as the minimum energy required to maintain life (Armsby, 1917) or as the amount of feed energy intake that will result in no net loss or gain of energy from tissues of the animal's body (NRC, 1996). Approximately 50 % of the feed consumed by cattle is required for maintenance (Armsby, 1917). According to Ferrell and Jenkins (1987) 70 % of the total metabolizable energy intake is required for maintenance by mature, producing cows and approximately 90 % by breeding bulls (NRC, 1996). Lofgreen and Garrett (1968) separated maintenance requirements from the requirements for body weight gain and expressed a net energy value for the two functions. The fasting animal has a heat production proportional to metabolic body weight ($BW^{0.75}$), which is then used in an equation to determine net energy maintenance (Lofgreen and Garrett, 1968).

Measurement of Efficiency

The estimate for MR can be determined by such methods as comparative slaughter, feeding trials, and calorimetric methods. Comparative slaughter methods were first used by Lawes and Gilbert (1861) to demonstrate the use of carbohydrates as a major source of energy for fat synthesis (NRC, 1996). Lofgreen and Garrett (1968) used comparative slaughter methods to propose the California Net Energy System, which was adopted by the NRC. Comparative slaughter measures metabolizable energy and retained energy to determine heat energy. When retained energy is equal to zero the metabolizable energy intake provides an estimate for MR (NRC, 1996).

A large group of animals are maintained under similar conditions in feeding trials. A known amount of feed with a known amount of energy is used to maintain the animals BW. The quantity of feed is adjusted until the animal is in a state of BW equilibrium. Thus a known amount of energy, to maintain an animal's weight for an extended period of time, can be determined. In practice it is easier to use a regression model to determine the actual energy required for BW equilibrium, because it is easier to allow animals to lose or gain weight than maintain body weight (McDonald et al., 2002). A regression equation with feed intake and body weight can then be used to determine MR.

Lavoisier was one of the first to use calorimetric methods to determine the chemical energy of an organic substance (Armsby, 1917). Calorimetry is used to measure the fasting heat production, and with the measurement of urinary energy lost, allows for fasting metabolism to be determined. Fasting metabolism is equal to the net energy value for maintenance. Calorimetry methods are not feasible and are not very easily adjusted to practical feeding scenarios (NRC, 1996).

Residual Feed Intake

Animals with the same BW and level of production require different amounts of feed (Byerly, 1941). Koch et al. (1963) was the first to conceptualize the idea of residual feed intake (RFI). Residual feed intake measures the variation in dry matter intake and efficiency, and uses the residual determined by comparing expected feed intake to actual feed intake at a certain production level. Production is independent of RFI, which suggest that it may show variation in basic metabolic processes (Herd and Arthur, 2009). The residual is then used to classify cattle as high efficiency (negative RFI) or low efficiency (positive RFI). Heifers that are more efficient as weanlings are more efficient as cows (Herd et al., 2003). Variations in feed efficiency can be caused by variations in feed intake, feed digestion, metabolism, activity, and thermoregulation (Herd and Arthur, 2009). Protein turnover, tissue metabolism, and stress accounted for approximately 37% of the variation in RFI (Herd and Arthur, 2009). Residual feed intake is positively correlated with gain in empty body fat (Herd et al., 2003; Basarab et al., 2003), carcass marbling, metabolizable energy intake, retained energy, and heat production (Basarab et al., 2003). Negative RFI animals, in a feedlot scenario, have increased DM digestibility (Richardson et al., 1996; Nkrumah et al., 2006), which may result in decreased methane production (Nkrumah et al., 2006). Adenosine triphosphate (ATP) is used as energy in the body. Mitochondria produce the majority of cellular ATP, but negative and positive RFI steers have similar ATP production (Kolath et al., 2006). Kolath et al. (2006) also determined that mitochondrial polymorphisms are not related to RFI in Angus steers. Many mechanisms are associated with RFI and further research is needed to determine the mechanisms responsible for variation in RFI. Physiological information coupled with molecular genetic information will become the basis for commercial identification of more efficient cattle (Herd and Arthur, 2009).

Factors Effecting Efficiency

Several factors such as breed, sex, age, physiological state, and season affect MR of cows. Blaxter and Wainmann (1966) found that Ayrshire steers had 20% greater fasting heat production (FHP) than Angus type cattle, when based on metabolic body weight. Holstein steers require more feed than Hereford steers to maintain body weight (Garrett, 1971). Simmental heifers and bulls require 19% more feed than Hereford heifers and bulls to maintain energy stasis (Ferrell and Jenkins, 1985a). Cattle that have been selected for beef production have a lesser MR than cattle that have been selected for milk production (Blaxter and Wainmann, 1966; Garrett, 1971). Cow breeds that produce large amounts of milk (Jersey cross and Simmental cross) have greater maintenance requirements than breeds (Angus x Hereford cross and Charolais cross) that produce less milk (Ferrell and Jenkins, 1984). Cow types that were similar in milk production but differed in size had similar MR (Ferrell and Jenkins, 1984). When MR is determined by metabolic body weight, cow size does not cause variation (Klosterman et al., 1968; Ferrell and Jenkins, 1984).

Fasting heat production (FHP) did not differ between steers and heifers (Garret, 1980). Ferrell and Jenkins (1985a) found that FHP was similar for Hereford heifers and bulls, while Simmental bulls had a greater FHP than Simmental heifers. Bulls have a 15% greater MR compared with heifers and steers (ARC, 1980).

It is generally considered that MR declines with age of cattle and sheep when measured per unit of size (Blaxter, 1962; Graham et al., 1974). Graham et al. (1974) determined that MR decreases 8% a year in sheep from birth to greater than two years of age. When initial MR was determined at 6 years of age, it was found that MR decreased 3% a year (Corbett et al., 1985; CSIRO, 1990). Age (15-81 wk) did not influence MR of steers (Blaxter et al., 1966). When beef heifers were studied from 275 to 475 kg, there was a 14% increase in metabolizable energy per MBW (Tyrrell and Reynolds, 1988).

Total heat production increases during gestation (Brody, 1945), however a direct increase in maintenance requirements does not occur (Ferrell et al., 1976). Lactating Hereford cows have a 30% greater MR than non-lactating Hereford cows (Neville and McCullough, 1969) and NRC (1996) determined that lactating cows have 20% greater MR than non-lactating cows.

Christopherson et al. (1979) and Webster et al. (1982) found decreased MR for cattle and bison during the fall (Christopherson et al., 1979), when compared with winter and spring. Fasting heat production of Hereford steers was approximately 10% less in the fall compared with the summer (Birkelo et al., 1989). Laurenz et al. (1991) noted that Angus and Simmental cattle have greater energy requirements to maintain weight in the summer compared with winter, potentially due to the fact that empty body fat increased in the summer.

METABOLIC HORMONES AND MAINTENANCE REQUIREMENTS OF COWS

Metabolic hormones may influence MR since hormones are involved in regulating appetite and metabolism. Greater plasma concentrations of leptin have been related to decreased intake (Foster and Nagatani, 1999), while greater leptin has also been associated with increased feed intake (Ciccioli et al., 2003). Dietary energy and protein intake influence plasma concentrations of insulin, insulin like growth factor-I (IGF-I), and thyroxine (Hayden et al., 1993; Ciccioli et al., 2003; Lents et al., 2005). Increased plasma concentrations of growth hormone are associated with a negative energy balance in cattle (Richards et al., 1991; Keisler and Lucy, 1996)

Thyroid Hormones

Thyroid hormones, such as thyroxine (T_4) and triiodothyronine (T_3), influence metabolic processes in most tissues. Thyroid hormones mediate metabolism of carbohydrates, lipids, and proteins. Thyroxine and T_3 increase metabolic rate and therefore reduce body weight due to protein breakdown or the loss of lean body mass (Moreno et al., 2008). Plasma concentrations of T_4 and T_3 are related to ambient temperature (Yousef et al., 1967; Pratt and Wettemann, 1986). Differences in residual feed intake are not related to plasma thyroxine and free triiodothyronine in cattle (Kelly et al. 2010). Thyroxine did not influence average daily gain, feed intake, or carcass composition of ram lambs. When T_4 and growth hormone (GH) were given alone or in combination, T_4 negated the stimulatory effect of GH on gain of carcass protein and muscle in ram lambs (Rosemberg et al., 1989). Muir and Wien (1983) found that T_4 reduced ADG and carcass protein in lambs. Type 2 iodothyronine deiodinase (D2) converts T_4 to T_3 in muscle tissue. In murine muscle tissue, D2 mRNA differs between fast and slow twitch muscle and increases during hypothyroidism, potentially allowing for greater T_3 action in muscle tissue (Marsili et al., 2010). Type 3 iodothyronine deiodinase, an inactivating enzyme, regulates concentrations of active T_4 and T_3 through inner ring deiodination (Ng et al., 2010; Dentice and Salvatore, 2011). Administration of T_3 increased food consumption in rats (Oppenheimer et al., 1991). Feed intake in cattle (Richards et al., 1995; Ciccioli et al., 2003) and sheep (Dukes and Swenson, 1970; Abecia et al., 2001) is positively associated with plasma concentrations of T_4. Ngongoni et al. (1987) determined that exogenous increases in T_4 increased gut motility and rumen outflow. Increased thyroxine concentrations in sheep increase wool production (Donald et al., 1994) and local changes in hypothalamic T_3 and T_4 appear to control photoperiod induced changes in reproduction (Bechtold and Loudon, 2007; Smith and Clarke, 2010). Consumption of thyroxine increases milk production in dairy cattle (Graham, 1934), and treatment with T_4 increased milk yield and milk protein of cows (Davis et. al, 1988) and ewes (Singh et al., 1956). However, dairy heifers genetically selected for greater milk yields, had lesser concentrations of thyroxine during gestation compared with heifers chosen to produce less milk (Bitman et al., 1984) and multiparous cows produced more milk and had greater T_3 and T_4 concentrations compared with primiparous cows (Meikle et al., 2004).

Thyroid Binding Protein

Thyroid binding globulin or thyroxine binding globulin (TBG) is the major binding protein for T_4 and T_3 (Snyder et al., 1976). Thyroxine binding globulin is 2 times greater in pregnant women compared with non-pregnant women (Glinoer, 1997). Less than 1 % of thyroid hormones in the body are unbound. Thyroid binding proteins may be present to assure that every tissue in the body is exposed to a uniform concentration of thyroid hormones because thyroid hormones bind to cells in the first deficient tissue contacted (Mendel et al., 1987). Affinities of thyroid binding globulin differs among breeds of swine (Nonneman et al., 2004). Thus, TBG influences the availability of thyroid hormones to cells.

Insulin-like Growth Factor-I Function

Insulin-like growth hormone I (IGF-I), also known as somatomedin C, is primarily produced by the liver in response to secretion of growth hormone. Insulin-like growth factor I may be useful to select efficient cattle since it is highly heritable (Davis and Simmen, 1997.) Increased nutrient intake increases concentrations of IGF-I in plasma of cattle (Houseknecht et al., 1988; Lents et al., 2005; Brito et al., 2007). Concentrations of IGF-I are positively correlated with growth rate in bulls (Lund-Larsen, 1977) and sheep (Olsen et al., 1981). Skottner et al. (1987) found that exogenous IGF-I increased weight of rats. Skeletal protein synthesis is increased in response to IGF-I production in ruminants (Lobley, 1992). Angus cattle with greater serum concentrations of IGF-I have greater BW and greater feed conversion efficiency compared with cattle with less IGF-I (Bishop et al., 1989). Cattle that have been selected for negative RFI (efficient) have decreased plasma concentration of IGF-I and there is a moderate positive correlation between RFI and IGF-I (Moore et al., 2005). There is a positive correlation in Angus bulls between RFI and IGF-I and the correlation is negative in Angus heifers (Lancaster et al., 2008). Serum concentrations of IGF-I are correlated with animal weight, and may not be predictable of growth rate or rate of gain (Davis and Simmen, 2006).

Insulin-like Growth Factor Binding Protein

Currently there are six insulin like growth factor binding proteins. These proteins have a higher affinity for IGF than the affinity of receptors and therefore regulate IGF availability to cells (Jones and Clemmons, 1995). Insulin like growth factor binding protein 3 (IGFBP-3) binds 70-90% of all IGF-I (Yamada et al., 2010). Yamada et al. (2010) concluded that IGFBP-3 knockout mice were heavier and had a lower resting metabolic weight, and decreased feed intake. Insulin-like growth factor binding protein 3 may act independently of IGF by binding to cell surface molecules unrelated to IGF and inhibits the growth of breast cancer epithelial cells (Oh et al., 1993). The IGFBP's may effect the ability of IGF-I to influence MR.

FACTORS EFFECTING BODY TEMPERATURE

Body temperature can be increased by many factors and the most important factor is ambient temperature above the thermoneutral zone of animals. An increase in relative humidity increases the effect of greater ambient temperature, therefore increasing rectal temperature (Arrillaga et al., 1952). Body temperature decreases prior to parturition in cattle (Wrenn et al., 1958; Aoki et al., 2005). Ewbank (1969) noticed similar decreases in body temperature of sheep prior to parturition. Rectal temperature of swine increase prior to and after parturition (Hendrix et al., 1978). Lammoglia et al. (1997) observed that cows carrying bulls had greater body temperature than cows carrying heifer calves. Estrus increases body temperature (Wrenn et al., 1958; Clapper et al., 1990). Rectal temperature increases due to tall fescue toxicity in Holstein calves (Hemken et al., 1981) and sheep (Aldrich et al., 1993). Prado-Cooper et al. (2009) and Rose-Dye et al. (2010) noted an increase in ruminal temperature due to sickness. Maintenance energy requirements are related to body temperature of mice selected for high or low heat loss (Kgwatalala and Nielson, 2004). Derno et al. (2005) suggested that body temperature could be used to determine MR in Hereford steers.

Ruminal Temperature

Ruminal temperature is correlated with rectal temperature (Rose-Dye et al., 2010). Ruminal temperature may be greater than rectal and tympanic temperatures (Prendiville et al., 2002). Water consumption decreases ruminal temperature for several hours depending on the quantity and temperature of water that is consumed (Brod et al., 1982; Bewley et al., 2008; Boehmer et al., 2009). Cattle exposed to *Mannheimia haemolytica* had an increase in ruminal temperature of approximately 1°C (Rose-Dye et al., 2010) and about a 2 °C increase in rectal temperature (Burciaga-Robles et al., 2010a). Ruminal boluses can be used in the cattle industry to determine estrus or disease.

CHAPTER III

MAINTENANCE ENERGY REQUIREMENTS, RUMINAL TEMPERATURE, WALKING ACTIVITY, AND PLASMA CONCENTRATIONS OF IGF-I, THYROXINE, AND TRIIODOTHYRONINE OF GESTATING BEEF COWS

ABSTRACT: Three experiments with spring calving, Angus cows (Exp. 1, n = 40; Exp. 2, n = 32; Exp. 3, n = 32) were conducted to determine the effects of maintenance energy requirement (MR) on plasma concentrations of insulin-like growth factor I, thyroxine (T_4), and triiodothyronine (T_3), walking activity, and ruminal temperature (RuT). Cows (4 - 7 yr; 5 - 7 mo gestation) with BW of 553 ± 5.9 kg, 556 ± 5.9 kg, 539 ± 8.0 kg for Exp. 1, 2, and 3, respectively, were individually fed a complete diet. Cows were initially fed a diet calculated to supply MR (Model 1, NRC 1996). Body weight was maintained for 21, 31, and 36 d for Exp. 1, 2, and 3, respectively. Blood samples were collected before and after consumption of feed on 2 d when cows consumed MR (gestation) and when cows had ad libitum prairie grass (lactation) (Exp. 1 and 2). Ruminal temperature was recorded hourly, using ruminal boluses (Smart Stock, LLC), for 4 consecutive days when cows consumed MR and when cows had ad libitum roughage (Exp. 2). Walking activity was recorded for 24 h using pedometers (Omron Healthcare, Inc.; Exp. 3). Cows were classified based on MR as low (> 0.5 SD less than mean, LMR), moderate (± 0.5 SD of the mean, MMR) or high (> 0.5 SD greater than mean, HMR). Average MR were 80.7 (SD = 4.84), 94.4 (SD = 8.00), and 95.5 (SD = 7.10) Kcal•kg$^{-0.75}$•day^{-1} for Exp. 1, 2, and 3, respectively. The differences between the least efficient and most efficient cow were 33, 32, and 35% for Exp. 1, 2, and 3, respectively. When cows had ad libitum prairie grass, LMR had greater concentrations of T_4 compared with HMR ($P = 0.05$) at1 h postprandial in Exp. 1. Ruminal temperature during maintenance and during ad libitum roughage was not influenced by MR. In Exp. 2 when cows consumed MR and were exposed to cooler temperatures (-5 °C), LMR cows had greater plasma T_4 ($P \leq 0.03$) compared with MMR and HMR. When exposed to warmer temperatures (15 °C), HMR cows had greater plasma T_3 compared with LMR and MMR ($P \leq 0.05$). During early lactation MMR had greater concentrations of T_4 compared with HMR cows ($P = 0.05$). When cows had ad libitum roughage during early lactation, HMR had greater ($P = 0.05$) plasma concentrations of IGF-I compared with LMR cows, and HMR had greater ($P = 0.04$) concentrations of IGF-I compared with LMR cows 1 h postprandial. Walking activity was not related to the amount of energy needed to maintain BW. Thyroxine, T_3, and IGF-I may have the potential to be biomarkers for MR. Identification of cows with lower MR could improve the profitability of beef production.

Keywords: beef cows, IGF-I, rumen temperature, thyroxine, triiodothyronine

INTRODUCTION

Profitability of cattle production can be increased by reducing maintenance energy requirements and feed costs. Maintenance energy requirement (MR) of cows accounts for approximately 50% of the total energy required for beef production (Ferrell and Jenkins, 1984) and is moderately heritable ($h^2 = 0.45 – 0.52$; Benyshek and Marlowe, 1973; Carstens et al., 1989; Hotovy et al., 1991).

Metabolic hormones regulate biological processes and may influence MR. Energy homeostasis is influenced by thyroid hormones (Muir and Wien, 1983; Moreno et al., 2008) and ambient temperature alters thyroid function (Yousef et al., 1967; Pratt and Wettemann, 1986). Thyroxine (T_4) and triiodothyronine (T_3) increase metabolic rate and reduce body weight by protein mobilization and loss of lean body mass in mice (Moreno et al., 2008) and cattle (Cowley et al., 1971; Novakofski and Kauffman, 1981). Concentrations of T_3 are positively related to food consumption of rats (Oppenheimer et al., 1991) and cattle (McGuire et al., 1991).

Insulin-like growth factor-I (IGF-I) is produced by the liver in response to secretion of growth hormone. Insulin like growth factor-I is highly heritable (Davis and Simmen, 1997) and is positively correlated with growth rate of cattle (Lund-Larsen, 1977) and sheep (Olsen et al., 1981). Serum concentrations of IGF-I are greater in cattle with greater BW and greater feed conversion efficiency (Bishop et al., 1989). Greater nutrient intake increases concentrations of IGF-I in plasma of cattle (Houseknecht et al., 1988; Lents et al., 2005). Cattle selected for negative residual feed intake (efficient) have decreased plasma concentrations of IGF-I compared with cattle selected for positive residual feed intake (Moore et al., 2005).

Physiological processes influence deep body temperatures of cattle. Body temperature decreases prior to parturition in cattle (Wrenn et al., 1958; Aoki et al., 2005; Prado-Cooper et al., 2011) and sheep (Ewbank, 1969), and body temperature is increased at estrus (Wrenn et al., 1958; Clapper et al., 1990; Prado-Cooper et al., 2011). Body temperature was positively related to maintenance energy requirements of Hereford steers (Derno et al., 2005).

A biomarker for MR of cows has not been identified. The objectives of this research were to determine MR of beef cows during mid-gestation and the effect of MR on ruminal temperature, walking activity, and plasma concentrations of IGF-I, thyroxine, and triiodothyronine.

MATERIALS AND METHODS

Animals and Determination of Maintenance Energy Requirements

The Oklahoma State University Animal Care and Use Committee approved all experimental procedures in this study. Angus cows (4 to 7 yr of age) were artificially inseminated to a single Angus sire after synchronizing estrous cycles with treatment of $PGF_{2\alpha}$ (Lutalyse, 25 mg, intramuscularly; Pfizer and Upjohn Co., New York, NY). HeatWatch (DDx Inc., Denver, CO) was used to determine estrus and cows were inseminated 12 h after the onset of estrus. If estrus was not detected after treatment with $PGF_{2\alpha}$, cows were given a second treatment with $PGF_{2\alpha}$ 11 d later, estrus was detected, and cows were inseminated. Cows were inseminated during the month of June (Exp. 1 and 2) and July (Exp. 3). Pregnancy was determined by fetal heartbeat at 30 d after insemination using ultrasonography (Aloka 500-V with a 7.5-MHz probe; Corometrics

Medical Systems, Wallingford, CT). The number of non-lactating, gestating (4-8 mo), cows used were 40, 32, and 32 for Exp. 1, 2, and 3, respectively. The duration of Exp. 1, 2, and 3 was 72, 88, and 88 d, respectively. Experiment 1, 2, and 3 began Oct. 27, Oct. 27, and Oct. 22, respectively, and concluded Jan. 9, Jan. 25, and Jan. 20, respectively. Body condition scores (1 = emaciated, 9 = obese; Wagner et al., 1988) were 4.9 ± 0.1, 4.4 ± 0.1, and 4.3 ± 0.1 and BW were 553 ± 6, 556 ± 6, and 539 ± 8 kg for Exp. 1, 2, and 3, respectively.

Cows were individually fed a complete diet once daily at 0730 h. The diet consisted of (as fed) dry rolled corn (36%), alfalfa pellets (35%), cottonseed hulls (22%), soybean meal (4%), cane molasses (3%), salt (0.2%) and vitamin A (0.01%). Calculated (NRC, 1996) CP and NE_m for the diet were 11.2% and 1.43 Mcal/kg, respectively. Samples of the ration were taken weekly for analyses and ground using a Wiley mill with a 2 mm screen. Subsamples (200 g) of the weekly samples, within experiment, were combined and analyzed in duplicate (Dairy One Laboratory, Inc., Ithaca, NY). Analyzed values of the ration (as fed) for CP and NE_m were 13.0% and 1.40 Mcal/kg, 14.2% and 1.61 Mcal/kg, and 15.4% and 1.93 Mcal/kg for Exp. 1, 2, and 3, respectively. Mineral supplement (46.1% NaCl, 50.0% dicalcium phosphate, 0.4% copper sulfate, 0.5% zinc oxide and 3.0% mineral oil) was fed for targeted consumption of 1 oz./head/d and ad libitum water.

Metabolic body weight ($BW^{0.75}$) was calculated based on initial shrunk BW, after removal of feed (23 h) and water (14 h). Shrunk BW was recorded twice a week during the experiments. Body condition score was recorded at the start and end of the experiment. Calf BW was recorded at birth, mid-lactation (2 mo), and at weaning (7 mo).

The diet was adjusted if cows gained or lost weight after consumption of the calculated MR for 2 wk. Additional adjustments in diet, at 2 wk or greater intervals, were made to maintain a constant BW. When BW increased or decreased (≥ 3 consecutive weights) the ration was decreased or increased (respectively) by 0.45 or 0.90 kg feed/d. Regression analyses (SAS Institute Inc., Cary, NC) were used to determine constant BW. Maintenance energy requirement was determined when BW was constant for 21, 31, and 36 consecutive days for Exp. 1, 2, and 3, respectively.   After calving, cows were managed as a group on native prairie pasture (*Andropogon scoparius, Andropogon gerardii*) and were supplemented with 1.8 kg of 38% CP when adequate forage was not available.

Mean BW and daily dietary energy (NE_m) intake were used to determine MR during the days when BW was constant, and MR was expressed as $Kcal \bullet kg^{-0.75} \bullet day^{-1}$. Cows were classified based on MR as low (> 0.5 SD less than mean, LMR), moderate (± 0.5 SD of the mean, MMR) and high (> 0.5 SD greater than mean, HMR).

Blood sampling and analyses

Blood samples were collected via caudal venipuncture on 2 d when cows consumed MR and on 2 d during early lactation when cows had ad libitum prairie grass. In Exp. 1, samples were collected from cows at 0700 and 1500 h on two consecutive days during both periods. Maximum ambient temperature was 2 and 13 °C for d 1 and 2, respectively, during the MR period, and 26 and 28 °C for d 1 and 2, respectively, during early lactation. For Exp. 2, samples were collected at 0700 and 1500 h on a day during MR when maximum ambient temperature was -5°C, and 2 wk later at the same times when maximum ambient temperature was 15°C. Samples were collected during early lactation at 0700 and 1500 h on two consecutive days when maximum ambient temperature was 32 and 28 °C for d 1 and 2, respectively. Blood samples collected at 0700 h during maintenance, for Exp. 1 and 2, were obtained after consumption of water was restricted for 14 h and feed consumption was restricted for 23 h. Cows had ad libitum water prior to samples collected at 1500 h and had consumed daily diets 7 h previously. During early lactation cows were gathered from native pasture and sampled at 0700 h and consumption of feed and water was restricted for 8 h before sampling at 1500 h. Blood samples (10 mL) were collected into evacuated tubes containing EDTA and placed on ice. Samples were centrifuged (2,500 g) within 2 h for 20 min at 4 °C, plasma was aspirated and stored at -20 °C until analyses.

Plasma samples collected during MR or lactation, within an experiment, were assigned to laboratory assay blocks based on MR and day of sample. The samples collected after consumption of feed, or after feed and water restriction, on the 2 collection days for a cow were analyzed in the same assay block and each block contained a similar number of cows from each treatment (LMR, MMR, and HMR). Plasma concentrations of thyroxine (T_4) were quantified with a solid phase RIA (Coat-A-Count Total T_4 kit, Diagnostic Products Corp.; Ciccioli et al., 2003). Intra and interassay CV were 3% and 10%, respectively. Concentrations of triiodothyronine (T_3) were quantified with a solid phase RIA (Coat-A-Count T3 kit, Diagnostic Products Corp.). The addition of 0.2, 0.5, 1.0, and 2.0 ng/mL of triiodothyronine (n = 3) to plasma resulted in the recovery of 95, 106, 105, and 99 %, respectively. When 37.5, 50, and 75 μL of bovine plasma were assayed, the concentrations of triiodothyronine (T_3) were parallel to the standard curve. Intra and interassay CV were 3% and 8%, respectively. Concentrations of IGF-I in plasma were quantified using RIA after acid ethanol extraction (Echternkamp et al., 1990). Intra and interassay CV were 4% and 9%.

Ruminal Temperature

A balling gun was used to place ruminal temperature (RuT) boluses into the rumen of each cow during the period of the experiment when cows consumed the maintenance diet. Data were collected with the Smart Stock system (SmartStock®, LLC, Pawnee, OK). The system consisted of a radio-frequency RuT bolus (8.25 cm x 3.17 cm; 114 g), antennas for data collection and transmission, a receiver antenna for transmitted data, and a computer for data storage. Three data collection antennas were strategically placed at the perimeter or in the drylot (60 x 80 m) where cows were maintained for 23.5 h/d. Cows were less than 50 m from an antenna while in the drylot. Date, time, cow identification, and RuT were recorded every hour. Ruminal temperature data were collected for four consecutive days during MR and four consecutive days when cows had ad libitum prairie grass hay in January.

Measurement of activity

Activity was determined using GOsmart^{TM} pedometers (Omron Healthcare, Inc., Kyoto-shi, Kyoto, Japan). Pedometers were placed in cloth pouches and glued on the lumbar region of cows for 24 h to record activity.

Statistical analyses

Plasma concentrations of hormones were analyzed using the MIXED procedure (SAS). Samples obtained during MR and early lactation were analyzed separately. The statistical model for T_4, T_3, and IGF-I included MR, day, sample, and the interactions. Assay block was included as a random function. To identify the best goodness of fit statistics, six covariance structures (variance component, compound symmetry, Huynh-Feldt, first-order autoregressive, Toepliz, and unstructured) were tested. The covariance test with the best goodness of fit were Toepliz for T_4, variance component for T_3, and unstructured for IGF-I. If treatment or interaction was significant, least squares means were compared using LSD (SAS).

Ruminal temperature was analyzed with the MIXED procedure (SAS). Data collected during MR were analyzed separately from data collected during ad libitum roughage. Average RuT for a cow was determined each day during MR and ad libitum roughage. It was required that cows had at least six readings per day to be included in analyses. To ensure that water drinking events did not influence RuT, values less than 37.72°C were excluded from data (Bewley et al., 2008; Boehmer et al., 2009; Prado-Cooper et al., 2011). The statistical model for RuT included MR, day, and the interaction. The best goodness of fit statistic was identified using six covariance structures (variance component, compound symmetry, Huynh-Feldt, first-order autoregressive, Toepliz, and unstructured). The covariance test with the best goodness of fit was Huynh-Feldt for RuT during MR and first-order autoregressive during ad libitum prairie hay. If treatment or interaction was significant least squares means were compared using LSD (SAS).

Activity was collected for 24 h for 20 % of the cows (n = 21) in each MR group on one of 5 d during Exp. 3. Data were analyzed with the GLM procedure (SAS) and the model included MR, with day as a covariate.

Calf birth weight and 205 d adjusted weaning weight were analyzed using the GLM procedure (SAS). The statistical model for birth weight included MR and sex as a covariate. The statistical model for 205 d adjusted weaning weight included MR. Calf 205 d adjusted weaning weight was calculated by determining ADG from birth to day of weaning and then adjusting to 205 d of age. The model included MR, sex, and the interaction.

Correlations between T_3, T_4, IGF-I, and MR were determined using the CORR procedure (SAS). Plasma concentrations of hormones within experiment were averaged during MR period and early lactation for correlations with MR.

RESULTS

Cow and calf performance

Cows were fed a complete diet for 10, 17, and 13 wk for Exp. 1, 2, and 3 respectively. Body weight was maintained for 21, 31, and 36 d for Exp. 1, 2, and 3 respectively. Body weight was maintained for 27, 25, and 22 cows for Exp. 1, 2, and 3, respectively. Average maximum ambient temperatures during the MR period were 9.4 ± 1.7, 4.4 ± 1.3, and 6.5 ± 1.1 °C for Exp. 1, 2, and 3, respectively. Average minimum ambient temperatures were -4.5 ± 1.1, -5.5 ± 1.1, and -6.0 ± 1.0 °C for Exp. 1, 2, and 3, respectively.

Initial BW was not influenced by MR for Exp. 1 and 2 (Table 1). Low MR cows had greater initial BW (*P* = 0.04) in Exp. 3, compared with MMR and HMR cows. Maintenance energy requirements tended to influence final BW in Exp. 1 (*P* = 0.06) and 2 (*P* = 0.09); MMR cows had greater final BW compared with LMR and HMR in both experiments. In Exp. 3 LMR, cows had greater (*P* = 0.05) final BW compared with MMR and HMR cows, however the percentage change from initial to final BW was not influenced by MR. Initial BCS was not influenced by MR for Exp. 1, 2, and 3 ($P \geq 0.10$) (Table 1). Final BCS was not influenced by MR in Exp. 1 and 2. In Exp. 3, HMR had less BCS compared with LMR and MMR cows ($P \leq 0.01$). Average MR for all cows was 80.7 ± 4.8, 94.4 ± 8.0, and 95.5 ± 7.1 $\text{Kcal}\bullet\text{kgBW}^{-0.75}\bullet\text{d}^{-1}$ for Exp. 1, 2, and 3, respectively (Table 2). The differences between the least efficient and most efficient cows were 33, 32, and 33% for Exp. 1, 2, and 3, respectively (Figure 1, Figure 2, and Figure 3). Within the 3 experiments the daily amount of energy required to maintain a constant BW differed for LMR, MMR, and HMR groups ($P \leq 0.001$).

Maintenance energy requirement of cows did not influence birth or 205 d adjusted weaning weight of calves in Exp. 1 and 2 ($P \geq 0.23$; Table 3). Birth weight of calves in Exp. 2 was greater ($P < 0.001$) than birth weight of calves in Exp. 1. There was a sex effect (*P* = 0.001) for 205 d adjusted weaning weights with steers having a greater adjusted weaning weight. Average daily gain of calves from birth to weaning was not influenced by MR in Exp. 1 and 2 (*P* = 0.37). Average daily gain from birth to weaning was similar for Exp. 1 and 2 (*P* = 0.32).

Experiment 1

Plasma concentrations of T_3 during MR were not effected by MR x day x sample ($P = 0.36$), MR x day ($P = 0.94$), or MR x sample ($P = 0.67$). During early lactation plasma concentrations of T_3 were not influenced by MR x day x sample ($P = 0.98$), MR x day ($P = 0.88$), or MR x sample ($P = 0.82$). Concentrations of T_3 in plasma were not influenced by MR when cows consumed actual MR ($P \leq 0.62$) or ad libitum prairie grass during early lactation ($P \leq 0.94$; Table 4).

Neither MR x day x sample ($P = 0.84$), MR x day ($P = 0.38$), nor MR x sample ($P = 0.62$) influenced plasma concentrations of T_4 during MR. During early lactation MR x day x sample ($P = 0.85$) and MR x day ($P = 0.99$) did not effect concentrations of T_4 in plasma. Plasma concentrations of T_4 were not influenced ($P = 0.58$) by MR when cows consumed actual MR (Table 4). During early lactation when cows consumed ad libitum roughage, there was a MR x sample effect on plasma T_4 (Figure 4). After consumption of ad libitum roughage (1 h postprandial), LMR cows had greater concentrations of plasma T_4 compared with HMR cows ($P = 0.05$). Concentrations of T_4 in plasma were not influenced by MR at 6 h postprandial ($P \geq 0.62$).

Plasma concentrations of T_3 were correlated with plasma concentrations of T_4 during the MR period and early lactation for Exp. 1 (r = 0.49, $P < 0.001$; r = .47, $P < 0.001$, respectively) and 2 (r = 0.41, $P < 0.001$; r = 0.22, $P = 0.03$, respectively). Concentrations of T_4 were correlated (r = 0.45, $P = 0.02$) with MR in Exp. 1 when cows consumed MR, but not during early lactation (r = 0.30, $P = 0.12$).

Experiment 2

Concentrations of T_3 in plasma were not influenced by MR x day x sample (P = 0.42) or MR x sample (P = 0.51) during MR. When cows had ad libitum roughage, MR x day x sample (P = 0.13), MR x sample (P = 0.87), and MR x day (P = 0.62) did not effect plasma concentrations of T_3. There was a MR x day effect (P = 0.05) on concentrations of T_3 in plasma when cows consumed MR (Figure 5). Concentrations of T_3 in plasma were not influenced by MR when ambient temperatures were cooler (-5 °C). However when ambient temperatures were warmer (15 °C) and cows consumed MR, HMR had greater concentrations of T_3 compared with LMR and MMR cows ($P \leq 0.05$). Plasma concentrations of T_3 were not influenced (P = 0.27) by MR when cows consumed ad libitum roughage during early lactation (Table 5).

Neither MR x day x sample (P = 0.49) nor MR x sample affected (P = 0.29) plasma concentrations of T_4 during MR. Concentrations of T_4 in plasma were not influenced by MR x day x sample (P = 0.35) or MR x sample (P = 0.96) during early lactation. There was a MR x day effect when cows consumed MR; when ambient temperature was cooler (-5 °C), LMR had greater (P = 0.03) concentrations of plasma T_4 compared with MMR and HMR cows (Figure 6). Concentrations of T_4 were not influenced by MR when ambient temperature was warmer (15 °C; P = 0.22). There was a treatment x day effect on concentrations of T_4 during early lactation when cows had ad libitum prairie grass; MMR had greater (P = 0.01) concentrations of T_4 compared with HMR cows on day 1 and MR did not influence ($P \leq 0.11$) concentrations of T_4 in plasma on day 2 (Figure 7).

Concentrations of IGF-I in plasma were not influenced by MR x day x sample (P = 0.63), MR x sample (P = 0.78), or MR x day (P = 0.85) when cows consumed MR.

Insulin-like growth factor-I concentrations in plasma were not effected by MR when cows consumed MR ($P = 0.58$; Table 5). Concentrations of IGF-I in plasma were not influenced by MR x day x sample when cows had ad libitum prairie grass ($P = 0.41$). When cows had ad libitum roughage during early lactation there was a MR x day effect on plasma concentrations of IGF-I; HMR had greater ($P = 0.05$) plasma concentrations of IGF-I compared with LMR cows on day 2 and MR did not influence ($P > 0.14$) concentrations of IGF-I on day 1 (Figure 8). There was a MR by time after feeding effect on IGF-I in plasma when cows had ad libitum roughage; HMR had greater ($P = 0.04$) concentrations of IGF-I compared with LMR cows 1 h postprandial but MR did not influence ($P > 0.18$) IGF-I concentrations 6 h postprandial (Figure 9).

In Exp. 2, concentrations of T_4 were correlated with MR when cows consumed MR and when cows had ad libitum roughage ($r = - 0.47$, $P = 0.02$; $r = - 0.45$, $P = 0.03$, respectively). Concentrations of IGF-I were positively correlated with maintenance energy requirements ($r = 0.41$, $P = 0.04$) when cows consumed MR, but not during early lactation ($r = 0.19$, $P = 0.39$).

Ruminal temperatures (RuT) associated with water consumption (< 37.72 °C, < 1 SD of the mean) were removed before data were analyzed. There was a MR x day effect ($P = 0.05$) for RuT when cows consumed MR, however this was a difference in magnitude of the response not a difference in direction of response (Figure 10). Maintenance energy requirement did not influence ($P = 0.81$) RuT of cows during consumption of ad libitum roughage for four consecutive days in late gestation (Figure 11). Daily average ambient temperatures ranged from 4 to 10 °C during collection of

RuT when cows consumed MR in January and -6 to 7 °C during collection of RuT when cows had ad libitum roughage during January.

Experiment 3

Walking activity evaluated during 24 hr period when cows consumed MR was not influenced by maintenance energy requirements of cows (*P* = 0.66; Figure 12).

DISCUSSION

Maintenance requirements were 80.7 ± 4.8, 94.4 ± 8.0, and 95.5 ± 7.1 Kcal NE_m•$kgBW^{-0.75}$•d^{-1} for Exp. 1, 2, and 3, respectively. In previous experiments conducted in our laboratory using the same methods, average MR ranged between 89.2 (Prado-Cooper, 2009) to 93.0 (Bailey, 2009) Kcal NE_m•$kgBW^{-0.75}$•d^{-1}. Other estimated MR for mature, non-lactating, non-gestating Angus cows range from 91.4 to 156.7 Kcal ME•$kgBW^{-0.75}$•d^{-1} (Ferrell and Jenkins, 1985; Solis et al., 1988; DiCostanzo et al., 1990; Laurenz et al., 1991). In the current experiments, and other studies conducted in our laboratory, MR was calculated using NE_m of the feed. When retained energy and physical activity of an animal is equal to zero (maintenance) then heat production is equal to metabolizable energy. Net energy requirement for maintenance is equal to heat production of a cow with zero feed intake (NRC, 1996). Differences in estimated MR between studies are influenced by environmental conditions and methods used to determine MR. Maintenance energy requirements are greater for cattle when ambient temperature is below the lower critical temperature (Young, 1981; Christopherson and Young, 1986; Robinson et al., 1986). Productivity decreases due to decreased feed intake and increased MR when ambient temperature is greater than the upper critical temperature (NRC, 1996).

Average maximum ambient temperature during MR was 5 °C greater in Exp. 1 compared with Exp. 2 and 2.9 °C greater compared with Exp. 3. Greater ambient temperature and less required heat production could be related to less energy required for maintenance in Exp. 1 compared with Exp. 2 and 3. The differences in NE_m between the least efficient and most efficient cows were 33, 32, and 35% for Exp. 1, 2, and 3, respectively. In previous studies at our laboratory, with a similar experimental design, differences between the least efficient and most efficient cows ranged between 24 and 29% (Prado-Cooper, 2009; Bailey, 2009). Other studies found that ME for maintenance varied 27% in Angus cows (DiCostanza et al., 1990) and 23% in Hereford steers. Differences in MR of cows may change due to season and physiological state. Seasonal differences have been observed in MR for Simmental and Angus cows; cows had greater requirements during summer compared with the winter (Laurenz et al., 1991). Neville and McCullough (1969) found a 30% increase in MR of lactating Hereford cows compared with non-lactating cows. Maintenance energy requirement is a moderately heritable trait ($h^2 = 0.45 – 0.52$; Benyshek and Marlowe, 1973; Carstens et al., 1989; Hotovy et al., 1991). This supports the idea that MR differs between cows, and producers could potentially select and breed to increase efficiency within a herd. Differences in MR among cows are apparent but may change over the duration of a year due to seasonal changes or physiological change.

Final body weight in Exp. 1 and 2 tended to be influenced by MR as MMR had greater BW compared with LMR and HMR cows. The differences in final BW of cows may be associated with greater BW of the cows at the initiation of the experiment. The percentage change in BW of cows in Exp. 3 was similar for all treatments. Body condition score at the end of the MR period was not influenced by MR in Expt. 1 and 2. However in Expt. 3, LMR and MMR had greater BCS compared with HMR cows. This may indicate that cows with greater MR have greater lean tissue mass. When cows have similar body fat, those with greater lean mass have higher maintenance requirements with approximately 89% of MR being used to maintain lean tissue (DiCostanza et al., 1990). Cows with greater fat tissue had lower MR (Klostermann et al., 1968; Thompson et al., 1983). Cows with greater body condition may have lesser MR due to differences in tissue turnover rate caused by the percentage of fat in the body (Wagner et al., 1988). Sheep with greater body fat had lesser MR compared with sheep with lesser body fat (Lambourne and Reardon, 1962). Similarly, Pullar and Webster (1977) observed that rats with greater body fat had lower MR. Cows with a greater percentage of lean mass may use a greater amount of MR for protein maintenance and lesser amounts of energy may be available to be stored as fat tissue. Alternatively, since the percentage change in BCS was similar for all treatments in Exp. 3, the differences in BCS could be related to less BCS for HMR cows at the initiation of the experiment.

Residual feed intake (RFI) measures variation in dry matter intake and efficiency. Residual feed intake is determined by comparing expected feed intake to actual feed intake of an animal at a specific production level. Production is independent of RFI, which suggest that it may indicate variation in basic metabolic processes (Herd and Arthur, 2009). Mitochondrial production of adenosine triphosphate is not influenced by RFI, indicating that cellular energy production is similar between feed efficient and inefficient cattle (Kolath et al., 2006). Residual feed intake is typically used to evaluate the feed efficiency of growing animals, however heifers that have negative RFI as weanlings continue to have negative RFI when mature (Herd et al., 2003). Residual feed intake may not influence reproductive performance of heifers (Lancaster, 2008). However, Shaffer et al. (2011) found that heifers selected for negative RFI had a greater age at puberty compared with heifers selected for positive RFI. Protein turnover, tissue metabolism, and stress accounted for approximately 37% of variation in RFI (Herd and Arthur, 2009). Further research should be conducted to determine if cows with low MR also have a negative RFI.

Calf birth and 205 d adjusted weaning weights were not influenced by MR. Previous work in our laboratory also determined that calf birth and 205 d adjusted weaning weights were not influenced by MR of cows (Prado-Cooper, 2009; Bailey, 2009). This indicates that the most efficient cows produce the same quantity and quality of milk as the least efficient cows. Milk production is the single most important factor that influences calf growth and weaning weight (Rollins and Gilbert, 1954; Clutter and Nielsen, 1987) and accounts for approximately sixty percent of the variation in calf weaning weight (Neville, 1962; Rutledge et al., 1971). Maintenance requirement is related to the potential for milk production of cows, as breeds with greater milk production have greater MR during lactation compared with breeds with lesser milk production (Blaxter and Wainman, 1966; Ferrell and Jenkins, 1984; Montano-Bermudez et al., 1990). Calf growth is related to milk production of dams, and current evidence indicates that cows can be selected for feed efficiency without sacrificing calf growth.

Maintenance energy requirements influenced plasma concentrations of T_4 in cows. Concentrations of T_4 were greater in LMR compared with HMR cows during early lactation when cows had access to ad libitum forage (1 h postprandial) in Exp. 1. In Exp. 2 plasma concentrations of T_4 were greater in LMR compared with HMR cows when cows were exposed to cool (-5 °C) ambient temperatures and consumed MR. However when ambient temperatures were warmer (15 °C) concentrations of T_4 were similar among MR groups. Concentrations of T_4 in plasma are positively associated with nutrient intake of cows (Richards et al., 1995; Ciccioli et al., 2003) and sheep (Dukes and Swenson, 1970; Abecia et al., 2001). In the present experiment, cows with greater feed intake had less plasma concentrations of T_4. In the current experiments all cows were fed to maintain BW, whereas in the studies of Richards et al. (1995) and Ciccioli et al. (2003) cows on different treatments received large differences in feed intake. Thyroxine has a major role in the metabolism of carbohydrates, lipids, and proteins in tissues such as liver, muscle, and adipose tissue. Increased concentrations of T_4 are associated with increase gut motility and rumen outflow leading to increased feed intake (Ngongoni et al., 1987). Ambient temperatures are negatively related to plasma concentrations of T_4. Similar to results of this study an increase in ambient temperature was associated with decreased plasma concentrations of T_4 in cows (Yousef et al., 1967; Magdub et al., 1982; Pratt and Wettemann, 1986).

Concentrations of T_3 in plasma were influenced by MR at only one sampling day. Concentrations of T_3 were greater in HMR compared with LMR and MMR cows when ambient temperatures were warmer in Exp. 2 and cows received maintenance diets. Similar to results in the present study, Pratt and Wettemann (1986) and Magdub et al.

(1982) found that ambient temperatures influence plasma concentrations of T_3 in cattle. Residual feed intake, a predictor of feed efficiency, was not related to concentrations of free T_3 in plasma of heifers (Kelly et al., 2010). Pethes et al. (1985) demonstrated that cows fed maintenance had decreased plasma concentration of T_3 compared with cows with ad libitum diets. Minimal concentrations of T_3 in cows fed maintenance has been attributed to decreased energy requirements by decreasing the catabolism of protein (Carter et al., 1975). Administration of T_3 to sheep (DiPierro et al., 1996) and rats (Ojamaa et al., 1993) increased contractions of smooth muscle in the heart without increasing oxygen consumption, indicating that increased concentrations of T_3 in plasma may improve energy efficiency of smooth muscle. Thyroid hormones have roles in metabolism and temperature homeostasis, however, the relationship of thyroid hormones with energy efficiency is not established.

Concentrations of T_3 and T_4 were positively correlated when cows consumed MR or had ad libitum roughage in Exp. 1 and 2. The thyroid gland in animals with normal thyroid production only produces approximately 20% of T_3 in plasma, which indicates that deiodination of T_4 provides the majority of T_3 (Laurberg, 1984). Thyroxine and T_3 are positively correlated due to T_4 conversion to T_3. Thyroxine and T_3 are positively correlated in humans (Laurberg, 1984; Varl and Pavlin, 1990) and rats (Frumess and Larsen, 1974).

In Exp. 1 T_4 concentrations were positively correlated with MR when cows were fed MR. However, T_4 and MR were negatively correlated in Exp. 2. Concentrations of T_4 were not correlated with MR when cows consumed ad libitum roughage. Thyroxine concentrations are positively correlated with energy intake in heifers (Balzer and

McCartor, 1966). Humans with greater caloric intake have greater concentrations of thyroxine (Reinehr, 2011). Plasma concentrations of T_4 are negatively associated with ambient temperature (Yousef et al., 1967; Magdub et al., 1982; Pratt and Wettemann, 1986). In Exp. 2, ambient temperatures were cooler compared with Exp. 1. Plasma concentrations of T_4 may have been negatively correlated with MR due to increased concentrations of T_4 in LMR cows to maintain body temperature. Similar to the present experiment, concentrations of T_4 were not influenced by MR of mice that were fed ad libitum (Kgwatalala et al., 2004). Plasma concentrations of IGF-I were positively correlated with MR when cows consumed actual MR. Concentrations of IGF-I in plasma are positively correlated with nutrient intake (Donaghy and Baxter, 1996). Plasma concentrations of IGF-I are regulated by nutrition; energy deficient humans have lesser concentrations of IGF-I due to the down regulation of growth hormone receptors in the liver (Thissen et al., 1994).

Thyroxine is converted to T_3 by iodothyronine deiodinases. Triiodothyronine is the active thyroid hormone and binds to nuclear receptors to initiate physiological functions (Oppenheimer et al., 1973; Jaffe and Means, 1977). Messenger RNA for the iodothyronine deiodinase D2 differs between fast and slow twitch murine muscle and increases during hypothyroidism (Marsili et al., 2010). Mammals contain two forms of thyroid hormone receptors, α and β, (Sap et al., 1986; Weinberger et al., 1986). Each receptor performs specific functions but some crossover does occur in mice deficient in thyroid hormone receptors (Ercan-Fang et al., 1996; Forrest et al., 1996). Brown adipose tissue is important in the regulation of body temperature in mammals (Seydoux et al., 1982; Wellman et al., 1986; Ootsuka et al., 2009), through activation of uncoupling protein (Carvalho et al., 1991), which is ultimately activated by the binding to thyroid receptor β (Ribeiro et al., 2010). Mice that are deficient for thyroid hormone receptor α must consume a greater amount of feed to maintain body temperature when ambient temperature is less than thermoneutral zone (Pelletier et al., 2008). Thyroid receptor specific ligands allow for the study of mechanisms of thyroid hormone within the body (Ribeiro and Bianco, 2011). Study of molecules that only bind to one thyroid receptor could enhance understanding of the effects of thyroxine and triiodothyronine on metabolism and improvement in energy efficiency of cows.

Concentrations of IGF-I were influenced by MR x day and MR x time after eating when cows had ad libitum roughage during early lactation. High maintenance requirement cows had greater concentrations of IGF-I on day 2 of sampling and 1 h postprandial compared with LMR cows. The potential for greater feed intake of cows with greater MR is similar to other studies in which concentrations of IGF-I in plasma were positively related to nutrient intake in cows (Ciccioli et al., 2003; Lents et al., 2005) and heifers (Houseknecht et al., 1988; Armstrong et al., 1993; Yelich et al., 1996). Concentrations of IGF-I were positively associated with intake when animals were fed large differences in energy in other studies, but in the present study animals with different MR had ad libitum prairie grass. Angus cattle with greater serum concentrations of IGF-I had a greater feed conversion ratio compared with cattle with lesser concentrations of IGF-I (Bishop et al., 1989). The relationship between IGF-I and RFI in cattle is not clearly established, and has been reported to be positively (Moore et al., 2005) or negatively (Lancaster et al., 2008b) correlated. Differing results between experiments indicate that additional research should be conducted to determine the relationship between IGF-I and feed efficiency.

There was a MR x day effect on RuT when cows consumed MR. Ruminal temperature differed over days within treatment, however there was no effect of MR on RuT within day. This demonstrates that MR may be related to the ability of cows to retain heat formed by fermentation, as LMR cows consumed less feed compared with MMR and HMR. Rectal temperatures are positively correlated with RuT (Prendiville et al., 2002; Rose-Dye et al., 2010). In contrast with the present results, Derno et al. (2005) found that rectal temperatures were positively associated with MR when beef steers were fed roughage. Greater heat loss was positively associated with increased feed intake and MR in mature mice selected for high or low heat loss (Nielsen et al., 1997). Heat production is positively correlated with residual feed intake and cattle selected for positive residual feed intake have greater heat production compared with cattle selected for negative residual feed intake (Richardson et al., 2001; Basarab et al., 2003).

Walking activity was measured to determine if cattle that required more energy to maintain BW had greater activity compared with cattle that required less energy. Energy requirement was not related to walking activity of cows. In contrast, Voisinet et al. (1997) found that physical activity was positively correlated with ad libitum feed intake in cattle. Tulloh (1960) observed that in a feedlot, cattle with less physical activity had increased live weight and increased ADG. Physical activity accounted for approximately 36% of the variation in feed intake in mice selected for high or low heat loss (Mousel et al., 2001). Body condition is negatively correlated with the postpartum anestrus interval in cows and when body condition is less than 4 the postpartum interval to estrus is greater compared with cows with greater body condition (Richards et al., 1986; Bishop et al., 1994; Wettemann et al., 2003). In contrast, differing amounts of physical activity did not influence the postpartum interval of cows consuming a constant ration, indicating that physical activity did not require a major increase in energy (Bellows et al., 1994).

SUMMARY

The difference in Kcal NE_m•$kgBW^{-0.75}$•d^{-1} between the most efficient and least efficient cow was 33, 32, and 35% for Exp. 1, 2, and 3, respectively. With a measurable difference between efficient and inefficient cows, and a moderate heritability for MR, selection for more efficient cows may potentially increase profitability of beef production. Greater MR of cows may be related to increased body protein, as protein tissue has a greater MR compared with fat tissue (Old and Garret, 1985). The amount of energy required for maintenance did not influence growth of calves. Energy requirements to maintain BW were not related to walking activity. Ambient temperature influenced the effect of MR on concentrations of T_3 and T_4 in plasma of beef cows. Thyroid hormones and IGF-I may be related to energy efficiency and may have potential as biomarkers to identify more efficient cows. Measurement of free thyroid hormones could give insight on the role of thyroid hormones in regulating MR. Identification of cows with lower MR and greater efficiency could improve the profitability of beef production.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Improvements in cattle efficiency could result in greater profitability of beef production. Maintenance energy requirement (MR) of cows accounts for approximately 50% of the total energy required for beef production from birth to slaughter (Ferrell and Jenkins, 1984). Small improvements in energy efficiency could markedly increase profits since feed costs are the greatest cost of beef production. Maintenance energy requirements are moderately heritable (Benyshek and Marlowe, 1973; Carstens et al., 1989; Hotovy et al., 1991). Maintenance requirements varied 32 % between the least efficient cow and most efficient cow in our research and did not effect calf growth. This finding indicates that cattle can be selected for efficiency and production can be improved through selective breeding without negatively influencing output. Cows with lower MR, that raise normal weight calves, will increase profitability of beef production.

Thyroid hormones are regulators of metabolism and may have a role in energetic efficiency. Plasma concentrations of thyroxine and triiodothyronine are influenced by ambient temperature (Yousef et al., 1967; Pratt and Wettemann, 1986) as well as by feed intake (Richards et al., 1995; Ciccioli et al., 2003; Lents et al., 2005). The influence of ambient temperature on plasma concentrations of thyroid hormone makes it difficult to determine the effect MR may have on plasma concentrations of thyroid hormones in cows.

Increased physical activity may be positively related to feed intake in feedlot cattle (Voisinet et al., 1997). Feeder cattle with decreased physical activity have increased live weight and ADG compared with active cattle (Tulloh, 1960). If cows utilize a greater amount of time walking this could increase the amount of energy needed to maintain BW. Our study found that physical activity was not related to the amount of energy needed to maintain BW. The lack of effect of walking activity on required energy may be related to the fact that physical activity accounted for approximately 10 % of the energy needed to maintain BW in dairy cows (Dairy NRC, 2001).

Body temperature of cows can be influenced by factors such as ambient temperature (Arrillaga et al., 1952), parturition (Wrenn et al., 1958; Aoki et al., 2005), estrus (Wrenn et al., 1958; Prado-Cooper et al., 2011), or sickness (Rose-Dye et al., 2011). Maintenance energy requirement of Hereford steers was associated with rectal temperature (Derno et al., 2005). However, our study found that RuT was not influenced by MR. This indicates that MR may not be related to the ability of a cow to dissipate heat produced during ruminal fermentation and cows that consume greater amounts of feed dissipate heat faster than those that consume lesser amounts of feed.

Our results indicate that variation in MR of beef cows, without altered production, makes it possible to select beef cows that are energetically more efficient. Development of methods to identify more efficient cows will increase the profitability of beef production.

Table 1. Least squares mean BW (kg) and BCS of cows with low (LMR), moderate (MMR), or high (HMR) maintenance energy requirements (MR)

	MR[1]				
Item	LMR	MMR	HMR	SEM	*P* - value
Exp. 1					
Cows, no.	8	10	9		
BW Initial[2]	579	605	582	6	0.15
BW Final[3]	541	572	540	6	0.06
BCS Initial	4.8	5.0	4.8	0.1	0.57
BCS Final	4.9	4.8	5.0	0.1	0.45
Exp. 2					
Cows, no.	10	6	9		
BW Initial[4]	549	581	551	7	0.18
BW Final[5]	556	595	556	7	0.09
BCS Initial	4.5	4.7	4.3	0.1	0.14
BCS Final	4.6	4.6	4.6	0.1	0.99
Exp. 3					
Cows, no.	9	7	6		
BW Initial[6]	567[a]	517[b]	527[b]	9	0.04
BW Final[7]	571[a]	533[b]	522[b]	7	0.03
BCS Initial	4.4	4.4	4.1	0.1	0.10
BCS Final	4.8[a]	4.7[a]	4.4[b]	0.1	0.01

[1] Cows were classified based on MR as low (> 0.5 SD less than mean, LMR), moderate (± 0.5 SD of the mean, MMR) and high (> 0.5 SD greater than mean, HMR).
[2] Mean BW and BCS of cows on first day (Oct. 27, 2008) of feeding.
[3] Mean BW and BCS of cows on last day (Jan. 9, 2009) of feeding MR.
[4] Mean BW and BCS of cows on first day (Oct. 27, 2009) of feeding.
[5] Mean BW and BCS of cows on last day (Jan. 25, 2010) of feeding MR.
[6] Mean BW and BCS of cows on first day (Oct. 22, 2010) of feeding.
[7] Mean BW and BCS of cows on last day (Jan. 20, 2011) of feeding MR.
[a,b] Means within a row without a common superscript differ ($P < 0.05$).

Table 2. Least squares mean maintenance energy requirements (MR) of non lactating, pregnant beef cows with low (LMR), medium (MMR), or high (HMR) MR in Exp. 1 (21d), Exp. 2 (31d), and Exp. 3 (36d) during the period of constant BW

	MR[1]			
Item	LMR	MMR	HMR	SEM
Exp. 1				
Cows, no.	8	10	9	
MR	75.95^a	79.64^b	86.24^c	0.48
Exp. 2				
Cows, no.	10	6	9	
MR	86.98^a	92.74^b	103.70^c	0.60
Exp. 3				
Cows, no.	9	7	6	
MR	89.24^a	95.75^b	104.59^c	0.73

[1] Maintenance energy requirements (MR, Kcal NE_m•kg$BW^{-0.75}$•d^{-1}). Cows were classified based on MR as low (> 0.5 SD less than mean, LMR), moderate (± 0.5 SD of the mean, MMR) and high (> 0.5 SD greater than mean, HMR).

[a,b,c] Means within a row without a common superscript differ ($P < 0.001$).

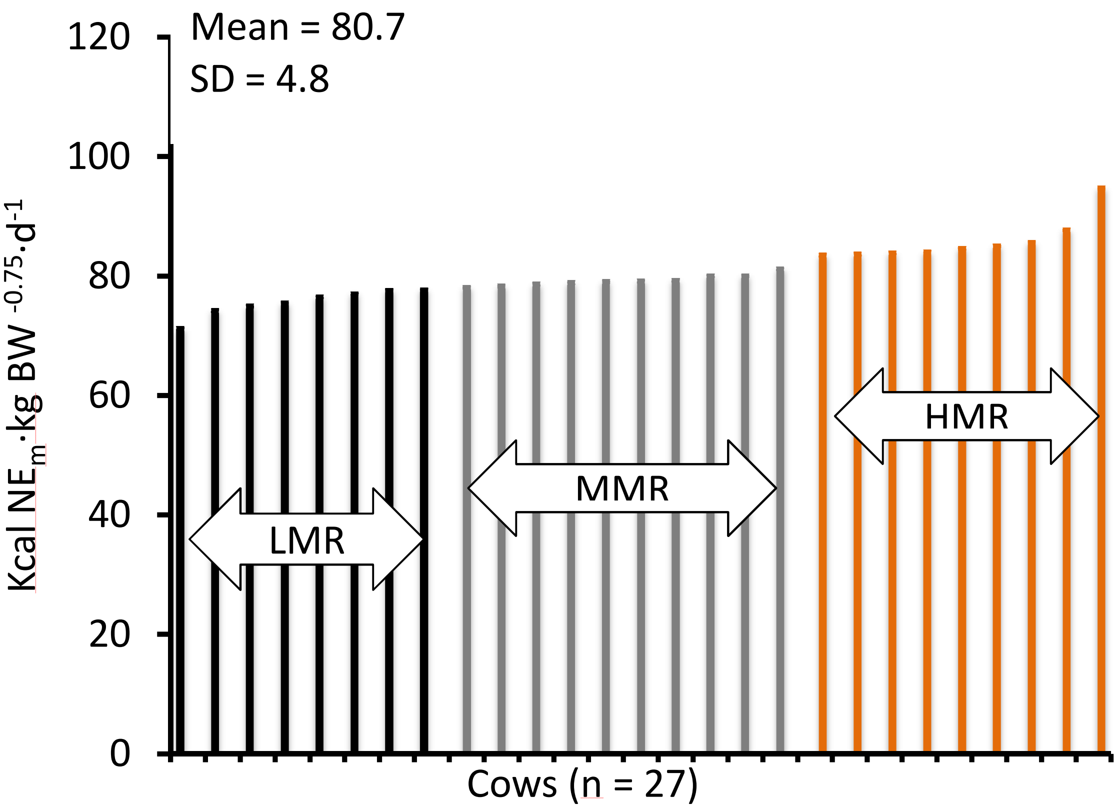

Figure 1. Maintenance energy requirements (MR, Kcal NE$_m$•kgBW$^{-0.75}$•d^{-1}) of cows during the period of body weight maintenance in Exp. 1. Each bar represents the MR of each cow that achieved maintenance. Cows were classified based on MR as low (> 0.5 SD less than mean, LMR), moderate (± 0.5 SD of the mean, MMR) and high (> 0.5 SD greater than mean, HMR).

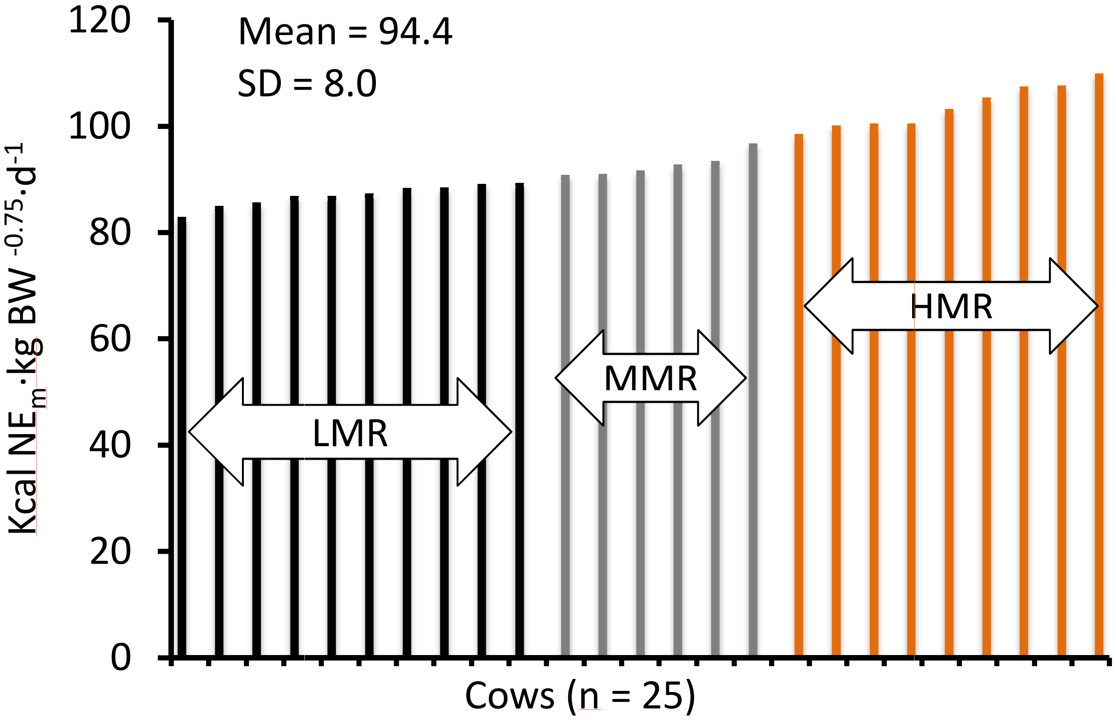

Figure 2. Maintenance energy requirements (MR, Kcal NE_m•kg$BW^{-0.75}$•d^{-1}) of cows during the period of body weight maintenance in Exp. 2. Each bar represents the MR of each cow that achieved maintenance. Cows were classified based on MR as low (> 0.5 SD less than mean, LMR), moderate (± 0.5 SD of the mean, MMR) and high (> 0.5 SD greater than mean, HMR).

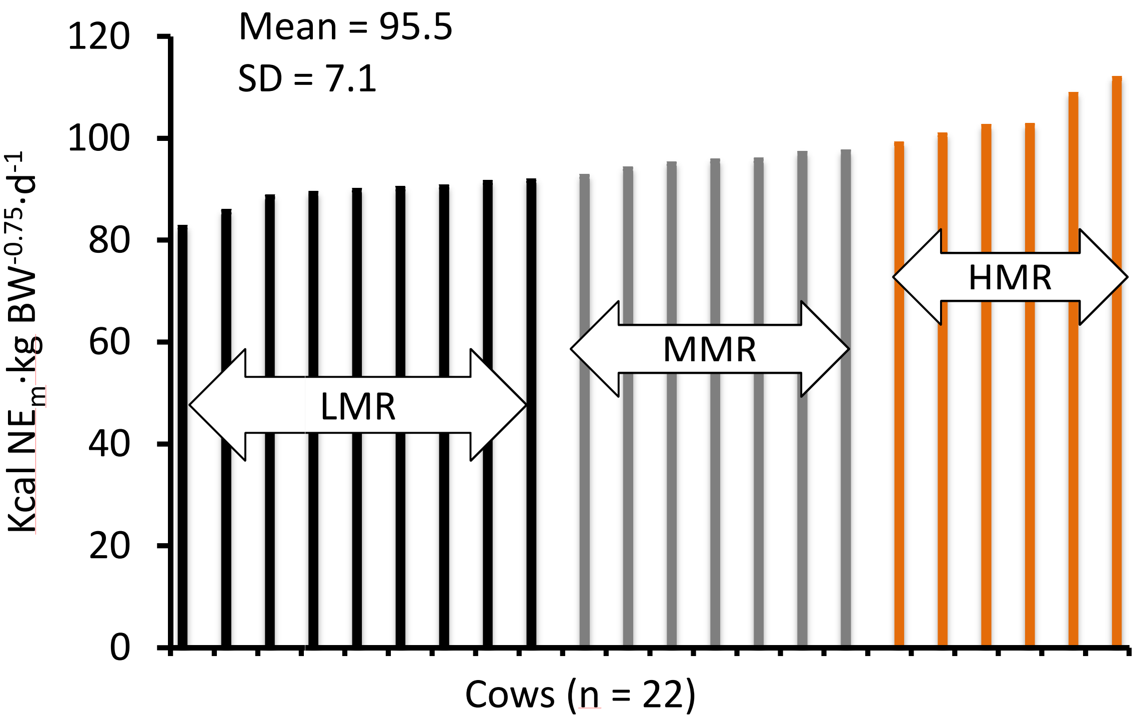

Figure 3. Maintenance energy requirements (MR, Kcal NE$_m$•kgBW$^{-0.75}$•d^{-1}) of cows during the period of body weight maintenance in Exp 3. Each bar represents the MR of each cow that achieved maintenance. Cows were classified based on MR as low (> 0.5 SD less than mean, LMR), moderate (± 0.5 SD of the mean, MMR) and high (> 0.5 SD greater than mean, HMR).

Table 3. Body weight of calves born to cows with low (LMR), moderate (MMR), or high (HMR) maintenance energy requirements (MR)

	MR[1]				
Item	LMR	MMR	HMR	SEM	*P* - value
Exp. 1					
Calves, no.	8	10	9		
Birth weight, kg	38.2	38.3	38.8	0.8	0.79
Exp. 2					
Calves, no.[2]	10	4	8		
Birth weight, kg	44.7	48.6	45.4	0.8	0.23
Exp. 1 and 2					
205 d Adjusted BW, kg	229	229	235	3	0.53
ADG, kg[3]	0.92	0.92	0.96	0.01	0.37

[1] Calves were classified based on MR of cows as low (> 0.5 SD less than mean, LMR), moderate (± 0.5 SD of the mean, MMR) and high (> 0.5 SD greater than mean, HMR).

[2] Two cows died shortly after calving and calves were sold.

[3] Average daily gain from birth to weaning.

Table 4. Concentrations of thyroxine and triiodothyronine in plasma of cows with low (LMR), moderate (MMR), or high (HMR) maintenance energy requirements (MR) fed MR or with ad libitum roughage in Exp. 1

	MR[1]				
Item	LMR	MMR	HMR	SEM	*P* - value
MR period[2]					
Cows, no.	8	10	9		
T_4, ng/mL	38.3	35.7	37.1	3.5	0.58
T_3, ng/mL	0.58	0.57	0.60	0.02	0.62
Early lactation[3]					
Cows, no.	8	10	9		
T_3, ng/mL	0.72	0.72	0.71	0.03	0.94

[1] Cows were classified based on MR as low (> 0.5 SD less than mean, LMR), moderate (± 0.5 SD of the mean, MMR) and high (> 0.5 SD greater than mean, HMR).

[2] Blood was sampled twice a day on two consecutive days when cows were fed MR.

[3] Blood was sampled twice a day on two consecutive days when cows had ad libitum roughage 65 ± 1 d after calving.

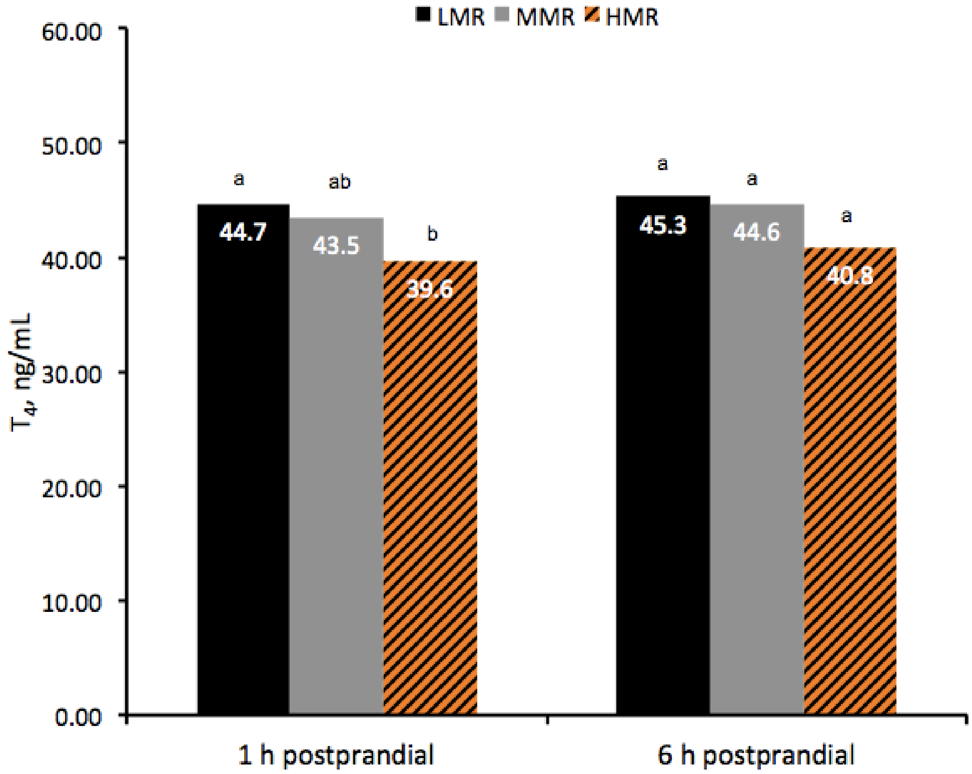

Figure 4. Effect of MR x time after consumption of diet on concentrations of thyroxine (T_4) in plasma of cows with ad libitum roughage during early lactation (65 ± 1 d) in Exp. 1. Samples were taken at 1 and 6 h postprandial on 2 days.

[a,b] Means within time without a common superscript differ ($P < 0.05$).

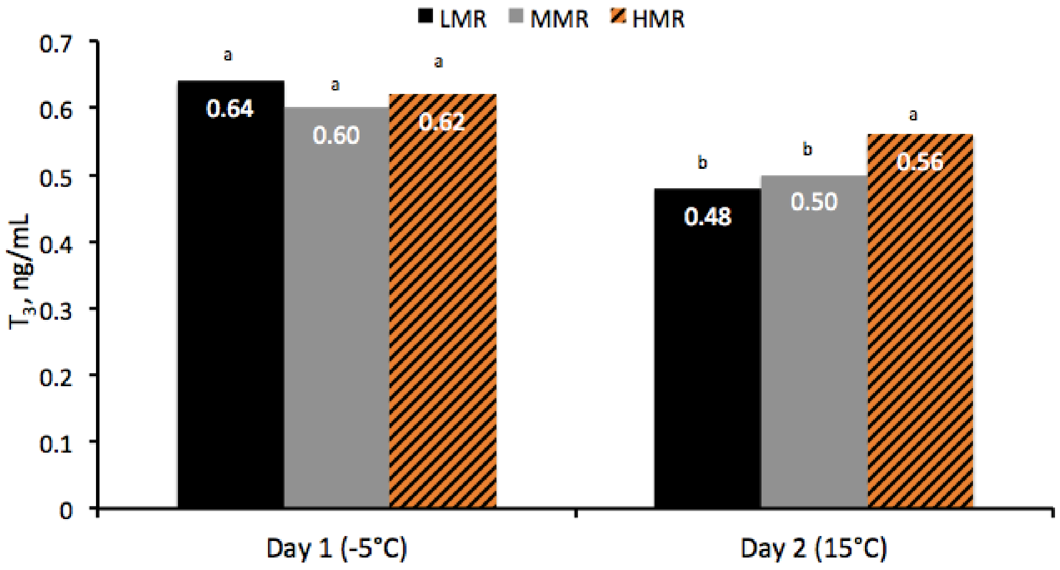

Figure 5. Effect of MR x day on concentrations of triiodothyronine (T_3) in plasma of cows fed MR (Exp. 2). Two samples were collected per cow on a day. Temperature is the maximum ambient temperature on that day.

^{a,b} Means within day without a common superscript differ ($P < 0.05$).

Table 5. Concentrations of triiodothyronine, and IGF-I in plasma of cows with low (LMR), moderate (MMR), or high (HMR) maintenance energy requirements (MR) fed MR or with ad libitum roughage in Exp. 2

	MR[1]				
Item	LMR	MMR	HMR	SEM	*P* - value
MR Period[2]					
Cows, no.	10	6	9		
IGF-I, ng/mL	101.8	130.8	117.7	21.9	0.58
Early Lactation[3]					
Cows, no.[4]	10	5	8		
T_3, ng/mL	0.58	0.59	0.54	0.04	0.27

[1] Cows were classified based on MR as low (> 0.5 SD less than mean, LMR), moderate (± 0.5 SD of the mean, MMR) and high (> 0.5 SD greater than mean, HMR).

[2] Blood was sampled twice a day on two days two weeks apart when cows were fed MR.

[3] Blood was sampled twice a day on two consecutive days when cows had ad libitum roughage 56 ± 2 d after calving.

[4] Two cows died after calving.

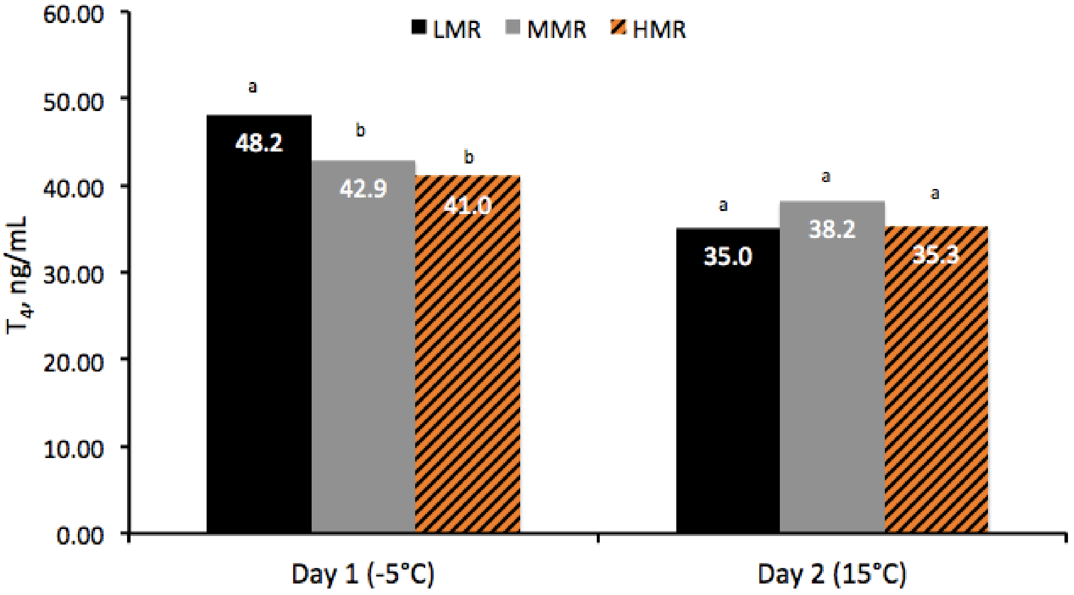

Figure 6. Effect of MR x day on concentrations of thyroxine (T_4) in plasma of cows fed MR (Exp. 2). Two samples were collected per cow on a day per cow on a day. Temperature is the maximum ambient temperature on that day.

^{a,b} Means within day without a common superscript differ ($P < 0.05$).

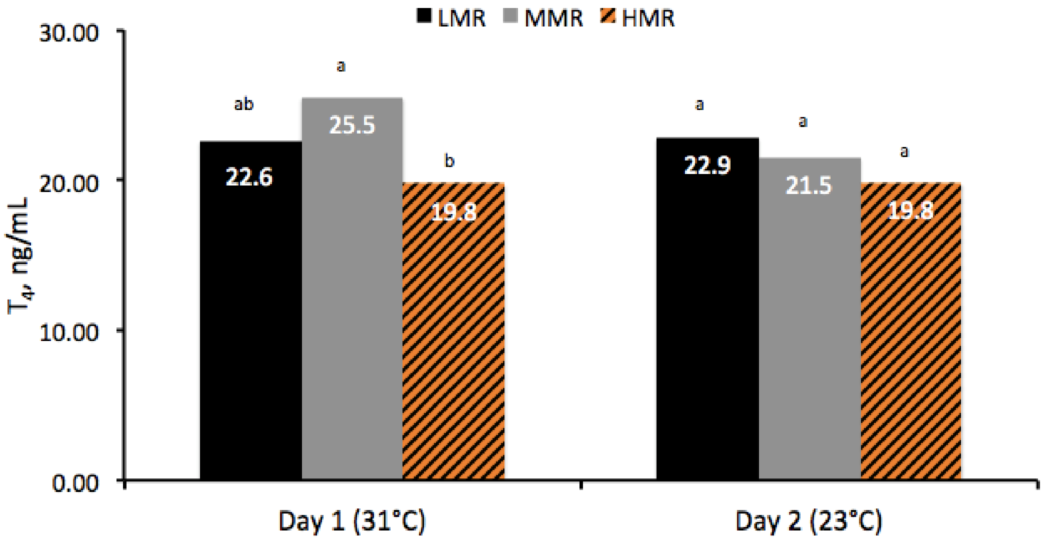

Figure 7. Effect of MR x day on concentrations of thyroxine (T_4) in plasma of cows with ad libitum roughage during early lactation (56 ± 2 d) Exp. 2. Two samples were collected per cow on a day per cow on a day. Temperature is the maximum ambient temperature on that day.
^{a,b} Means within day without a common superscript differ ($P < 0.05$).

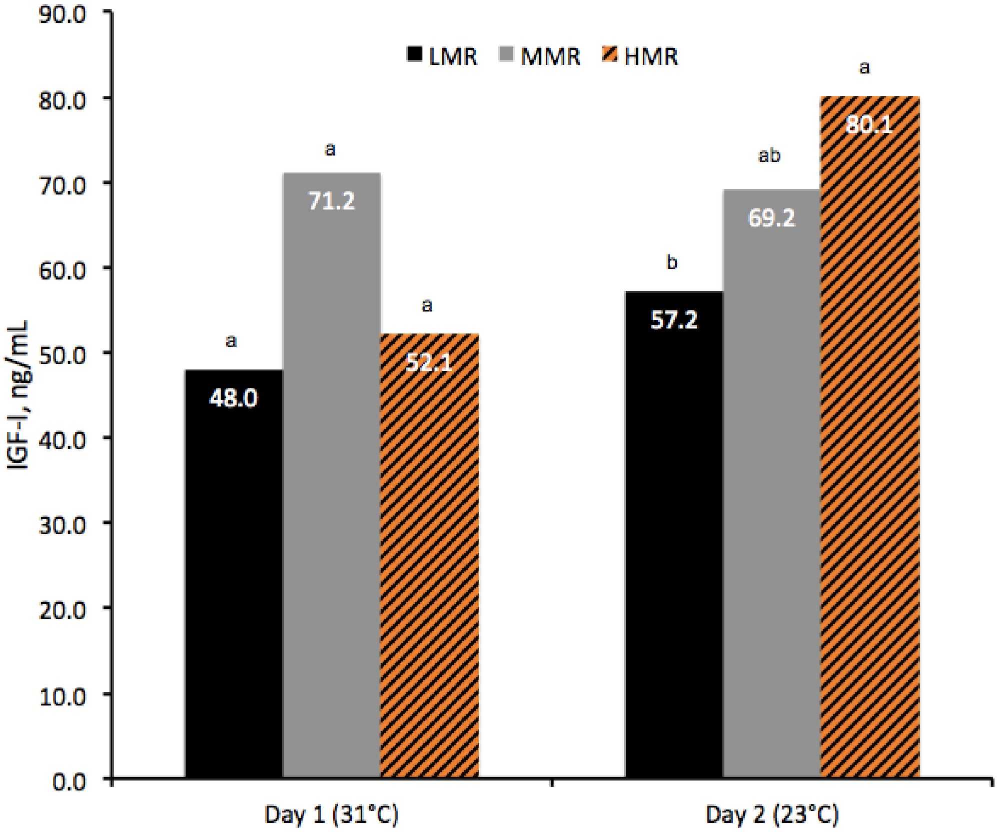

Figure 8. Effect of MR x day on concentrations of insulin-like growth factor-I (IGF-I) in plasma of cows with ad libitum roughage during early lactation (56 ± 2 d) in Exp. 2. Two samples were collected per cow on a day per cow on a day. Temperature is the maximum ambient temperature on that day.

^{a,b} Means within day without a common superscript differ ($P < 0.05$).

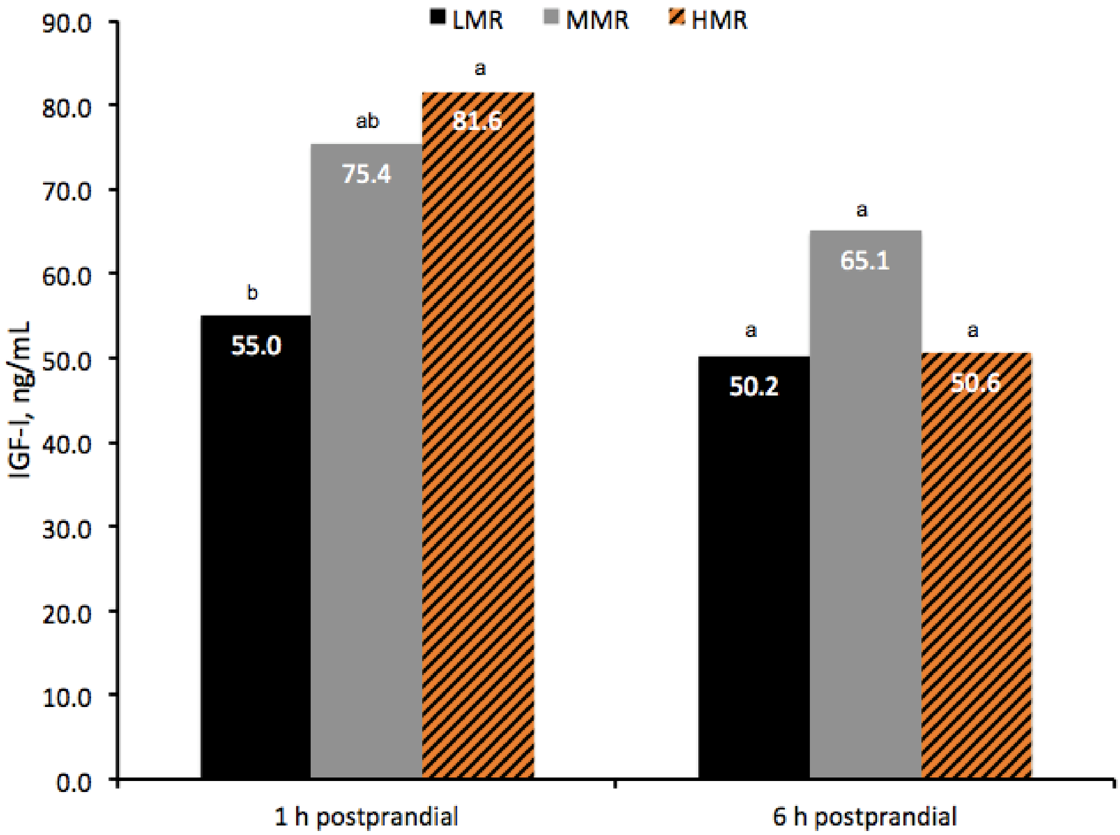

Figure 9. Effect of MR x time after consumption of diet on concentrations of insulin-like growth factor-I (IGF-I) in plasma of cows with ad libitum roughage during early lactation (56 ± 2 d) in Exp. 2. Samples were taken at 1 and 6 h postprandial on 2 d.

^{a,b} Means within full/shrunk without a common superscript differ ($P < 0.05$).

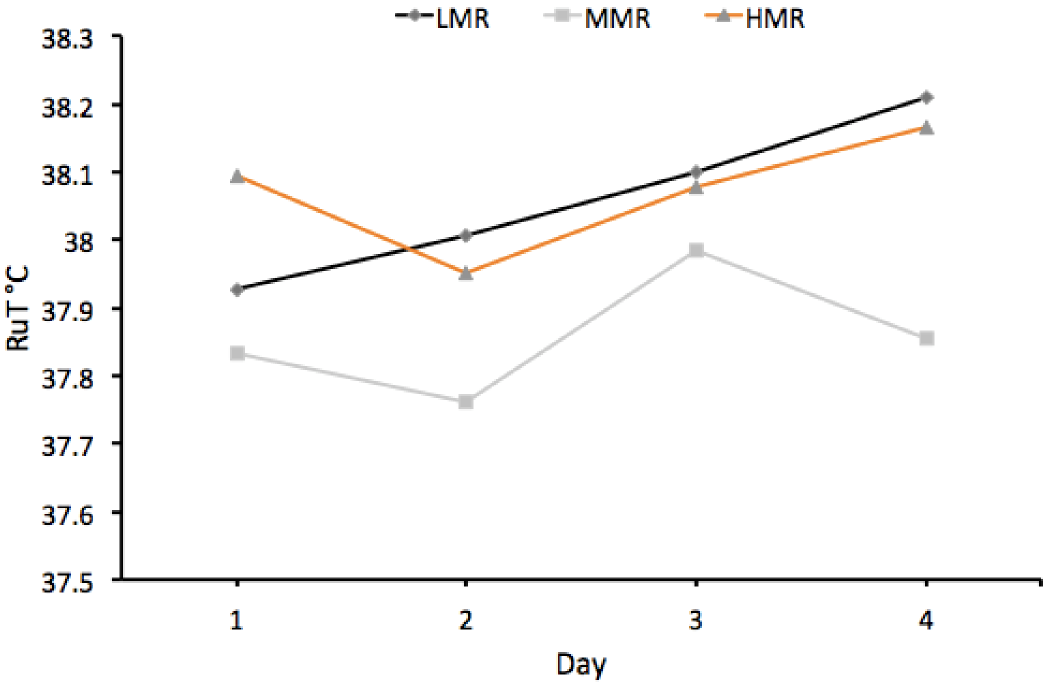

Figure 10. Effect of MR x day on ruminal temperature (RuT) of cows fed maintenance energy requirements during Exp. 2. MR x day (*P* = 0.05).

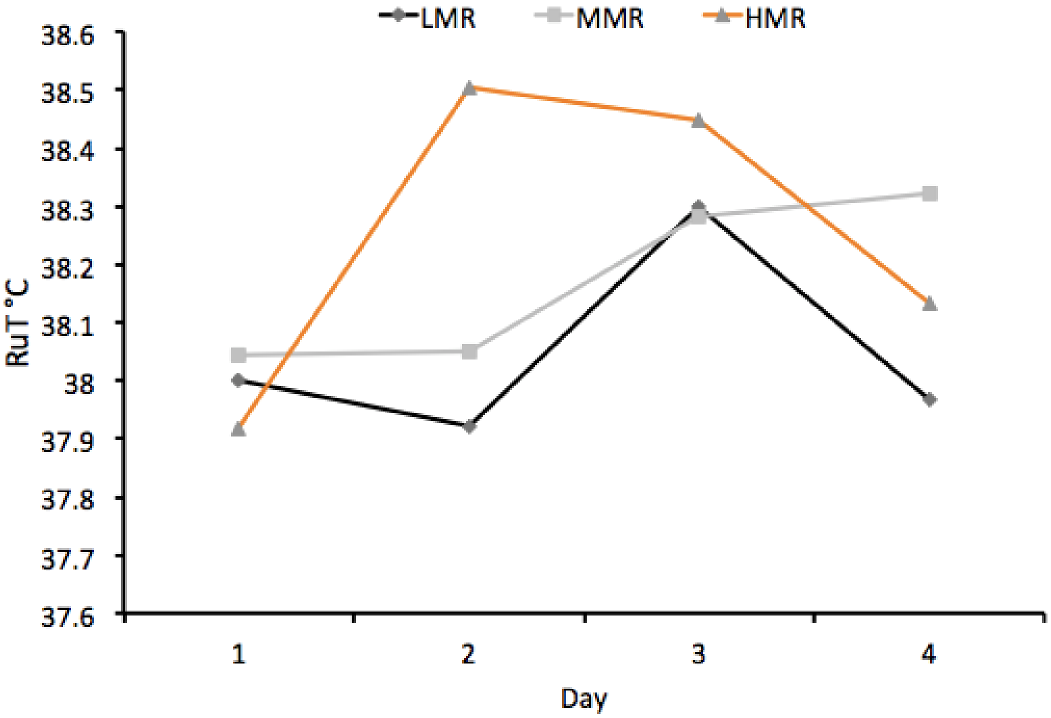

Figure 11. Effect of MR x day on ruminal temperature (RuT) of cows with ad libitum prairie hay during Exp. 2. MR x day (*P* = 0.18).

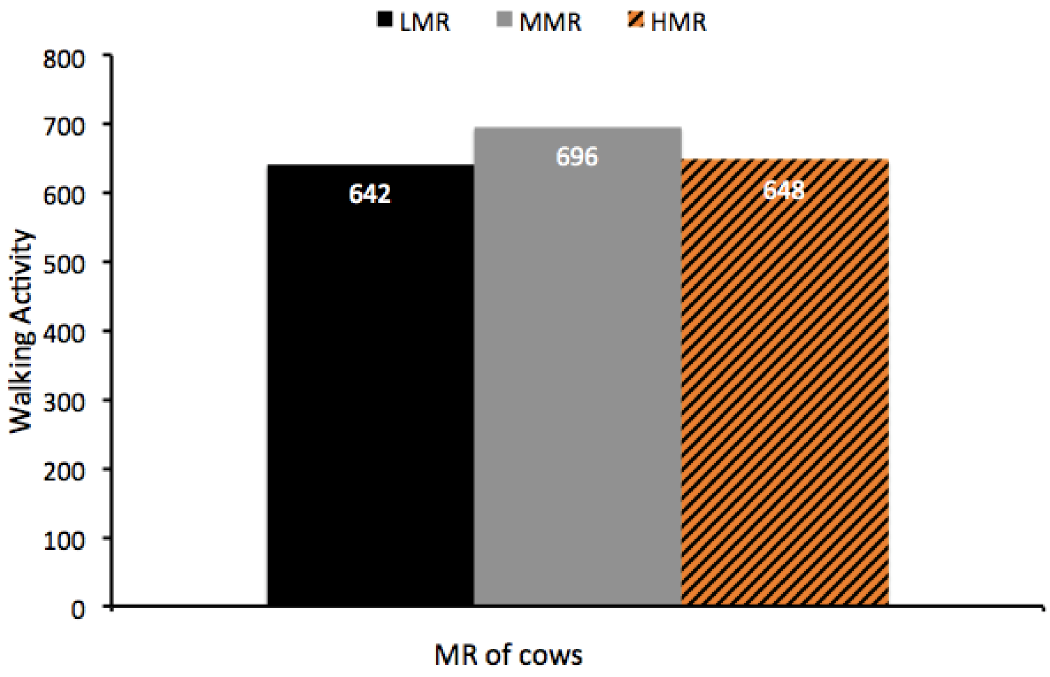

Figure 12. Least squares mean walking activity of cows with low (LMR), moderate (MMR), or high (HMR) maintenance energy requirements (MR). Cows were classified based on MR as low (> 0.5 SD less than mean, LMR), moderate (± 0.5 SD of the mean, MMR) and high (> 0.5 SD greater than mean, HMR). Walking activity represents the movement of cows as measured with a pedometer.

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APPPENDICES

Table 7. Least squares mean concentrations of thyroxine (T_4) and triiodothyronine (T_3) in plasma of cows fed maintenance energy requirements or with ad libitum roughage in Exp. 1

	Full			Shrunk				*P* - value			
Item	LMR	MMR	HMR	LMR	MMR	HMR	SEM	MR x sample x day	MR x sample	MR x day	MR
MR Period[3]											
Cows, no.	10	6	9	10	6	9					
Day 1[4]											
T_4, ng/mL	49.2	42.8	44.0	47.1	43.0	38.1	3.2	0.49	0.29	0.02	0.11
T_3, ng/mL	0.66	0.59	0.62	0.61	0.62	0.61	0.03	0.42	0.51	0.05	0.19
Day 2[5]											
T_4, ng/mL	35.1	39.5	36.0	37.3	36.8	35.2	3.2				
T_3, ng/mL	0.49	0.53	0.55	0.47	0.47	0.58	0.04				
Early Lactation[6]											
Cows, no.	10	5	8	10	5	8					
Day 1[7]											
T_4, ng/mL	22.4	24.7	19.9	22.9	26.4	19.6	1.7	0.35	0.96	0.04	0.12
T_3, ng/mL	0.61	0.70	0.58	0.61	0.58	0.54	0.05	0.13	0.87	0.62	0.27
Day 2[8]											
T_4, ng/mL	22.2	21.5	19.0	21.5	23.5	20.6	1.7				
T_3, ng/mL	0.53	0.48	0.49	0.57	0.60	0.53	0.05				

[1] Blood was sampled at 1500 h after consumption of MR (MR Period) and at 0700 h after cows were gathered off of native range pasture (Early Lactation).

[2] Blood was sampled at 0700 h prior to consumption of MR (MR Period) and at 1500 h after cows had been gathered off of native range pasture at 0700 h (Early Lactation).

[3] Blood was sampled twice a day on two days two weeks apart when cows were fed MR.
[4] Blood was sampled on a day when ambient temperature was 2 °C.
[5] Blood was sampled on a day when ambient temperature was 13 °C.
[6] Blood was sampled twice a day on two consecutive days when cows had ad libitum roughage 65 ± 1 d after calving.
[7] Blood was sampled on a day when ambient temperature was 26 °C.
[8] Blood was sampled on a day when ambient temperature was 28 °C.

Table 8. Least squares mean concentrations of thyroxine (T_4), triiodothyronine (T_3), and IGF-I in plasma of cows fed maintenance energy requirements or with ad libitum roughage in Exp. 2

	Full			Shrunk				*P* - value			
Item	LMR	MMR	HMR	LMR	MMR	HMR	SEM	MR x sample x day	MR x sample	MR x day	MR
MR Period[3]											
Cows, no.	10	6	9	10	6	9					
Day 1[4]											
T_4, ng/mL	49.2	42.8	44.0	47.1	43.0	38.1	3.2	0.49	0.29	0.02	0.11
T_3, ng/mL	0.66	0.59	0.62	0.61	0.62	0.61	0.03	0.42	0.51	0.05	0.19
IGF-I, ng/mL	110.1	119.6	128.5	109.9	139.8	117.8	26.0	0.63	0.78	0.85	0.58
Day 2[5]											
T_4, ng/mL	35.1	39.5	36.0	37.3	36.8	35.2	3.2				
T_3, ng/mL	0.49	0.53	0.55	0.47	0.47	0.58	0.04				
IGF-I, ng/mL	96.7	127.3	105.0	90.4	136.5	119.3	24.3				
Early Lactation[6]											
Cows, no.	10	5	8	10	5	8					
Day 1[7]											
T_4, ng/mL	22.4	24.7	19.9	22.9	26.4	19.6	1.7	0.35	0.96	0.04	0.12
T_3, ng/mL	0.61	0.70	0.58	0.61	0.58	0.54	0.05	0.13	0.87	0.62	0.27
IGF-I, ng/mL	50.7	75.9	61.9	45.3	66.6	42.2	16.7	0.41	0.02	0.03	0.24
Day 2[8]											
T_4, ng/mL	22.2	21.5	19.0	21.5	23.5	20.6	1.7				
T_3, ng/mL	0.53	0.48	0.49	0.57	0.60	0.53	0.05				
IGF-I, ng/mL	59.3	74.8	101.2	55.0	63.6	59.0	17.4				

[1] Blood was sampled at 1500 h after consumption of MR (MR Period) and at 0700 h after cows were gathered off of native range pasture (Early Lactation).

[2] Blood was sampled at 0700 h prior to consumption of MR (MR Period) and at 1500 h after cows had been gathered off of native range pasture at 0700 h (Early Lactation).

[3] Blood was sampled twice a day on two days two weeks apart when cows were fed MR.

[4] Blood was sampled on a day when ambient temperature was -5 °C.

[5] Blood was sampled on a day when ambient temperature was 15 °C.

[6] Blood was sampled twice a day on two consecutive days when cows had ad libitum roughage 56 ± 2 d after calving.

[7] Blood was sampled on a day when ambient temperature was 31 °C.

[8] Blood was sampled on a day when ambient temperature was 23 °C.

Table 9. Ruminal temperature (RuT) of cows with low (LMR), moderate (MMR), or high (HMR) maintenance energy requirements

	MR[1]				*P* - value	
Item	LMR	MMR	HMR	SEM	MR	MR x day
MR Period[2]						
Cows, no.[3]	7	3	8			
RuT °C					0.59	0.05
Day 1	37.93	37.80	38.09	0.22		
Day 2	38.01	37.76	37.95	0.28		
Day 3	38.10	38.00	38.08	0.29		
Day 4	38.20	37.86	38.17	0.23		
Ad libitum roughage[4]						
Cows, no.	7	3	8			
RuT °C					0.81	0.18
Day 1	38.04	37.92	38.00	0.47		
Day 2	38.05	38.51	37.92	0.47		
Day 3	38.28	38.45	38.30	0.49		
Day 4	38.32	38.13	37.97	0.48		

[1] Cows were classified based on MR as low (> 0.5 SD less than mean, LMR), moderate (± 0.5 SD of the mean, MMR) and high (> 0.5 SD greater than mean, HMR).

[2] Ruminal temperature was collected for four consecutive days while cows consumed maintenance energy requirements.

[3] Cows had ≥ 6 readings per day.

[4] Ruminal temperature was collected for four consecutive days while cows had ad libitum roughage.

Simple correlation coefficients (r/*P* value), among maintenance energy requirements (MR), thyroxine (T_4), and triiodothyronine (T_3) for pregnant, nonlactating beef cows (n = 27) fed maintenance (MR Period) and for nonpregnant cows (n=27) during early lactation in Exp. 1

MR Period[1]	T_3	T_4
MR	0.09	0.45
	0.61	0.02
T_4	0.49	
	< 0.001	
Early Lactation[2]		
MR	- 0.21	0.30
	0.29	0.12
T_4	0.47	
	< 0.001	

[1] Blood was sampled twice a day on two consecutive days when cows were fed MR.

[2] Hormone samples averaged for each cow (n = 27), when correlated with MR, during MR period and early lactation.

[3] All hormone samples used for correlation (n = 108).

[4] Blood was sampled twice a day on two consecutive days when cows had ad libitum roughage 65 ± 1 d after calving.

Correlation coefficients (r/*P* value), between maintenance energy requirements (MR), thyroxine (T_4), triiodothyronine (T_3), and insulin-like growth factor-I (IGF-I) for pregnant, nonlactating beef cows (n = 25) fed maintenance (MR Period) and for nonpregnant cows (n = 25) during early lactation in Exp. 2

MR Period[1]	IGF-I	T_3	T_4
MR[2]	0.41	0.21	- 0.47
	0.04	0.31	0.02
T_4[3]	- 0.00	0.41	
	0.98	< 0.001	
T_3	0.18		
	0.10		
Early Lactation[4]			
MR	0.19	- 0.29	- 0.45
	0.39	0.18	0.03
T_4	- 0.03	0.23	
	0.77	0.03	
T_3	0.02		
	0.87		

[1] Blood was sampled twice a day on two days two weeks apart when cows were fed MR.

[2] Hormone samples averaged for each cow (n = 25), when correlated with MR, during MR period and early lactation.

[3] All hormone samples used for correlation (n = 100).

[4] Blood was sampled twice a day on two consecutive days when cows had ad libitum roughage 56 ± 2 d after calving.

VITA

Timothy Austin Pye

Candidate for the Degree of

Master of Science

Thesis: MAINTENANCE ENERGY REQUIREMENTS, RUMINAL TEMPERATURE, WALKING ACTIVITY, AND PLASMA CONCENTRATIONS OF IGF-I, THYROXINE, AND TRIIODOTHYRONINE OF GESTATING BEEF COWS

Major Field: Animal Science

Biographical:

Education:

Completed the requirements for the Master of Science in Animal Science at Oklahoma State University, Stillwater, Oklahoma in July, 2011.

Completed the requirements for the Bachelor of Science in Animal Science at Oklahoma State University, Stillwater, Oklahoma in May, 2009

Experience:

Oklahoma Agricultural Experiment Station, Stillwater, OK
Animal Science Research Assistant, June 2009 – May 2011

Trendsetter Genetics, Stillwater, OK
Operations Manager, August 2005 – May 2011

Professional Memberships: American Society of Animal Science

Name: Timothy A. Pye Date of Degree: July, 2011

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: MAINTENANCE ENERGY REQUIREMENTS, RUMINAL TEMPERATURE, WALKING ACTIVITY, AND PLASMA CONCENTRATIONS OF IGF-I, THYROXINE, AND TRIIODOTHYRONINE OF GESTATING BEEF COWS

Pages in Study: 73 Candidate for the Degree of Master of Science

Major Field: Animal Science

Scope and Method of Study: Three experiments of spring calving, Angus cows were used to determine the effect of maintenance energy requirements (MR) on ruminal temperature (RuT), walking activity, and plasma concentrations of IGF-I, thyroxine (T_4), and triiodothyronine (T_3). Cows (4 – 7 yr: 5 – 7 mo gestation) were individually fed a complete diet, calculated to supply MR (Model 1; NRC, 1996), for 10, 17, and 13 wk for Exp. 1, 2, and 3, respectively. The diet was adjusted weekly, no more often than once every two wk, until constant BW was achieved (regression analysis). Body weight was maintained for 21, 31, and 36 d for Exp. 1, 2, and 3, respectively. Cows were classified based on MR as low (> 0.5 SD less than mean, LMR), moderate (± 0.5 SD of the mean, MMR) and high (> 0.5 SD greater than mean, HMR).

Findings and Conclusions: Average MR was 80.7 (SD = 4.84), 94.4 (SD = 8.00), and 95.5 (SD = 7.10) Kcal $NE_m \bullet kg^{-0.75} \bullet day^{-1}$ for Exp. 1, 2, and 3, respectively. The difference in the least efficient and most efficient cow was 33, 32, and 35% for Exp. 1, 2, and 3, respectively. When cows consumed ad libitum prairie grass (early lactation), MR did influence plasma concentrations of T_4; when cows were full (1 h postprandial) LMR had greater concentrations of T_4 compared with HMR ($P = 0.05$). In Exp. 2 when cows consumed MR and were exposed to cooler temperatures (-5 °C), LMR cows had greater plasma T_4 ($P \leq 0.03$) compared with MMR and HMR. When exposed to warmer temperatures (15 °C), HMR cows had greater plasma T_3 compared with LMR and MMR ($P = 0.05$). During early lactation MMR had greater concentrations of T_4 compared to HMR cows ($P = 0.05$). When cows had ad libitum roughage during early lactation HMR had greater ($P = 0.05$) plasma concentrations of IGF-I compared with LMR cows on day 2 and HMR had greater ($P = 0.04$) concentrations of IGF-I compared with LMR cows 1 h postprandial. Ruminal temperature and walking activity were not influenced by MR. Identification of cows with lower MR and greater efficiency could improve the profitability of beef production.

Keywords: beef cows, IGF-I, rumen temperature, thyroxine, triiodothyronine

ADVISER'S APPROVAL: Dr. Robert P. Wettemann