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FACULDADE DE ZOOTECNIA E ENGENHARIA DE ALIMENTOS

BARBARA ROQUETO DOS REIS

Identification of energetically efficient mature cows and characterization of biological differences between efficient and inefficient cows

PIRASSUNUNGA
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Corrected version

A Dissertation submitted to Faculdade de Zootecnia e Engenharia de Alimentos da Universidade São Paulo in partial fulfillment of the requirements for the degree of Master of Science

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LIST OF ABBREVIATIONS

ADF	Acid detergent fiber
ADG	Average daily gain
ARC	Agricultural research council
BCS	Body condition score
BW	Body weight
$BW^{0.75}$	Metabolic body weight
CF	Crude fat
CH_4	Methane
CHO	Carbohydrate
CP	Crude protein
CVDS	Cattle Value Discovery System
DE	Digestible energy
DEI	Digestible energy intake
DM	Dry matter
DMD	Dry matter digestibility
DMI	Dry matter intake
EB	Energy balance
ECM	Energy corrected milk
EEI	Energy Efficiency Index
EPD	Expected progeny difference
FBW	Final body weight
FE	Fecal energy
FECHO	Fecal carbohydrate
FEFAT	Fecal fat
FEPROT	Fecal protein
FHP	Fast heat production
GE	Gaseous energy

HE	Heat energy
HP	Heat production
HR	Heart rate
IBW	Initial body weight
IE	Intake energy
IFAT	Internal fat
IMF	Intramuscular fat
iNDF	Indigestible neutral detergent fiber
Km	Efficiency of metabolizable energy used for maintenance
LMA	Longissimus muscle area
LW	Live Weight
ME	Metabolizable energy
MEI	Metabolizable energy intake
MEm	Metabolizable energy required for maintenance
MER	Metabolizable energy requirement
N	Nitrogen
NDF	Neutral detergent fiber
NRC	National research council
O_2	Oxygen
O_2P-	HR Oxygen Pulse Methodology
OM	Organic matter
PKM	Predicted peak milk
PROT	Protein
RE	Retained energy
SD	Standard deviation
STP	Standard temperature and pressure
UE	Urinary energy
WW	Weaning weight

REIS, B.R. **Identification of energetically efficient mature cows and characterization of biological differences between efficient and inefficient cows**. 2018. 65 f. Dissertation– Faculdade de Zootecnia e Engenharia de Alimentos, Universidade de São Paulo, Pirassununga, 2018.

ABSTRACT

Beef cows classified as efficient utilize less resources to achieve the same output than inefficient animals in a sustainable environment. The objective of this study was to utilize a mathematical model to identify beef cows that use energy more efficiently to support maintenance requirements and calf growth based an energy efficiency index (EEI). The EEI was computed as the ratio of metabolizable energy requirements (MER) of the cow to weaning weight of the calf. Data were collected from one herd of 69 Angus crossbred cows over two consecutive years for a performance experiment. The EEI was used to rank the cows for efficiency, cows with low EEI are more efficient because they require less metabolizable energy for the same calf weaning weight. After the cows were ranked in year 1, low (n=8) and high (n=8) EEI cows were selected for an energy metabolism experiment during late lactation and late gestation in year 2. Relationships among performance and efficiency traits were computed with PROC CORR of SAS. Metabolism experiment data were analyzed as a randomized complete block design using PROC MIXED of SAS with side of barn as the random blocking factor. Correlation coefficients were considered different from zero and LSmeans were considered different at $P < 0.05$. The EEI was strongly negatively correlated ($P < 0.05$) with model predicted peak milk and calf weaning weight, and moderately, positively correlated ($P < 0.05$) with cow body weight in both years such that more efficient cows weaned heavier calves and had lesser body weight. Energy efficiency index was moderately, positively correlated ($P < 0.05$) among years indicating that those cows ranked as efficient in one year tend to be more efficient cows in subsequent years. Low EEI cows had lesser ($P < 0.05$) dry matter digestibility during late lactation, but not during late gestation than high EEI cows. There were no differences in energy metabolism between low and high EEI cows during late lactation or late gestation. In conclusion, more efficient cows based on EEI wean heavier calves and require less energy but the mechanism by which low EEI cows are more efficient does not appear to be differences in the energy partitioning.

Key words: energy efficiency, beef cattle, energy efficiency index.

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RESUMO

Vacas de corte classificadas como eficientes utilizam menos recursos para obter o mesmo resultados que animais ineficientes em um ambiente sustentável. O objetivo do presente estudo foi a utilização de um modelo matemático para identificar vacas de corte que utilizam energia de forma mais eficiente para suportar sua exigência de mantença e a exigência de crescimento do bezerro baseado no índice de eficiência energética (IEE). O Índice de eficiência energética foi computado como a relação entre a exigência de mantença da vaca e o peso do bezerro ao desmame. Foram utilizadas 69 vacas cruzadas da raça Angus durante dois anos consecutivos para um experimento de desempenho. As vacas foram ranqueadas pelo IEE, vacas com menor IEE são mais eficientes, pois necessitam de menos energia metabolizável para o mesmo peso ao desmame de bezerros. Após os animais serem ranqueadas por eficiência no ano 1, vacas com baixo (n=8) e alto (n=8) EEI foram selecionas para um experimento de metabolismo energético durante o fim da lactação e fim da gestação no segundo ano. Foi utilizado o PROC CORR do SAS para as análises de desempenho e eficiência. As interpretações dos resultados do experimento de metabolismo foram realizadas utilizando o PROC MIXED do SAS sendo o lado da baia como efeito aleatório do bloco. Os coeficientes de correlação foram considerados diferente de zero e a medias foram consideradas diferentes quando $P<0.05$. O índice de eficiência energética foi negativamente correlacionado ($P < 0.05$)

com o pico de leite predito pelo modelo e com o peso do bezerro ao desmame, e teve o correlação positiva moderada ($P< 0.05$) com o peso corporal das vacas nos dois anos de estudo, vacas mais eficientes desmamaram bezerros mais pesados e possuem menor peso corporal. Entre os anos, EEI apresentou uma correlação positiva moderada ($P< 0.05$) indicando que as vacas consideradas eficientes tendem a ser eficientes nos próximos anos. Vacas com baixo IEE apresentaram ($P<0.05$) menor digestibilidade da matéria seca durante o fim da lactação em relação as vacas com alto IEE, porém, não apresentaram diferenças durante o fim da gestação. Vacas com baixo e alto IEE não apresentaram diferença estatística em relação ao metabolismo energético durante o fim da gestação e lactação. Como conclusão, vacas eficientes baseada no IEE desmamam bezerros mais pesados e necessitam de menor quantidade de energia, entretanto, o mecanismo pelo qual vacas com menor IEE se apresentam mais eficientes não se apresenta relacionado com as diferenças no particionamento de energia.

Palavras chaves: eficiência energética, vacas de corte, índice de eficiência energética.

1. INTRODUCTION

The production of beef has increased in the last 40 years due to enhancements in animal efficiency (FAO,2011). However, the system has to continue to improve the efficiency to meet the expected increase in world population from 7,4 billion in 2016 to 8,1 billion in 2025 making world food demand in 2050 60% higher than in 2006 (FAO, 2016). Beef production is a relatively inefficient process with 70 to 75% of feed used for maintenance requirements (Ferrell and Jenkins, 1985).

In a sustainable environment, to produce the same output efficient beef cows need to use fewer resources (Tedeschi et al, 2004). The profitability of the system depends on inputs and outputs and feed is the greatest input cost, thus, the selection for more efficient animals in growth phase has received a lot of attention to improve economic and environmental sustainability of the beef cattle industry (Herd et al., 2011; Arthur et al., 2004). However, less research has focused on improving feed efficiency of the cow-calf sector of the beef industry. According to Ferrell and Jenkins, (1982) the cow-calf sector uses 65% of the metabolizable energy (ME) consumed from conception to harvest. Jenkins and Ferrell (1994) found that the ranking of different beef breeds for feed efficiency during the cow-calf sector was dependent upon feed availability indicating that the biological type of beef female that is most efficient will be different for different nutritional environments. Fox et al (2004) indicated that the identification of the most efficient cows could contribute to best matching of ME requirements with feed energy available, which would improve system efficiency. Therefore, to improve feed efficiency of the cow-calf sector, traits that identify cows with greater ability to convert feed into heavier weaned calves are needed.

The Cattle Value Discovery System (CVDS) is a mathematical model developed by Tedeschi et al. (2006) to calculate an Energy Efficiency Index (EEI) for beef cows to estimate the ratio of energy required (metabolizable energy- ME, Mcal) by a cow to pounds (or kilos) of weaned calf (energy efficiency index- EEI, Mcal/lb or Mcal/kg), the lower EEI represents the more efficient cow. However, little data is available evaluating energy efficiency index in beef cows, but EEI shows potential as a trait to identify efficient beef cows. It is important to evaluate the accuracy of the model to identified cows that are more energetically efficient as well as relationships with other production traits.

2. LITERATURE REVIEW

2.1 Cow energy Efficiency

In the last forty years a significant increase in productivity has been occurring accompanied by an improvement in quality as a result of research directed toward improving the efficiency of the beef production system. Much of this research has been directed toward of the requirements for maintenance and weight gain in growing and finishing beef cattle; the efficiency of the mature beef cow has received little attention. However, the importance of the mature beef cow cannot be neglected, with 60 to 70% of the total of energy expenditure used to produce beef being attributed to the cow-calf sector (Johnson et al., 2003); approximately 50% of this energy is expended to maintain the cow.

The energy requirement for maintenance represents the quantity of energy required to maintain body weight constant (Crooker et al., 1991), and is equivalent to fasting heat production (Reynolds, 2002). As described by Ferrell (1988), at least 70% of feed expenses are directed toward cow maintenance. Ferrell and Jenkins (1985) found that 73% of ME consumed by a mature cow are utilized for maintenance and feed costs represented about 42% of total annual cow costs (Mc Grann,1999). Therefore, an ability to select for a reduction in maintenance requirements would help to improve the efficiency of energy use.

Cow efficiency has been described as the ability of the cow to convert feed resources to calf weight at weaning (Jenkins and Ferrell, 1994). Efficient beef cows use fewer resources to produce the same weaning weight in a sustainable environment, according to Tedeschi et al. (2004). Measures of cow efficiency have been expressed as the ratio of output to input. Green et al. (1991) calculated the efficiency as the calf weight gain per metabolizable intake (MEI) for cow and calf; Jenkins and Ferrell (2004) as grams of calf weight gain per kg of dry matter intake by cow and calf.

It is important to realize that a particular cow that is efficient under one production situation may not be the same under all conditions. In a more restrictive nutritional environment animals having genetic potential for high production (e.g., milk production, rate of growth) may have less advantage compared with animals having low potential for production concluding that requirements for maintenance per unit of metabolic body weight ($BW^{0.75}$) is positively related to production potential (Ferrell and Jenkins, 1984,1985).

Pregnant, nonlactating and nonpregnant cows seems to be similar estimates of maintenance but maintenance requirements are increased during lactation (Ferrell and Jenkins, 1985). The 23% of the variation in energy requirements for maintenance can be explained by milk production variation (Montano- Bermudez et al., 1989). The primary source of maintenance energy expenditure variation is assigned to variation in body composition as reported by Graham (1974), Graham et al. (1976), and Ferrell et al. (1979), who showed body lean or protein mass to be strongly correlated with maintenance energy expenditures; maintenance energy requirements were poorly correlated with body fat mass.

DiCostanzo et al. (1991) characterized efficient and inefficient beef cows, noted that inefficient cows have a more complete digestion of feedstuffs than efficient cows, and suggested that to meet their higher maintenance energy costs they may need to utilize their feed more efficiently. DiCostanzo et al. (1991) also noted that inefficient beef cows had higher ME requirements for maintenance and this may be explained because they tended to have less fat and higher rate of protein accretion than average or efficient beef cows, which, for beef cattle, it is more energetically efficient to maintain fat than protein (Kielanowski,1976). There are many factors, such as temperament, maintenance requirements, and milk production, which might affect the ability of the cow to convert available forage resources to pounds of calf weaned. For these reasons, new techniques for identifying more efficient beef cows need to be evaluated.

2.2 Energy and Maintenance Requirements

The ruminant’s efficiency in using food energy is low compared with nonruminant species (Blaxter, 1962). Due to the forage-based diets fed to ruminants, fecal energy losses are substantially greater in ruminant than nonruminant species accounting for the single greatest loss of food energy in ruminant animals. Heat production is the second greatest loss of food energy. Heat production is positively correlated with dry matter intake, body size, thermoregulation and fat and protein deposition (Herd et al., 2004).

Digestible energy (DE) varies with the physical and chemical nature of the feed that affect nutrient digestion and thus fecal energy losses (AFRC, 1993). Conversion of DE to ME is affected by urinary energy losses, primarily due to incomplete combustion of nitrogenous compounds, and gaseous energy losses due to methane produce as end product of anaerobic fermentation in the rumen, but also loss of carbon dioxide, nitrous oxide, and hydrogen sulfide from the rumen (NRC, 1996). Metabolizable energy is defined as the energy available for the production of heat and deposition of body tissue (energy retained) and/or for lactation, gestation, egg production (Ferrell and Jenkins, 1985; NRC, 1996). Thus, metabolizable energy required for maintenance is established when retained energy is zero and all ME ingested by the animal is converted to heat (NRC, 2016). The maintenance requirements for mature animals varies according to changes in physiological state and is influenced by factors such as physical activity, hair length, heat or cold stress; and because of this, the net energy requirement for maintenance and production were separated (Crooker et al., 1991; NRC, 2001). The net energy required for maintenance is defined as the amount of energy required for heat production in the fasted stage, being equivalent to 77 Kcal/BW$^{0.75}$ (Lofgreen & Garret, 1968) for British breeds of beef cattle.

The energy requirements for maintenance, growth, gestation and lactation change with the type of animal. Ferrell and Jenkins (1985) suggested that body condition variation may not be a determinant factor of the maintenance requirement, although other researchers consider that body condition quantifies beef cows energy status and their variation alters mature cows energy requirements for maintenance (Santos & Amstalden,1998). Reynolds & Tyrrell, (2000) evaluated non-lactating and lactating Hereford X Angus cows and found that heat production was lower for non-lactating than for lactating heifers which also had higher metabolizable intake suggesting that lactating animals have a higher maintenance requirement.

During a complete production cycle, the energy cost for a 500 Kg cow to produce 1400 kg of milk during 205 days of lactating period would be 5450 Mcal of ME; i.e., 1400 Mcal of ME for lactation (Jenkins & Ferrell, 1983), 535 Mcal ME for gestation (Ferrell et al., 1976) and 4825 Mcal of ME for maintenance (NRC 2001). Jenkins & Ferrell (1993), found in a study with multiparous cows of different sizes and milk production levels that those receiving less amounts of food weaned lighter calves, however, they were more efficient in converting energy from diet to calf weight, which indicates that breeds or breed crosses characterized by intermediate potential for growth and milk production are more efficient during lactation.

Three methods are used to measure maintenance requirements. These include the use of long-term feeding trials to determine the amount of feed needed to maintain body weight after feeding a predetermined amount of feed over a long period of time (Taylor et al., 1981, 1986), calorimetric methods and comparative slaughter (NRC, 2016).

2.3 Oxygen Pulse Methodology (O_2P-HR)

The main factors according to the literature that affect energy partitioning in ruminants are: food intake level, environmental conditions, energy expenditure or heat production, milk production or gain in body tissue and energy efficiency for maintenance and production (Brosh, 2007). Calculating animal energy balance, heat production represents a substantial component of the ruminant’s energy balance (Castro Bulle et al.,2007).

Respiration chambers (Rodriguez et al., 2007) and double labeled water (Fancy et al., 1986) can be used to determine heat production (HP). However, these methods are expensive and executed in artificial conditions and training of animals is required. Other methods have been studied by researchers to estimate heat production under natural conditions. The possibility of measuring HP from heart rate (HR) has been studied by several research groups (Webster, 1967; Warnold & Lenner, 1977, Brosh, 2007). The correlations between HP and HR in humans (Andrews, 1971) and animals (Webster, 1967) is strong such that HR can be a reliable method to measure HP of animals in their natural conditions.

Based on long-term measurements (24-h periods) of HR and oxygen pulse (O_2P; mL of O_2 consumed/heart beat) the O_2P-HR method can be an alternative technique to determine HP (Brosh, 2007). This technique is highly correlated with that obtained directly in the calorimetric chamber (r= 0.943) (Ceesay et al.,1989).

To obtain accurate heat production estimates and the volume of the O_2 consumed per day, the HR should be monitored for at least 24 hours and oxygen consumption by heart rate for a period of 15- 20 minutes (Aharoni et al., 2003; Brosh et al., 1998). The oxygen consumption per heart beat of each individual is considered constant since the animal is not under stress, which allows the O_2P-HR methodology to be performed in short periods of evaluation (Aharoni et al., 2007). It is important to minimize animal stress during measurements, if the animals are under stress the HR can be more than 20% of that expressed under normal conditions and the estimates of HP will be overestimated (Brosh, 2007).

2.4 Energy Efficiency Index (EEI)

Due the expected increase of 34% in human population by 2050, the global demand for food protein (e.g., meat, fish, eggs, and dairy) is expected to increase (National Research Council; NRC,2016). Under these circumstances, innovations and investments are needed in animal science research and development in order to meet this increased demand (Tedeschi et al., 2005). Mathematical ruminant nutrition models is a tool to be used to integrate the knowledge of feed, intake and microbial growth efficiency, through estimating animal requirements and nutrients derived from feed in different farm production scenario to improve efficiency (Tedeschi et al.,2005). Based on the models described by Fox et al. (1988) and Reynoso-Campos et al. (2004) with some modifications, Tedeschi et al. (2004) developed a beef cow model for use in the Cattle Value Discovery System (CVDS). The model uses available inputs from production such as body weight of cows, birth and weaning weight of calves, and forage nutritive value to make an estimation of energy requirements for maintenance, gestation and lactation energy requirements for each cow. The EEI is then computed as the ratio of total metabolizable energy required to weaning weight of the calf (Mcal/kg).

The model was developed to estimate cow’s daily energy requirements with interactions between lactation and calf weaning weight. Briefly, requirements for maintenance are adjusted for conceptus weight, environment, physical activity, and physiological status, as predicted by NRC (2000). Requirements for pregnancy and lactation are also calculated using NRC (2000) recommendations. Milk production is computed through iteration, by changing peak milk until predicted WW matches the observed calf weaning weight (WW). Estimates of forage and milk intake by the calf are obtained from a model based on data from Abdelsamei (1989).

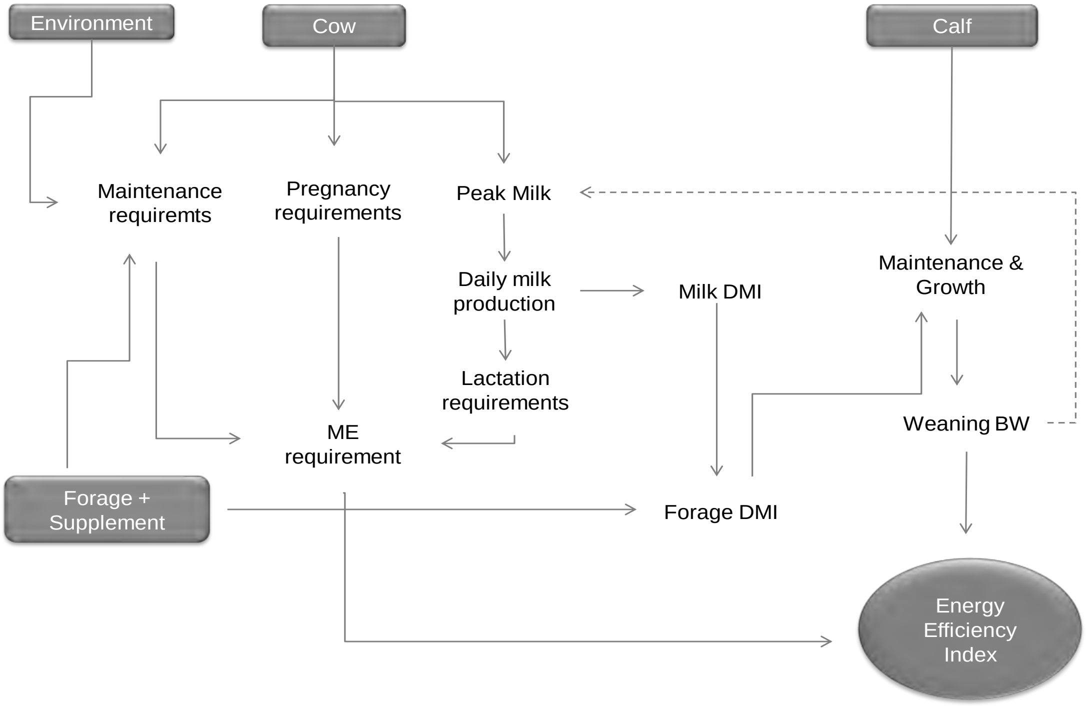

Figure 1 - Flowchart of the mathematical model to predict EEI, adapted from Tedeschi et al. (2006).

In a prior analysis a database was collected from Bell Ranch, NM using 182 beef cows (Tedeschi et al., 2006). This preliminary analysis was used to evaluate the model's ability to rank cows based on EEI from most to least efficient animals. Results indicated that the CVDS beef cow model was able to identify those females that had been culled, and those which had been judged efficient based on observations from the ranch's management team. The model appears to be accurate in ranking cows within a herd based on their ME requirements relative to calf weaning weight.

Bourg (2011) evaluated EEI in 140 Santa Gertrudis cows over 4 production cycles. In this study, EEI was positively correlated (0.39 to 0.56) across production cycles indicating that efficient cows in one year were likely to be efficient in subsequent years. In addition, EEI had a heritability of 0.58 in this study indicating that EEI could be used as a selection trait to improve EEI of mature cows. The results from this study also indicated that EEI was negatively correlated with milk expected progeny difference (EPD) of cows indicating that the most efficient cows produced more milk. Although, EEI was not correlated with weaning weight, average daily gain, hot carcass weight, ribeye area, marbling or residual feed intake EPD. This suggests that more efficient cows could be selected by EEI without correlated responses in growth, body weight, or carcass merit of offspring.

The CVDS beef cow model offers an option to improve energy efficiency of beef cows as a ratio of inputs to outputs, with minimal input data requirements. However, no research has evaluated maintenance energy expenditure or other characteristics of mature cows identified as efficient by the CVDS beef cow mathematical model.

CHAPTER I

IDENTIFYING EFFICIENT BEEF COWS UNDER GRAZING CONDITIONS USING A MECHANISTIC NUTRITION MODEL

OBJECTIVES

The objective of this study was to utilize a mechanistic nutrition model to identify beef cows that use energy more efficiently to produce pounds of weaned calves, based on cow body weight (BW), calf birth and weaning weight, as well as forage quality. Energy efficiency index (EEI), computed as metabolizable energy requirement (MER) of the cow divided by calf weaning BW, was used to rank the cows in a herd as efficient or inefficient, based on their ability to convert available forage into milk simultaneously meeting requirements for maintenance and gestation.

MATERIAL AND METHODS

The Animal Care and Use Committee of the Institute of Food and Agricultural Sciences at the University of Florida approved all procedures involving animals in the present study (IACUC Protocol #201408317).

Animals and Management

This study was conducted at the Range Cattle Research and Education Center (RCREC) in Ona, FL between May 2013 and July 2015. One herd of approximately 69 Angus-Brangus crossbred cows, ranging in age from 3 to 12 years, were used for this study to estimate the ratio of energy required (metabolizable energy- ME, Mcal) by a cow to kilos of weaned calf (i.e. energy efficiency index – EEI, Mcal/kg, lower EEI is more efficient). Cows and their calves grazed Bahia Grass (*Paspalum notatum)* pastures year-round in 4 herds rotated weekly among 20 4-ha pastures. Cows were fed LimpoGrass (*Hermathria altpissima) hay from December through March each year and supplemented with 16% CP liquid molasses at 5 lb AF/hd/d. Cows were* bred by natural service to Angus or Brangus bulls from mid-January to April each year to calve from late October through December. Pregnancy determination occurred in June each year and open cows were removed. Only cows that completed 2 production cycles were used in this experiment.

Data Collection and Calculations

Cow and calf data were collected from May 2013 through July 2015; 2 production cycles. Cow body weight (BW) and body condition score (BCS) were collected at pregnancy determination (June), and body condition score was also collected at calving (November to December) and again in March during mid-lactation. Calf body weight was collected at calving and at weaning (July).

To calculate the cow weight adjusted to body condition score 5, live weight and body condition score at pregnancy check was utilized for each cow. To access the energy mobilized in moving to the score 5 the NRC (2000) APPENDIX TABLE 13 was used as base for the calculation. After calculating the required energy for each 0.25 score needed to reach the score 5, the adjusted score 5 for each cow was known. The calving interval for years 2014 and 2015 was calculated. For year 2014 the calving interval was computed as the date of calf birth in 2014 subtract from the 2013 calf birth date. For 2015 the calf interval was calculated subtracting the calf birth date in 2015 from the calf birth date in 2014.

The calves adjusted weaning weight at 240 days was calculated for years 1 and 2. For each year the calf weaning weight was subtract from the calf birth weight, the value obtained was subtract from de weaning age of each calf and then multiplied for 242, the value was added to each calf birth weight and computed as the calf adjusted weaning weight at 240 days.

Table 1.1 Chemical Composition and energy concentration of the Hay fed to Angus Crossbred cows in 2013, 2014 and 2015 (%, DM basis)

Item	2013	2014	2015
Chemical Component			
DM	93.2	94.03	93.6
CP	7.3	5.53	5.12
NDF	77.5	76.83	77.62
ADF	46.4	41.6	41.1
Crude Fat	1.5	1.1	1.12
Ash	4.56	3.31	3.47
Energy Concentration			
TDN	49	51.67	43.15
ME, Mcal/kg	1.78	2.03	2.09
NEM, Mcal/kg	0.92	0.99	1.23
NEG, Mcal/kg	0.38	0.44	0.67

DM = dry matter; CP = crude protein; ADF = acid detergent fiber; NDF = neutral detergent fiber; TDN = total digestible nutrients; NEM = calculated net energy for maintenance; ME: metabolizable energy (NRC, 2000); NEG = calculated net energy for gain (NRC, 2000).

Table 1.2 Chemical Composition and energy concentration of the pasture fed to Angus Crossbred cows in 2013, 2014 and 2015 (%, DM basis)

Item	2013	2014	2015
Chemical Component			
DM	91.67	92.04	93.23
CP	9.77	12.96	10
NDF	71.93	66.76	68.03
ADF	40.16	37.71	37.58
Crude Fat	1.69	2.31	1.71
Ash	5.6	5.86	5.23
Energy Concentration			
TDN	56.71	57.77	59.62
ME, Mcal/kg	2.02	2.23	2.29
NEM, Mcal/kg	1.17	1.17	1.41
NEG, Mcal/kg	0.61	0.64	0.83

DM = dry matter; CP = crude protein; ADF = acid detergent fiber; NDF = neutral detergent fiber; TDN = total digestible nutrients; NEM = calculated net energy for maintenance; ME: metabolizable energy (NRC, 2000); NEG = calculated net energy for gain (NRC, 2000).

Statistical analysis

As described by Tedeschi et al. (2004) the data collected were used as model inputs to compute EEI: (1) compute cow mature weight, (2) compute cow pregnancy requirement, (4) predict cow peak milk from calf weaning BW and age, (5) compute cow lactation requirement, (6) compute calf forage ME intake, (7) compute total ME required, (8) compute EEI. As summarized by Tedeschi et al. (2004), maintenance requirements are adjusted for conceptus weight, environment, physical activity, and physiological status, as recommended by the NRC (2000). Requirements for pregnancy and lactation are also predicted using NRC (2000) recommendations. Milk production is computed through iteration, by changing peak milk until predicted WW matches the observed calf WW. Equations to estimate forage and milk intake of the calf were obtained from data from Abdelsamei (1989).

PROC CORR of SAS version 9.4 (SAS Inst. Inc., Cary, NC) was used to determine relationships between energy efficiency index (EEI) with cow and calf performance data, model-predicted peak milk and BCS at different times during the production cycle. The interpretations were made using a 5% level of significance.

RESULTS AND DISCUSSION

Cow and Calf Performance

The summary of original data and adjusted data for years 1 and 2 are shown in Table 1.3. Cows averaged approximately 490 kg LW at a body condition score of 4.8 in each year. When adjusted to BCS of 5, average LW of cows was approximately 497 kg. Calving interval averaged approximately 368 d each year indicating consistent rebreeding in the herd. Calves were weaned at 242 and 244 d of age weighing 233 and 240 kg WW in Year 1 and 2, respectively, which resulted in average model predicted peak milk of 7.4 and 5.0 kg/d. When adjusted to constant age in each year, calf weight at weaning was 234 and 245 kg in Year 1 and 2, respectively, which lead to model predicted peak milk of 5.9 and 5.1 kg/d. Average EEI was 34.57 and 31.96 Mcal/kg in Year 1 and 2, respectively. After adjusting cow LW to BCS of 5 and calf weaning weight to constant age, EEI averaged 33.31 and 30.78 Mcal/kg in Year 1 and 2, respectively.

Tables 1.4 and 1.5 present the correlation among original performance and efficient traits and among adjusted performance and efficiency traits in Year 1 and 2. respectively. Cow LW at pregnancy determination was moderately, positively correlated (*P* < 0.05) with BCS at pregnancy determination in both Year 1 and 2 but was only correlated with BCS at calving and mid-lactation in Year 1. However, in the adjusted performance dataset, cow LW at pregnancy determination was not correlated with BCS at calving or mid-lactation in either year. Calving interval was not correlated (*P* > 0.05) with any of the BCS measurements in either year for either the original or adjusted performance datasets. Body condition score is used to assess cattle nutritional status influencing productive responses and reproductive performance of beef cows (Wagner et al.,1988; Cooke et al., 2009). Across years, cow BCS at pregnancy determination and mid-lactation, but not calving, were strongly, positively correlated (P < 0.05) indicating that cows generally maintained the same body condition at similar time points in successive production cycles. Beef cows with body condition scores less than 4 on a 9-point scoring scale have longer postpartum intervals (Richards et al. 1986). Additionally, Spitzer et al. (1995) reported a positive relationship during gestation among cow BCS and calf birth weight, but BCS of cows at parturition did not affect calf WW. Bohnert et al. (2013) reported reduced calving rate and calf BW in cows having BCS 4.5 or less during the last trimester of gestation. In the current study, cow BCS was not correlated with calf BW, but cow BCS at calving in Year 1 and mid-lactation in Year 2 were moderately, positively correlated with calf WW.

Cow LW was moderately positively correlated (*P* < 0.05) with calf WW, but not calf BW in both years in the original performance dataset. In the adjusted performance dataset, cow LW was weakly, positively correlated ($P < 0.05$) with calf WW in Year 1, but not Year 2. Mourer (2012) used Angus calving cows to evaluate the effect of mature size on forage intake, milk yield and calf weaning weight during early lactation, late lactation and late gestation. An efficiency index was calculated as the intake/ adjusted weaning weight to allocation the cows to treatment groups. The author found a greater live weight (LW) and forage intake for large cows compared with light cows during late lactation but no difference when DMI was expressed as a percent of mature BW. During late gestation heavy cows had a greater adjusted LW and DMI compared with light cows. During early lactation, adjusted LW= kept greater for heavy cows, but BCS was lower for large cows and no difference in DMI was observed between large and light cows. Weaning weight was not influenced by cow size, although, efficient cows weaned 50kg more calf a consumed 350 kg less forage DM annually in this study.

Model predicted peak milk was strongly, positively correlated ($P < 0.05$) with calf WW each year in both datasets as would be expected based on the method used to compute peak milk. Cortés- Lacruz et al. (2017) reported a genetic correlation of calves weaning weight at 150 day of life and peak milk being moderate and positive (r=0.48). Meyer et al. (1994) founded a strong and positive genetic correlation between weaning weight and actual milk yield of 0.80.

Energy efficiency index was moderately, positively correlated ($P < 0.05$) with cow LW in Year 1, but not Year 2 in both datasets. Additionally, EEI was strongly, negatively correlated ($P < 0.05$) with PKM and calf WW in both years of both datasets. Bourg (2011) collected data from one herd of 140 Santa Gertrudis cows over four-year period and estimated EEI per calving cycle, conception to weaning. Peak milk and EEI were moderately to highly negatively correlated within a year, with r= -0.87, -0.58, -0.58, -0.85 for years 1,2,3 and 4; respectively. Efficient cows indicated by the model had a higher predicted peak milk and grater milk expected difference in progeny (EPD). Weaning weight EPD was moderate correlated with actual calf WW for the 4 years and Milk EPD was also moderated correlated with calf WW each year. These results indicate a potential in low EEI cows, the more efficient, to wean heavier calves. Energy efficiency index was positively correlated with internal fat (IFAT) in most of the years, indicating that efficient cows are leaner because they had less IFAT.

Compared with the original performance data, the strength of the correlations with cow LW were reduced when adjusted to constant BCS. The strength of the relationship between PKM and calf WW was reduced in Year 1, but similar in Year 2 compared with the original performance data. The strength of the relationship between EEI and PKM was increased in the adjusted performance dataset indicating more emphasis on greater PKM with selection for lower EEI. However, the strength of the relationship between EEI and calf WW was decreased indicating less emphasis on greater weaning weight with selection for lower EEI.

The correlation among years for cow LW was very strong (r = 0.91; $P < 0.05$) indicating that cow mature size is relatively constant. Moderate, positive correlations among years were found ($P < 0.05$) for PKM (0.32 and 0.43), calf WW (0.43 and 0.31) and EEI (0.42 and 0.48) for original and adjusted performance datasets, respectively, indicating that more efficient cows tend to remain more efficient across production cycles. Bourg (2011) also reported positive correlations (0.39 to 0.56) for EEI across 4 production cycles in 140 Santa Gertrudis cows. In addition, EEI had a heritability of 0.58 in this study, suggesting that EEI may be repeatable for cows across years and could be used as a selection tool to improve EEI of mature cows.

Table 1.3. Summary statistics of growth and efficiency traits of cows in Year 1 and 2

	Year 1		Year 2	
Trait	Mean	SD	Mean	SD
Original data				
Cow LW, kg	489.3	58.2	492.6	53
Cow BCS1	4.83	0.57	4.79	0.61
Calving Interval, d	367.1	24.1	369.3	21.5
Calf BW, kg	32.8	5	33.8	5.1
Calf WW, kg	233.7	25.3	240	39.8
Wean Age, d	241.9	20.6	244.3	29.9
PKM, kg/d	7.43	0.82	5.02	1.03
EEI, Mcal/kg	34.57	3.21	31.96	6.71
Adjusted data				
Cow LW, kg	494.2	54.3	499.1	49
Cow BCS1	5	--	5	--
Calving Interval, d	367.1	24.1	369.3	21.5
Calf BW, kg	32.8	5	33.8	5.1
Calf WW, kg	234.3	24.2	245.6	32.6
Wean Age, d	242	--	250	--
PKM, kg/d	5.92	0.77	5.06	0.97
EEI, Mcal/kg	33.31	3.31	30.78	4.03

LW = live body weight; BW = birth weight; WW = weaning weight; BCS 1= body condition score at pregnancy check; PKM = predicted peak milk; EEI = energy efficiency index.

Table 1.4 Pearson correlation coefficients among adjusted performance and efficiency traits for cows in Year 1 and 2

Trait	EEI	Cow LW	PKM	BCS1	BCS2	BCS3	CI	Calf BW	Calf WW
EEI	**0.42***	0.46*	-0.62*	0.16	-0.05	0.24*	-0.27*	-0.22	-0.65*
Cow LW	0.15	**0.91***	0.33*	0.37*	0.35*	0.26*	-0.14	0.13	0.35*
PKM	-0.67*	0.29*	**0.32***	0.14	0.28*	0.02	0.03	0.47*	0.96*
BCS1	0.08	0.40*	0.11	**0.63***	0.55*	0.51*	-0.1	0.06	0.17
BCS2	-0.07	0.07	-0.07	0.34*	**0.2**	0.58*	-0.02	-0.04	0.32*
BCS3	-0.09	0.21	0.18	0.52*	0.36*	**0.52***	-0.19	0.03	-0.01
CI	0.02	0.36*	-0.22	0.15	0.15	0.22	**0.41***	-0.36*	0.15
Calf BW	-0.21	0.1	0.38*	0.19	-0.09	-0.05	-0.35*	**0.04**	0.38*
Calf WW	-0.81*	0.32*	0.85*	0.17	0.07	0.25*	0.16	0.27*	**0.43***

Year 1 above the diagonal; Year 2 below the diagonal; correlations between years on the diagonal

EEI = energy efficiency index; PKM = model predicted peak milk; BCS1 = cow body condition score at pregnancy determination in June; BCS2 = cow body condition score at calving in fall; BCS3 = cow body condition score in March; CI = calving interval; LW = live body weight; BW = birth weight; WW = weaning weight.
* Correlation are different from zero at P<0.05.

Table 1.5 Pearson correlation coefficients among adjusted performance and efficiency traits for cows in Year 1 and 2

Trait	EEI	Cow LW	PKM	BCS1	BCS2	BCS3	CI	Calf BW	Calf WW
EEI	**0.48***	0.39*	-0.72*	--	-0.2	0.12	-0.33*	-0.16	-0.47*
Cow LW	0.16	**0.91***	0.32*	--	0.16	0.08	-0.12	0.11	0.24*
PKM	-0.77*	0.34*	**0.43***	--	0.32*	-0.01	0.15	0.36*	0.74*
BCS1	--	--	--	**--**	--	--	--	--	--
BCS2	-0.07	-0.08	0.06	--	**0.2**	0.58*	-0.03	-0.04	0.21
BCS3	-0.24	-0.02	0.32*	--	0.36*	**0.52***	-0.19	0.03	0.01
CI	-0.1	0.32*	0.18	--	0.15	0.22	**0.41***	-0.36*	-0.32*
Calf BW	-0.01	0.03	0.23	--	-0.1	-0.06	-0.35*	**0.04**	0.68*
Calf WW	-0.74*	0.24	0.87*	--	-0.07	0.2	-0.22	0.38*	**0.31***

Year 1 above the diagonal; Year 2 below the diagonal; correlations between years on the diagonal.

EEI = energy efficiency index; PPM = model predicted peak milk; BCS1 = cow body condition score at pregnancy determination in June; BCS2 = cow body condition score at calving in fall; BCS3 = cow body condition score in March; CI = calving interval; LW = live body weight; BW = birth weight; WW = weaning weight.
* Correlation are different from zero at P<0.05.

CHAPTER II

EFFECT OF ENERGY EFFICIENCY INDEX CLASSIFICATION ON ENERGY METABOLISM IN MATURE BEEF COWS

OBJECTIVE

The objective of this study was to determine differences in energy partitioning between cows identified as efficient or inefficient based on EEI. Efficient and inefficient cows were selected for an energy metabolism experiment during late lactation and late gestation during the second production cycle. The hypothesis of the current study was that low EEI cows have lesser maintenance energy requirement and greater efficiency of ME use compared to high EEI cows.

MATERIAL AND METHODS

The Animal Care and Use Committee of the Institute of Food and Agricultural Sciences at the University of Florida approved all procedures involving animals in the present study (IACUC Protocol #201408317).

Animals and Management

This study was conducted at the Range Cattle Research and Education Center (RCREC) in Ona, FL. The study occurred between April 2015 and September 2015. Low (n= 8) and high (n= 8) EEI Angus x Brangus crossbred mature cows were selected from the original group of 69 cows described in Chapter I for an energy metabolism experiment during late lactation and late gestation.

Lactation metabolism experiment

The first metabolism experiment began on April 20th, 2015 with a two-week adaptation period and concluded on June 3rd, 2015. Cow-calf pairs were housed in individual pens for 44 days during late lactation. The cow-calf pairs were fed individually LimpoGrass (*Hermathria altpissima)* hay (Table 4.1) twice daily (at 0800 and 1600 hours) ad-libitum. Cows and calves were fed separately such that cows and calves only had access to their respective feed. Feed delivered and feed refused were weighed daily. Cows and calves were weighed after overnight withdrawal from feed at the start and end of the experiment. Milk yield was determined by weigh-suckle-weigh technique on d 21, 27 and 35 of the metabolism experiment. Apparent total tract nutrient digestibility and heat production were determined for each animal during the trial.

Table 2.1 Chemical Composition and energy concentration of the Hay fed to Angus Crossbred cows during Late Lactation period (%, DM basis)

Item	
Chemical Component	
DM	93.2
CP	12.3
NDF	75.6
ADF	40.9
Crude Fat	1.8
Ash	5.9
Energy Concentration	
TDN	54
NEM, Mcal/kg	0.50
NEG, Mcal/kg	0.25

DM = dry matter; CP = crude protein; ADF = acid detergent fiber; NDF = neutral detergent fiber; TDN = total digestible nutrients; NEM = calculated net energy for maintenance (NRC, 2000); NEG = calculated net energy for gain (NRC, 2000).

Gestation metabolism experiment

The second metabolism experiment began on August 17th , 2015 and concluded on September 29th , 2015. The same cows used in the first experimental period were housed 43 days during late gestation and fed individually LimpoGrass (*Hermathria altpissima)* hay (Table 4.2) twice daily (at 0800 and 1600) at ad-libitum for 32 d and 0.5X expected maintenance requirement for 7 days before being returned ad libitum intake. Feed delivery and feed refusal were weighed daily; during the 0,5X maintenance intake period the cows consumed the entire amount of feed offered each day. The calculation for 0,5 X maintenance intake levels were made for each individual cow from estimated ME of diet, which was computed from chemical analysis of hay, and expected metabolizable energy requirement for maintenance of 110 kcal/kg$^{0.75}$.

Cows were weighed at the start and end of the experiment after overnight withdrawal from feed. Body condition score was obtained from 2 trained personnel at the start and end of the experiment. Body composition measurements of 12th rib fat thickness, LMA, rumpfat thickness, IMF percent and kidney fat depth were determined using ultrasonography (SPECS OF ULTRASOUND EQUIPMENT) by a trained technician on day 15 of the experiment. Apparent total tract nutrient digestibility and heat production were determined for each animal during the experiment.

Table 2.2 Chemical Composition and energy concentration of the Hay fed to Angus Crossbred cows during Late Gestation period (%, DM basis)

Item	
Chemical Component	
DM	90.2
CP	12.9
NDF	70
ADF	40.1
Crude Fat	1.8
Ash	7.59
Energy concentration	
TDN	54
NEM, Mcal/ kg	0.50
NEG, Mcal/kg	0.25

DM = dry matter; CP = crude protein; ADF = acid detergent fiber; NDF = neutral detergent fiber; TDN = total digestible nutrients; NEM = calculated net energy for maintenance (NRC, 2000); NEG = calculated net energy for gain (NRC, 2000).

Apparent total tract digestibility

Feed and fecal samples were collected during each metabolism experiment to determine apparent total tract nutrient digestibility of dry matter (DM), organic matter (OM), crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), and acid detergent fiber (ADF). All feed samples were frozen and stored at -20°C after collection. Fecal samples were collected twice daily (0800 and 1600 hours) from the ground of the pens during five consecutive days of each period, then frozen and stored at -20°C after collection. After the end of the experiment, feed and fecal samples were dried at 55°C in a forced air oven and ground in a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA) to pass a 1mm screen, and composited within cow and feeding period for further analysis.

Determination of OM and DM of feed and fecal samples was performed according to official method 950.02 (AOAC, 1995) by drying 0.5g in duplicate in a forced air oven at 100°C for 24 hours then ashing at 550°C for 3 hours. Neutral detergent fiber and ADF concentration of feed and fecal samples were determined using an Ankom 200 fiber Analyzer (Ankom Technology Corp., Macedon, NY) according to Van Soest et al., (1991). A macro elemental nitrogen (N) analyzer (Vario Max CN, Elementar Americas Inc. Mt Laurel NJ) was used following official method 992.15 to determine the concentration of nitrogen in feed and feces by rapid combustion (AOAC, 1995). Feed and fecal samples were sent to Dairy One Forage Laboratory (Ithaca, NY) for determination of ether extract.

Methods developed by Cole et al., (2011) with modifications proposed by Krizsan et al. (2013) were used to determine concentrations of indigestible NDF (iNDF) in feed and feces, which was used as an internal marker for determination of digestibility. Samples were weighed (approximately 0.5g) in duplicate in Ankom F57 filter bags, placed in a mesh nylon bag and incubated in situ in the rumen of steers for 288 hours, to ensure that all digestible NDF was completely digested. After incubation, samples were dried, weighed and analyzed for NDF as described above. Fecal output was determined by total marker (iNDF) intake divided by the marker concentration in the feces.

Heat Production

Heat production was determined using the oxygen pulse technique (Brosh et al., 2002). Cows were monitored 48 hours for heart rate using Polar heart rate monitors (RS800CX Science, Polar Electro Inc., Lake Success, NY), whose electrodes were adjusted on the animal's thorax. The data were recorded at 1-minute intervals and then sent to the computer by infrared sensor.

The oxygen consumed per heart beat was calculated by simultaneous measurement heart rate and volume of O2 consumed for a period of 20 to 30 minutes (Brosh et al., 2002). A mask was used in order to facilitate the oxygen consumption measurement. The gas exchange and heart rate were measured for 30 minutes, before and after 48-hr measurement of heart rate to collect an AM and PM measurement for determination of oxygen pulse (oxygen consumed per heart beat). The 48-hr heart rate and oxygen pulse measurements were collected for two 48-hr periods during the lactation metabolism experiment at ad libitum feed intake. During the gestation metabolism experiment, 48-hr heart rate and oxygen pulse were measured once at ad libitum and once at 0.5X expected maintenance energy requirement.

Prior to the beginning of the metabolism trial, each cow was brought into the squeeze chute and allowed to stand with the mask attached for 20- 30 minute to allow the cows to adapt to the conditions for gas exchange and oxygen consumption measurement in order to prevent stress conditions.

To measure the gas exchange of oxygen and carbon dioxide, a respiration calorimetry system (Field Metabolic System, Sable Systems International, Las Vegas NV) was used. The Field Metabolic System (FMS) controlled and recorded mass flow (50-500 L/min) and recorded fuel cell oxygen (FC-1B,), infrared carbon dioxide (CA-2A, $\lambda = 4.26$ μm) and dew point and water vapor pressure (RH300, Sable Systems) of the incoming airstream at 5 second intervals.

Before the initial oxygen pulse measurement, the system was calibrated by spanning the oxygen concentration and carbon dioxide analyzers using nitrogen gas and using a standard mixed gas containing known concentrations of oxygen (19.4%) and carbon dioxide (1.5%). Nitrogen gas recovery averaged 99.2 and 102.9% across 4 calibration runs for the lactation and gestation experiments, respectively. Before and after measurement of each cow, oxygen and carbon dioxide concentration of ambient air (baseline) was measured for 5 minutes. To evaluate data quality the respiratory quotient was computed after the data was collected.

The average daily oxygen consumption was calculated by multiplying oxygen pulse by average 48-hr heart rate. Heat production was calculated according to McLean and Tobin (1990) using the formula (-4.90 kcal/L of O_2) × (volume of expired air at STP dry) × (oxygen in exhaust air – oxygen in inlet air at STP dry).

Energy calculations

Energy intake was determined as described by NRC (2001) using the formula:

$IE = ((4.15 \times CHO + 5.65 \times PROT + 9.39 \times FAT) * 1000)/MBW$, where IE is energy intake, CHO is the amount of dietary carbohydrate consumed (kg), PROT is the amount of protein consumed (kg) and FAT is the amount of fat consumed (kg). Digestible energy was determined as described by Tedeschi et al. (2005):

$DE = 4.15 \times (CHO - FECHO) + 5.65 \times (PROT - FEPROT) + 9.39 \times (FAT - FEFAT)/DMI$, where DE is digestible energy, CHO is the amount of dietary carbohydrate consumed (kg), FECHO is the amount of carbohydrate excreted (kg), PROT is the amount of protein consumed (kg), FEPROT is the amount of protein excreted (kg), FAT is the amount of fat consumed (kg), and FEFAT is the amount of fat excreted (kg). Carbohydrate (CHO) and FECHO were calculated as organic matter minus protein and fat consumed or excreted, respectively.

Gaseous energy (GE) loss was calculated as described by Blaxter and Clapperton (1965) using the formula $(4.67 + 0.047 \times (DE/IE \times 100)) * (IE/100)$, where DE and IE are digestible and intake energy, respectively. Urinary energy (UE) loss was determined as described by Blaxter and Clapperton (1965) using the formula $U = 0.25P + 1.6$, where U is urinary energy loss (kcal/100kcal IE) and P is the concentration of protein in the diet.

Metabolizable energy was determined as described by NRC (2000), multiplying DE by 0.82. As previously described, heat production was measured using the oxygen pulse technique. Retained energy was calculated as ME minus HP, where ME is metabolizable energy and HP is heat production (NRC, 2000).

To calculate metabolizable energy required for maintenance (ME_m) the log of HP was regressed on MEI. Fasting heat production (FHP) was defined as the intercept of the regression equation, and MEm was defined as the point where HP equals MEI. Efficiency of ME used for maintenance (km) was defined as the slope of the regression line between FHP and MEm.

Statistical analysis

Performance data, nutrient digestibility, energy intake and loss, and energy requirements were analyzed using the MIXED procedure of SAS (V. 9.4; SAS Inst. Inc., Cary, NC) using the model:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij}$$

where the animal was considered the experimental unit, Y_{ij} is the dependent variable, μ is the overall mean, α_i is the fixed effect of Efficiency Energy Index group and β_j is the side of the barn which was considered the random effect. The interpretations were made using a 5% level of significance.

RESULTS AND DISCUSSION

***Late lactation experiment*.** Performance of cows classified as low or high EEI and their calves during late lactation are presented in Tables 2.3. Low EEI cows had lesser ($P \leq 0.05$) BW than high EEI cows at the beginning of the late lactation metabolism experiment and tended (*P* ¸0.10) to have lesser BW at the end resulting in no difference in ADG during the late lactation metabolism experiment. There was no difference ($P >$

0.05) in DMI, milk yield or milk composition between low and high EEI cows. Calves of low EEI cows were heavier at the start and end of the late lactation metabolism experiment, but calf ADG and DMI was not different between low and high EEI cows.

Larger cows can only be more efficient than smaller cows if they have differences in metabolic energy efficiency (Tedeschi et al., 2004). Ferrell and Jenkins, (1984) reported that cow size (BW) does not influence the efficiency of energy use. And, small and large cows may have the same efficiency (EEI) if larger cows wean heavier calves (Tedeschi et al., 2004). However, the calves from the heavier high EEI cows were not heavier than calves from lighter low EEI cows such that efficiency was not similar between low and high EEI cows.

Higher-milking cows require more energy per pound of BW than cows that produce less milk, because they have lower energy efficiency (ME efficiency); a consequence of heavier internal organs (Ferrell and Jenkins, 1985). The chance of producing a heavier calf is increased when the milk production is higher (Lewis et al., 1990), even though there was no difference in milk yield among efficient and inefficient cows, calves of low EEI cows had greater IBW and FBW. The heavier calf weight for low EEI cows may be the result of greater milk yield during early lactation, which was not measured in this study.

Dry matter intake was not different between low and high EEI cows, but low EEI cows consumed more DM per unit of BW given their lesser BW. Requirements for maintenance and DMI are based on stage of production (ARC, 1980) and cow size (Lemenager et al.,1980). Feed intake control in ruminants is complex. Reviews by Mertens (1994), Fisher (2002), and Roche et al (2008) provide a discussion about intake regulation theories. Feed intake is affected by body composition, specifically fatness (NRC, 2016). According to Fox et al. (1988) for each 1% increase in body fat content ranged of 21.3 to 31.5% body fat, DMI decreases 2.7%.

Apparent digestibility of diet components during late lactation is presented in Table 2.4.

Unexpectedly, differences in apparent DM and OM digestibility were observed (P= 0.03 and 0.01) between low and high EEI with low EEI cows having lower digestibility. The lower DM and OM digestibility for low EEI cows is likely due to the greater DMI per unit of BW compared with high EEI cows rather than digestive process, but differences in digestive processes cannot be ruled out at this point. No differences were observed (P > 0.21) in digestibility of CP, EE, NDF and ADF between low and high EEI cows.

In the current study cow EEI group did not affect energy partitioning during late lactation (Table 2.6). No differences (P>0.511) were observed in energy intake (IE), digestible energy (DE), urinary energy loss (UE) or gaseous energy loss (GE). Urinary energy loss accounts for 3-5 % of IE according to Blaxter (1962). The amount of nitrogen excreted as Hippurate is the principal factor for the variation in urinary energy losses in beef cattle and is associated with the amount of protein in the diet (Blaxter and Clapperton,1965). A lower methane production, the main source of gaseous energy (GASE), relative to energy intake can be considered a feature of energy efficient cows (Yan et al. 2010). Feed efficiency measured as gain:feed was positively correlated with CH_4 when enteric CH_4 emissions were measured in cattle varying in feed efficiency (Freetly et al., 2013). The lack of difference in UE and GE in the current study is likely due to no difference in DMI given that UE and GE were calculated from IE.

There was no difference (*P* > 0.05) in ME between low and high EEI cows. Metabolizable energy intake is considered the energy available to the animal (NRC, 2016). Metabolizable energy can be lost as heat (HE) during physiological processes. Heat in beef cattle is produced during digestion and absorption of nutrients, activity and has been reported to increase about 60% during the process of eating and for grazing cattle accounts for 11.4% of metabolizable energy intake (Blaxter, 1989). No difference (P = 0.51) was observed in HP between low and high EEI cows. Barasab et al. (2003) reported that low residual feed intake (RFI) steers had 9% lesser HP compared to high RFI steers when fed at ad-libitum intake. The lack of difference in HP between low and high EEI cows may be due to the slightly greater milk yield of low EEI cows such that the greater DMI per unit BW of low EEI cows was used for milk production rather than oxidized producing heat.

No difference (P > 0.05) was observed in RE or energy balance (EB) for low and high EEI cows. Retained energy is considered the energy that is retained in products: body tissue, conceptus or milk in beef cows.

***Late gestation experiment*.** In late gestation, there was no difference (*P* > 0.05) in initial or final BW between low EEI and high EEI cows (Table 2.6). There was also no difference (*P* > 0.05) in DMI between low and high EEI cows. Efficient cows had less (*P* < 0.05) 12th rib fat thickness and IMF than inefficient cows, suggesting that low EEI cows deposit less fat than high EEI cows. Change in body condition score results trended the same direction as 12th rib fat thickness with low EEI cows losing more body condition but was not significant. Body condition score influences reproductive performance in beef cows (Richards et al., 1986). A thin BCS at calving extends the interval postpartum estrus and are related to percentage of open cows, calving interval and calf birth weight (Randel, 1990). Bohnert et al. (2013) reported greater pregnancy rates in the next breeding season and greater BCS at weaning in cows managed to sustain BCS ≈ 5.5 during the last trimester of gestation compared with cows managed to maintain a BCS ≈ 4.5. It might be possible that cows with low EEI have a prolonged postpartum anestrous interval (Spitzer et al., 1995) and pregnancy rates affected once they had less fat deposited and consecutive a lower BCS. Nutritional plane is one of the factors that affects fat deposition. Fat is the latest tissue to develop in beef cattle. Andrews, (1985) suggested the following consecutive order of fat deposition in cattle: internal fat, intermuscular fat and intramuscular fat. The intramuscular fat (IMF) contributes to meat quality, tenderness and other sensory properties of meat are determined by IMF content (Hocquette et al., 2010; Fernandez et al.,1999). Sex, age, genetic background, diet and body weight influence IMF content (Bruns, Pritchard, & Boggs, 2004).

There was no difference (P = 0.48) in apparent DM or OM digestibility in late gestation between low and high EEI cows as was observed during late lactation (Table 4.7). Similar to the late lactation experiment, there was no difference ($P > 0.05$) in apparent digestibility of CP, EE, NDF or ADF in late gestation.

No differences (P > 0.49) were observed in energy partitioning between low and high EEI cows when fed *ad-libitum* or 0.5X maintenance during late gestation (Table 2.8). Eventhough no difference (P = 0.18) was founded in HP, low EEI cows had 12% and 7% less energy lost as heat when fed at *ad-libitum* and 0.5X maintenance, respectively, when compared with high EEI cows. Considering the fact that fat is more energy dense (9 Kcal/g) than protein (4 kcal/g), retained energy should be greater in high EEI cows, however, RE was 20% and 5% higher in low EEI cows at the *ad-libitum* and 0.5 maintenance periods, respectively.

Body weight and body composition in mature cow have changed over the years, BW have increased significantly as a result of the genetic changes, this may have influenced feed intake and energy requirements even though the feed requirement for maintenance of BW was estimated 30 years ago (Walker et al.,2015; Jenkins and Ferrell, 1983). In the current study, no differences ($P>0.45$) in maintenance energy requirements (ME_m) or fast heat production (FHP) were found between low and high EEI cows. Differences in body composition may have an effect on ME_m, DiCostanzo et al., (1990) in a study evaluating mature non-pregnant non-lactating cows, reported a strong negative correlation of ME_m with omental and mesenteric fat ($r= -0.78$) and estimated that 1kg of protein required 192 kcal to be maintained compared to 20.7 kcal to maintain 1 kg of fat, suggesting that ME_m in leaner cows would be greater. The lack of differences in protein mass as assessed by LMA and internal fat as assessed by kidney fat depth may be contributing to the lack of differences in MEm between low and high EEI cows.

In this study, the daily ME_m for mature gestating cows was 111.33 kcal ME. $BW^{0.75}$ $d.^{-1}$ for low EEI cows and 123.75 kcal ME. $BW^{0.75}$ $d.^{-1}$ for high EEI cows (Table 2.9). The daily ME_m for mature nonlactating and nonpregnant Angus cows reported in other studies between 100 and 118 kcal ME. $BW^{0.75}$ $d.^{-1}$ (Ferrell and Jenkins, 1985; Solis et al., 1988; Laurenz et al., 1991). According to Ferrell et al. (1976), the maintenance requirement is similar for nonpregnant and pregnant heifers. In agreement with this result, Ferrell and Jenkins (1985) observed similar maintenance energy requirements for nonpregnant, pregnant and nonlactating cows. Although, the maintenance requirement of lactating cows is greater than the maintenance requirement of nonlactating cows (Neville, 1974). Ferrell and Jenkins (1985) also suggested that variation in maintenance requirement exists between cows due to size or milk production potential.

Efficiency of ME use for maintenance (km) was not different (P=0.37) between low and high EEI cows (Table 2.9). The values for km was higher (0.933 and 0.927) when compared to the literature data. Chizzotti et al. (2008) reported in feedlot a km= 0.67, Porto et al. (2012) found a km= 0.58 in grazing conditions. CSIRO (2007) suggested for animals with low quality diets a km= 0.62.

Table 2.3. Performance of cows classified as low or high EEI and their calves during late lactation metabolism experiment in Year 2

Trait	Low EEI	High EEI	SEM	P-value
Cow IBW, kg	418	465.2	15.2	0.05
Cow FBW, kg	399.2	445.9	16.3	0.06
Cow ADG, kg/d	-0.45	-0.46	0.2	0.95
Cow DMI, kg/d	10.53	10.71	0.73	0.86
Milk yield, kg/d	3.97	3.02	0.88	0.16
Milk fat, %	2.25	2.75	0.27	0.22
Milk protein, %	2.63	2.85	0.08	0.06
Milk lactose, %	4.65	4.79	0.09	0.15
ECM yield, kg/d	3.25	2.7	0.69	0.38
Calf IBW, kg	160.8	132.8	8.7	0.04
Calf FBW, kg	182.7	152.7	7.9	0.02
Calf ADG, kg/d	0.52	0.4	0.07	0.2
Calf DMI, kg/d	1.88	1.72	0.14	0.41

IBW = initial body weight; FBW = final body weight; ADG = average daily gain; DMI = dry matter intake; ECM = energy corrected milk.

Table 2.4. Effect of Efficiency Energy Index group on apparent nutrient digestibility in Angus crossbred mature cows fed *ad-libitum* during late lactation

Trait	Low EEI	High EEI	SD	*P*-value
Late Lactation				
No of Cows	8	8		
Metabolic BW, kg of BW ^{0,75}	90.85	98.47	2.52	0.05
DMI, kg/d	11.21	11.18	0.81	0.98
Fecal Output, kg DM/d	5.52	5.44	0.39	0.90
	Apparent digestibility %			
DM	42.60	44.75	1.20	0.03
OM	42.88	45.47	1.20	0.01
CP	51.65	52.97	1.74	0.44
EE	44.67	44.32	2.79	0.90
NDF	44.99	46.35	1.36	0.21
ADF	29.80	32.13	3.13	0.33

DMI = dry matter intake; DM = dry matter; OM = organic matter; CP = crude protein; EE = ether extract; NDF = neutral detergent fiber; ADF = acid detergent fiber.

Table 2.5. Effect of Efficiency Energy Index group on energy partitioning in Brangus crossbred mature cows fed *ad-libitum* during late lactation

Trait	Low EEI	High EEI	SD	*P*-value
Ad-libitum Period, kcal/kg of BW$^{0.75}$				
Intake energy	455.10	428.26	28.07	0.51
Digestible energy	204.50	202.83	14.97	0.94
Urinary energy	19.68	18.52	1.21	0.51
Gaseous energy	30.86	29.53	2.01	0.65
Metabolizable energy	167.69	166.32	12.28	0.94
Heat production	139.92	138.92	8.71	0.91
Retained energy	30.21	27.73	13.72	0.90
Milk energy	15.69	10.83	5.62	0.25
Pregnancy energy	0.50	0.49	0.08	0.73
Energy balance	6.71	11.94	14.32	0.80

Means significantly different from 0 ($P < 0.05$)

Table 2.6. Performance of cows classified as low or high EEI during late gestation metabolism experiment in Year 2

Trait	Low EEI	High EEI	SEM	P-value
Cow IBW, kg	444.6	468.5	15	0.28
Cow FBW, kg	453	484.7	15.7	0.18
Cow ADG, kg/d	0.2	0.4	0.16	0.41
Cow DMI, kg/d	9.52	9.22	0.62	0.74
Initial BCS	4.5	4.65	0.2	0.59
Final BCS	4.31	4.59	0.28	0.36
BCS change	-0.19	-0.06	0.2	0.38
LMA, cm^2	52.53	49.53	3.55	0.56
12th rib fat thickness, cm	0.32	0.48	0.05	0.03
Rump fat thickness, cm	0.31	0.37	0.05	0.49
IMF, %	2.87	3.57	0.18	0.01
Kidney fat depth, cm	11.58	11.07	0.49	0.47

IBW = initial body weight; FBW = final body weight; ADG = average daily gain; DMI = dry matter intake; BCS = body condition score; LMA = longissimus muscle area; IMF intramuscular fat.

Table 2.7. Effect of Efficiency Energy Index group on apparent nutrient digestibility in Angus crossbred mature cows fed *ad-libitum* during late gestation

Trait	Low EEI	High EEI	SD	*P*-value
Late Gestation				
No of Cows	8	8		
Metabolic BW, kg of BW ^{0,75}	102.88	109.60	2.68	0.10
DMI, kg/d	11.12	10.42	0.88	0.58
Fecal Output, kg DM/d	9.53	9.64	1.01	0.93
	Apparent digestibility %			
DM	60.23	60.56	0.32	0.48
OM	60.60	61.28	0.29	0.12
CP	62.50	62.41	0.73	0.87
EE	77.62	75.37	0.85	0.08
NDF	60.20	60.80	0.61	0.32
ADF	60.62	61.27	0.90	0.33

DMI = dry matter intake; DM =dry matter; OM = organic matter; CP = crude protein; EE = ether extract; NDF = neutral detergent fiber; ADF = acid detergent fiber.

Table 2.8. Effect of Efficiency Energy Index group on energy partitioning in Angus crossbred mature cows fed *ad-libitum* and 0.5X their estimated maintenance energy during late gestation

Trait	Low EEI	High EEI	SD	*P*-value
Ad-libitum, kcal/kg of BW$^{0.75}$				
Intake energy	432.48	406.6	36.63	0.63
Digestible energy	265.87	250.37	22.40	0.68
Urinary energy	18.70	17.58	1.58	0.63
Gaseous energy	32.59	30.75	2.76	0.65
Metabolizable energy	216.37	205.30	18.37	0.68
Heat production	127.96	140.14	6.08	0.18
Retained energy	88.40	65.16	18.71	0.39
0.5X maintenance kcal/kg of BW$^{0.75}$				
Intake energy	107.05	105.90	1.70	0.49
Digestible energy	65.07	64.89	1.27	0.87
Urinary energy	4.62	4.58	0.07	0.49
Gaseous energy	8.05	7.98	0.14	0.63
Metabolizable energy	53.36	53.21	1.05	0.87
Heat production	103.42	108.55	5.11	0.49
Retained energy	-49.41	-54.69	4.96	0.47

Means significantly different from 0 ($P < 0.05$).

Table 2.9. Effect of Efficiency Energy Index group on fasting heat production, metabolizable energy required for maintenance, and efficiency of ME used for maintenance in Angus crossbred cows

Trait	Low EEI	High EEI	SD	*P*-value
FHP, kcal/kg of $BW^{0.75}$	96.28	99.57	5.46	0.67
MEm, kcal/kg of $BW^{0.75}$	111.33	123.75	7.35	0.253
km	0.86	0.81	0.033	0.37

FHP = fasting heat production and MEm = Metabolizable energy maintenance were calculated as by regressing the ln of HP on metabolizable energy intake (MEI) to Energy efficiency use for maintenance (km). Means significantly different from 0 ($P < 0.05$).

CONCLUSION

Evaluation over 2 production cycles suggest that CVDSbc estimates of Energy Efficiency Index (EEI) in mature beef cows results in identification of more efficient beef cows (lower EEI) that have a greater model-predicted peak milk and wean heavier calves. The cows did not differ in DMI or energy partitioning during the late lactation or late gestation stages of production. Results of this study indicate similarities in km and no differences were observed in FHP and ME_m between the group of animals differing in efficiency. Energy Efficiency Index could be a useful tool in selecting cows that are more efficient at converting available forage in to heavier weaned calves. Further research is needed to evaluate differences in energy partitioning and maintenance energy requirements during early lactation, and identify biological mechanisms associated with low EEI in mature beef cows.

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