



Maternal biological efficiency of beef cattle
by Jeffrey David Stevens

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
Animal and Range Sciences
Montana State University
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Abstract:

A study was conducted to evaluate maternal biological efficiency under Montana range conditions. Data were collected on 51 cow-calf pairs during each of four years (1991 to 1994). Cow biological types represented included straightbred Hereford (HH), straightbred Tarentaise (TT) and the Fi reciprocal cross (HT). Data was collected during five periods (November, February, May, June and September) throughout the production year. Cow organic matter intake (OMI) for the production year was not different between the three breed groups and was influenced by the average cow weight during the production year. Calf weights differed by cow breed type with TT and HT cows weaning the heaviest calves ($P < 0.05$) while HH cows weaned the lightest calves. Biological efficiency was defined four ways: 1) EFF - calf weaning weight \div cow OMI, 2) EFF(FO) = calf weaning weight \div cow fecal output (FO), 3) EFFZBW = calf weaning weight \div cow OMI on a per unit of cow body weight (BW) basis and 4) EFF(FO)ZBW = calf weaning weight \div cow FO per unit of cow BW. Biological efficiency differed by cow breed group with TT and HT cows being more efficient ($P < 0.05$) for all measures of efficiency than HH cows. Milk production (summed over the three periods for May, June and September) was a significant covariate for EFF and EFF(FO) ($P < 0.05$). The quadratic regression of EFF on milk and EFF(FO) on milk indicated an optimum amount of milk to be approximately 36 to 37 kg and 37 to 40 kg, respectively. Average cow weight and cow weight change were significant covariates for EFF/BW and EFF(FO)/BW ($P < 0.05$). Standard partial regressions indicated cow weight change was approximately three times as important as average cow weight for EFFZBW and EFF(FO)ZBW. Maternal heterosis was positive under all definitions of efficiency at 3.0, 3.4, 5.6 and 5.9% for EFF, EFF(FO), EFFZBW and EFF(FO)ZBW, respectively and was significant for EFFZBW and EFF(FO)ZBW ($P < 0.05$). It was concluded that cow breed group was important for determining efficiency in North Central Montana.

(KEY WORDS: Beef Cattle, Biological Efficiency, Intake)

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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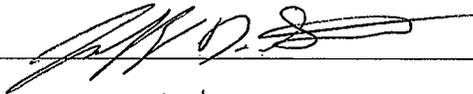
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ABSTRACT

A study was conducted to evaluate maternal biological efficiency under Montana range conditions. Data were collected on 51 cow-calf pairs during each of four years (1991 to 1994). Cow biological types represented included straightbred Hereford (HH), straightbred Tarentaise (TT) and the F₁ reciprocal cross (HT). Data was collected during five periods (November, February, May, June and September) throughout the production year. Cow organic matter intake (OMI) for the production year was not different between the three breed groups and was influenced by the average cow weight during the production year. Calf weights differed by cow breed type with TT and HT cows weaning the heaviest calves ($P < 0.05$) while HH cows weaned the lightest calves. Biological efficiency was defined four ways: 1) $EFF = \text{calf weaning weight} / \text{cow OMI}$, 2) $EFF(FO) = \text{calf weaning weight} / \text{cow fecal output (FO)}$, 3) $EFF/BW = \text{calf weaning weight} / \text{cow OMI on a per unit of cow body weight (BW) basis}$ and 4) $EFF(FO)/BW = \text{calf weaning weight} / \text{cow FO per unit of cow BW}$. Biological efficiency differed by cow breed group with TT and HT cows being more efficient ($P < 0.05$) for all measures of efficiency than HH cows. Milk production (summed over the three periods for May, June and September) was a significant covariate for EFF and EFF(FO) ($P < 0.05$). The quadratic regression of EFF on milk and EFF(FO) on milk indicated an optimum amount of milk to be approximately 36 to 37 kg and 37 to 40 kg, respectively. Average cow weight and cow weight change were significant covariates for EFF/BW and EFF(FO)/BW ($P < 0.05$). Standard partial regressions indicated cow weight change was approximately three times as important as average cow weight for EFF/BW and EFF(FO)/BW. Maternal heterosis was positive under all definitions of efficiency at 3.0, 3.4, 5.6 and 5.9% for EFF, EFF(FO), EFF/BW and EFF(FO)/BW, respectively and was significant for EFF/BW and EFF(FO)/BW ($P < 0.05$). It was concluded that cow breed group was important for determining efficiency in North Central Montana.

(KEY WORDS: Beef Cattle, Biological Efficiency, Intake)

CHAPTER 1

INTRODUCTION

Since the introduction of the continental breeds of beef cattle, ranchers have had a large variety of cattle biological types from which to select. Cow/calf efficiency data of these breeds and breed crosses is limited and needs to be determined for different production environments. Most of the research has been limited to experiments conducted in the drylot (Marshall et al., 1976; Montano-Bermudez and Nielsen, 1990; Jenkins et al., 1991; Ferrell and Jenkins, 1994; Miller et al., 1999; Jenkins et al., 2000) while most ranch operations are conducted on the range. Cattle grazing open range require more energy (Allison, 1985; Wagner et al., 1986) and those with the potential to produce a large amount of milk may be limited by feed resources.

Energy expenditure during grazing and lactation energy requirements may affect the differences expressed between biological types for efficiency estimates. Dry matter intake by the cow plays a vital role in the efficiency estimates of the cow/calf unit. With limited feed resources, those breeds with a higher genetic potential for milk production may have longer anestrous periods. However, with an adequate supply of forage, efficiency seems to be more dependent on milk production and breed potential for preweaning calf growth (Montano-Bermudez and Nielsen, 1990; Jenkins et al., 2000).

CHAPTER 2

LITERATURE REVIEW

Forage Intake Differences

Forage intake differences between cattle and between biological types of cattle have been shown to exist (Holloway and Butts, 1984; Allison, 1985; Ferrell and Jenkins, 1985; Montano-Bermudez and Nielsen, 1990). Cow size, body condition, environment, level of milk production, and availability of forage all affect the forage intake of cattle.

Cow size

Maintenance requirements appear to be influenced by both size and milk production potential of the cows, even during the non-lactating times (Ferrell and Jenkins, 1987). The general method for determining the amount of forage a particular animal will consume is by multiplying 2% by the animals' body weight. However, cows weighing more may not require more feed as a unit of metabolic body weight than do small cows (Allison, 1985).

Holloway and Butts (1984) found large framed cows grazing fescue-legume pastures to consume more digestible energy (DE) than small frame size cows, especially early in the growing season when forage quality is very high. This is similar to what Kronberg et al. (1986) found while studying Hereford and $\frac{1}{4}$ Hereford x $\frac{3}{4}$ Simmental cattle. The 83 kg heavier cows ($\frac{1}{4}$ Hereford x $\frac{3}{4}$ Simmental) consumed 1.1 kg/d more organic matter than the Herefords. However, Holloway and Butts (1984) found on fescue

pasture, there was little difference noted in DE intakes among cattle of varying frame size. Forage quality seems to play a role in the DE intakes of cattle. It is possible that large frame size cattle were limited by gut fill and therefore could not consume as much DE as small frame size cattle.

Adams et al. (1986) found cows of large body size consumed more total forage but ate less per unit body weight than cows of smaller body size. Similarly, Green et al. (1991) found daily metabolizable energy intake for zero weight change was different ($P < 0.01$) for Brahman cross and Pinzgauer cross cattle than for Sahiwal cross and Hereford x Angus cross cattle. They suggested that this was probably due to the larger cow size and (or) higher milk production.

Grings et al. (1996) found cow organic matter intake (OMI) was affected by cow size and milk production. Calf growth potential, however, did not affect OMI by the cow. In this study, short, thin cows were different than tall, heavy cows. Tall, heavy cows consumed more total forage but ate less per unit body weight than did short, thin cows.

Size alone does not play a role in changing forage intake levels as a percent of body weight. However, the level of production, whether it be milk production or rate of growth may change an animals maintenance requirements (Ferrell and Jenkins, 1985).

Body Condition

Allison (1985), in a review article, found animal related factors such as level of milk production, body weight and body condition have been shown to affect forage intakes. Body condition often varies less in pen fed animals than in grazing animals

(Allison, 1985). This may be due to less variation in quality of forage being consumed by the cows, environmental conditions, or energy expenditures required for grazing animals.

Holloway and Butts (1984) studied cows grazing either fescue-legume or fescue pastures and found that during times of high quality forage availability, fatter cows tended to consume more forage than thinner cows. When forage quality decreased, cows on fescue pasture of thin body condition were able to consume more digestible energy than those of fatter condition. Balch and Campling (1962) and Nutt (1980) found a negative correlation between body condition and intake. When looking at rumen capacity, Nutt (1980) found fatter cows had distinctly smaller ($P < 0.01$) rumen capacities than thinner cows. Holloway and Butts (1984) found weight and fatcover accumulation indicated that cows that were initially fat had the propensity for consumption of forage and shunting nutrients toward the further accumulation of fat when allowed. Those cows of thin condition were not able to take advantage of high quality forage to increase fatcover.

Barlow et al. (1988) found DMI was similar on high and medium quality pastures and was considerably lower on low quality pastures. Body condition scores of the cows averaged 6.9, 4.6 and 3.9 on high, medium and low quality pastures, respectively.

Environment

Ferrell and Jenkins (1985) suggested that animals with high levels of production (milk production, growth rate) may have less advantage in a suboptimal environment and differences in DMI between genotypes (Barlow et al., 1988) will reflect the interaction

between animal and pasture system in both the long and short run. Results of Smith et al. (1987a) and Smith et al. (1987b) support this conclusion. They performed studies with different genotypes on shortgrass prairies and parkland grazing in Canada, and the ranking for efficiency changed with the changing environments.

Certain breeds have adapted to an environment that gives them an advantage over other breeds in that environment. An example would be the *Bos indicus* breeds, which can survive and reproduce in an extremely harsh and parasite rich environment. Frisch and Vercoe (1984) found differences when comparing Hereford x Shorthorn (HS) steers Brahman (BB) steers and HS x BB steers. Maintenance requirements, fasting metabolism, daily gain and voluntary feed intake (pen conditions) were highest for HS steers and lowest for BB steers while in an optimal environment. However, in a suboptimal environment, one that contained ticks, parasites and heat, the BB steers were able to withstand these stresses more effectively and outgain the HS and HS x BB crosses. The only time the HS x BB cross was able to outperform the other two breeds in growth was in an environment in which the parasites were controlled.

Dickerson (1978) indicated that in hot, dry climates with seasonal grazing that is sparse, genetically smaller cattle are better able to forage, mature and reproduce earlier than larger cattle. It was indicated that biological adaptation of body size to climatic, seasonal grazing and feed resource environments can be important.

According to Ferrell and Jenkins (1985), selecting animals that have a genetic potential for high productivity may place these animals at a disadvantage in a more restrictive environment. This led them to state,

Selection may result in a population of animals becoming highly adapted to a specific environment, but may render it less adapted to a different environment. Correlated responses to selection may also result in decreased adaptability to fluctuating environments. Thus, germ plasm resources should be synchronized with the production environment.

Milk production

Clutter and Neilsen (1987) found a 16.9-kg advantage in 205-d weight for calves suckling high milking cows over those suckling low milking cows. However, this advantage has a cost. Evidence indicates a positive relationship between genetic potential for milk production and food energy expenditure for maintenance (Lemanger et al., 1980; Jenkins and Ferrell, 1983; Ferrell and Jenkins, 1984; Montano-Bermudez et al., 1990). Even during the non-pregnant, non-lactating times the net energy for maintenance (NEm) for cows of similar size but larger potential for milk production is higher (Table 1). Ferrell and Jenkins (1987) associated approximately 70% of the variation in maintenance requirements with variation in milk production. According to Clutter and Nielsen (1987), differences in milk production tend to increase as the dams get older and peak at 6 to 8 yr of age (Rutledge et al., 1971; Neville et al., 1974) or 5 to 10 yr (Melton et al., 1967).

Results presented by Ferrell and Jenkins (1985) stated there is a positive relationship between maintenance requirement and genetic potential for measures of production, e.g. rate of growth or milk production. Montano-Bermudez and Nielsen (1990), citing McCorris and Wilton (1986) found an increase in milk yield of 1 kg per day was associated with an increase of .28 kg dry matter per day in feed consumption during lactation. If milk production is increased by 2-kg through an average lactation of 205 d, DMI will increase by 114.8 kg throughout the entire lactation cycle for that cow.

Casebolt et al. (1983) suggested that crossbred dams maintained a more persistent lactation compared to Hereford cattle. This could further increase the DMI of the crossbred cattle during lactation.

Greater milk production results in greater forage intakes of beef cows (Ferrell and Jenkins, 1987). Barlow et al. (1988) found crossbred cows to have higher DMI than straightbred cows during lactation. This may be a result of the crossbred cows having a greater persistency in lactation than the straightbred cows (Casebolt et al., 1983 and Anderson et al., 1986), heterosis was 21% for persistency of lactation in the study by (Anderson et al., 1986). Conversely, Barlow et al. (1988) has shown that there is no difference in DMI among grazing nonlactating genotypes. There was a difference in forage intake between the genotypes studied but the differences varied with pasture type and stage of lactation.

Wiltbank et al. (1962) and Totusek et al. (1973) have shown that the amount of nutrients available to a beef cow, both prior to and during lactation, have an effect on the amount of milk produced. Conversely, Holloway and Butts (1984) stated that cows establish their level of milk production prior to the time large pasture quality differences were available and any differences in persistency due to poor pasture conditions were not detected ($P > 0.82$). However, they did question whether the ability of the calf to consume milk is what kept milk production high with cows on low quality pastures.

According to Schingoethe et al. (1988) the nutritional needs of a beef cow may not increase at all during the shift from non-lactating to lactating, or at most will increase by one-third. Rosiere et al. (1980) found dry 2-yr-old heifers consumed only 67% as much forage as lactating 2-yr-olds.

Grings et al (1996) found OMI was affected by cow milk production. In their study, milk production had a larger effect on OMI when the cows were of large size, heavy and increasing body condition. Milk was not the sole driving force affecting monthly changes in intake however. Wagner et al. (1986), when studying 5 breeds (crosses) during June, July and August found that breed influenced ($P < 0.01$) intake when cattle were lactating. There was no difference when the same cattle were not lactating. Data from 2-yr have shown that the larger $\frac{3}{4}$ Simmental $\frac{1}{4}$ Hereford consumed an average of 1.1 kg of forage per kg milk produced while Herefords consumed 1.3 kg of forage per kg of milk. It is also interesting to note that Angus x Hereford and Simmental x Hereford cattle represented the widest range in milk production, yet their intake levels were essentially the same. This lends credence to the finding of (Grings et al., 1996) in that milk is not the sole driving force of intake during lactation.

Kronberg et al. (1986), also using Hereford and $\frac{1}{4}$ Hereford $\frac{3}{4}$ Simmental cattle, found that these cow types consumed 23 to 39% more forage, respectively, during lactation than their non-lactating counterparts. Lactation was the only factor explaining differences in intake between lactating and non-lactating cows. They concluded that as the cows' energy demand attributable to lactation increases, forage intake should also increase.

Havstad et al. (1986), measuring intake as lbs/1000 lbs body weight, found that as forage digestibility was different, different biological types during lactation had different intakes. Daily forage intake of $\frac{3}{4}$ Simmental $\frac{1}{4}$ Hereford cows was 16% greater than Hereford cows during lactation when forage digestibility was 36%. When forage digestibility was 50% there was no difference between the biological types for forage

intake. Some observations that were noted were that forage consumption was 53% greater for lactating cows than for non-lactating cows. Physiological status of an animal obviously influenced forage consumption in this study. It was also determined that intake differences between lactating cows of different biological types are related to milk production. Sixty percent of the variation in their study was explained by milk production. This is similar to the data presented by Taylor et al. (1986) who found approximately 70% of the variation in maintenance to be associated with variation in milk production. Ferrell and Jenkins (1987) attributed approximately 40% of variation in maintenance requirements to milk production potential when milk production is measured by the weigh-suckle-weigh technique.

Miller et al. (1999) found increasing milk yield was associated ($P < 0.10$) with increased average daily energy intake during the lactating period, although total feed energy intake was not associated with milk yield. No effect of non-lactating intake ($P > 0.05$) was found. Ferrell and Jenkins (1984) stated that muscle mass energy expenditure per unit weight is low compared to the energy expenditure of the internal organs per unit weight. Mass of these organs, as proportions of weight, have been shown to vary with breed type and physiological state (Ferrell and Jenkins, 1985). Cows with the potential to produce large quantities of milk have larger visceral organs than do cows that give moderate or little quantities of milk.

Table 1. Estimates of metabolizable energy required for maintenance of various breeds or breed crosses

Breed or breed cross ^a	Physiological State	Maintenance, kcal*kg ^{-0.75} *d ⁻¹
Angus-Hereford	Nonpregnant, nonlactating, 9-10 yr	130
Charolais X	" " "	129
Jersey X	" " "	145
Simmental X	" " "	160
Angus	Nonpregnant, lactating, 5-6 yr	149
Hereford	" " "	141
Simmental	" " "	166
Charolais	" " "	165
Angus	Nonpregnant, nonlactating, 5-6 yr	118
Hereford	" " "	120
Simmental	" " "	134
Hereford	Growing-finishing, 9-15 mo	106
Simmental	" " "	126
Angus-Hereford	Pregnant, lactating 8-9 yr	151
Red Poll X	" " "	157
Brown Swiss X	" " "	156
Gelbvieh X	" " "	158
Maine Anjou X	" " "	146
Chianina X	" " "	174

^acrossbred cows produced by mating Angus, Hereford, Charolais, Jersey, Simmental, Red Poll, Brown Swiss, Gelbvieh, Maine Anjou or Chianina bulls to Angus or Hereford cows. (Ferrell and Jenkins, 1985)

Breed differences

Bos indicus cattle have a 10% lower NEM than does a typical beef breed. Cattle of the dairy variety have a 20% higher NEM than does a typical beef breed (NRC, 1996). This supports data by Ferrell and Jenkins (1985) showing cattle with high milk have higher maintenance requirements even during the non-lactating times than do cows that give lower milk. This is most likely due to the internal organ size of the animals in question. Cows with higher milk production tend to have larger internal organs,

primarily the heart and gastrointestinal tract (Ferrell and Jenkins, 1985) which requires more energy for maintenance.

Bos taurus cattle on lush pastures consume more forage than *Bos indicus* cattle of similar body size. However, on poor quality forage *Bos indicus* cattle consume more forage. This may be a result of the ability of the *Bos indicus* cattle to recycle urea nitrogen (Frisch and Vercoe, 1991).

Milk production potential

According to Taylor et al. (1986) about 70% of the variation in maintenance requirements is associated with variation in milk production. Conversely, Montano-Bermudez et al. (1990) state the variation in milk production accounts for 23% of the variation in energy requirements for maintenance between three groups of cattle. It is agreed however, that there is a positive relationship between milk production potential and maintenance requirements (Ferrell and Jenkins, 1984; Montano-Bermudez et al., 1990; Taylor et al., 1986).

Taylor (1992) stated that the level of milk produced by the dam is a result of the ability of the calf to consume milk. If the calf is not vigorous at birth, the dam's milk production will be decreased. Anything that causes a female to reduce her level of milk production is likely to cause some regression of mammary tissue, therefore preventing the resumption of full milk production.

Drylot vs. range

Cows grazing rangeland are estimated to use 30% more energy than confined cows (Osuji, 1974). Research has been conducted (Ferrell and Jenkins, 1985 and Montano-Bermudez and Nielsen, 1990) in the drylot with a known amount of feed consumed by each biological group of animals. However, under range conditions, animals expend more energy grazing, moving to get water and finding shelter. This increases an animals energy requirement as shown in Table 2.

Table 2. Energy costs for different cow activities

AVG TIME OR AMT	ACTIVITY	ENERGY EXPENDED
	Basal Req. (Resting)	81 kcal*MBW
5 km	Walking	82 kcal/100 kg BW/km
9 h	Grazing	78 kcal/100 kg BW/h
5 h	Ruminating	24 kcal/100 kg BW/h
2 h	Stands Idle	34 kcal/100 kg BW/h
Last Trimester	Fetal Growth	400 kcal/d
.33 kg/d	Growth	.33kg*4200kcal/kg new tissue
	Lactation	25-35% > than basal

From: (Sprinkle, 1992 citing Havstad, 1981)

Havstad et al. (1986) studying grazing patterns of five different biological types of cows concluded there was no difference in either the time spent grazing or the distribution of grazing use between these biological types on the same range. They further implied that different biological types use the resources provided by the rangeland similarly and the energy costs associated with grazing in a range environment are equivalent for different biological types.

Reproductive rate

Reproductive rate plays a vital role in the efficiency of any herd. "Higher female rates of reproduction or of production reduces maintenance and replacement overhead for breeding females per unit of product" (Dickerson, 1978). Lesmeister et al. (1973) found heifers which became pregnant early in the breeding season continued to calve early in subsequent seasons and had higher production rates annually during their lifetime than did later calving heifers. According to Marshall et al. (1976), cow weight, condition and milk production all had negligible effects on reproduction. In the same study it was concluded that heterosis for reproductive performance is a major advantage for the crossbred cow.

Milk potential

Increasing reproductive rate reduces female replacement, maintenance feed and fixed costs in almost direct proportion to $1/\text{reproductive rate}$ (Dickerson, 1978). When the level of nutrition is inadequate, the cow attempts to maintain a level of milk production according to her genetic potential at the expense of her body reserves, subsequent reproduction efficiency is effected (Boggs et al., 1980; Holloway et al., 1979).

Montano-Bermudez et al. (1990) found cows of different potential for milk production that are not limited by forage have no differences in overall reproductive rate. However, under range conditions, cattle may be limited on the quality if not the quantity of forage, which could affect the overall reproductive rate of the herd. Boggs et al.

(1980) stated high milk production was negatively related to the post-partum interval. "Each additional kilogram of milk per day delayed rebreeding by 1.4 days." Jenkins and Ferrell (1994) found reproductive rates increased with increasing available dry matter; however, at low levels of available dry matter, increased cow size coincided with a decrease in reproductive rate.

Laster et al. (1979) indicated that breeds selected for milk production tend to reach puberty earlier than breeds of similar mature size but that have a lower level of milk production.

Differences due to cow age

Reproductive efficiency changes as the cow ages and this change is different for different breed groups. According to Kress et al. (1990) Hereford cattle had poor weaning weights per cow exposed as 2-yr olds. Each additional year of age increased the weaning weight per cow exposed to a maximum level reached at 5+ years of age. Angus-Hereford cattle, had high weaning weights per cow exposed as 2-yr olds, this decreased as 3-yr olds and decreased even further as 4-yr olds. The highest level of weaning weights per cow exposed was in the 5+ year olds. There was no difference between Simmental-Hereford cattle and Angus-Hereford cattle. However, the $\frac{1}{4}$ Simmental, $\frac{3}{4}$ Hereford cattle had the lowest weaning weights per cow exposed as 2-yr olds and the highest as three year olds with 5+ year olds being moderate. The $\frac{3}{4}$ Simmental, $\frac{1}{4}$ Hereford cattle were moderate as 2, 3 and 4 year olds with the highest weaning weight per cow exposed as 5+ year olds. This indicates that different breeds or breed crosses will have different levels of pregnancy at different ages. Doornbos et al. (1983) found

age of the dam to have a significant effect ($P < 0.05$) on the age at conception for their heifers. Heifers from 4-yr and older dams became pregnant approximately 10-d earlier than heifers from 3-yr-old dams.

Buttram and Willham (1989) found in first parity dams, breed composition was a significant source of variation. Small heifers had a higher calving rate ($P < 0.05$) than heifers from large breed composition cattle, medium cattle ranked between them. Second parity dams followed the same ranking for both cycling rate (% of cows showing estrus) and conception rate. Small cattle had the highest cycling rate and conception rate ($P < 0.05$), large cattle had the lowest with medium cattle in the middle. In the third parity, small cattle had more calves ($P < 0.05$) than medium or large cattle. It was decided that under less than optimum conditions for cycling at 14 to 15 mo of age, smaller cattle, which can mature at lighter weights and an earlier age should be considered.

Van Oijen et al. (1993) broke cattle into three breed groups depending upon their level of milk production as well as the ages of these cattle by breed group. Reproductive performance was measured as calf crop percentage. The low milk group had 73.6, 78.7 and 93.2% calf crop as 1, 2 and 3+-yr-old cows, respectively. The medium milk group had 92.5, 80.6 and 90.4% calf crop as 1, 2 and 3+-yr-old cows, respectively. Lastly, the high milk group had 81.3, 83.8 and 87.1% calf crop as 1, 2 and 3+-yr-old cows, respectively. This study was performed under confinement situations where feed intake was not a limiting factor.

Related to Body Condition Score (BCS)

An animal's condition plays a vital role in its reproductive capacity. Body condition score is an easy and effective way to evaluate an animal's condition. Richards et al. (1986) said "energy restrictions during the late prepartum period results in thin body condition at calving, extends the interval to first postpartum estrus, and decreases the likelihood of a high percentage of cows exhibiting estrus early in a finite breeding season." Cows being fed different nutritional levels that calved with a BCS ≥ 5 returned to estrus an average of 14-d earlier than those that calved with a BCS ≤ 4 (Richards et al., 1986). In this same study nutritional management also did not affect the interval to pregnancy. However, cows that calved with a BCS ≤ 4 had a 6-d longer interval to pregnancy than those with a BCS ≥ 5 .

Buttram and Willham (1989), found cycling rate was the same for cattle of different size at one ranch (high quality forage), however, large cattle had a decrease of approximately 20% in their cycling rate and calving rate at another ranch when compared to small cattle. This second ranch had a harsh dry environment where forage was limited and quality was poor. Presumably, the larger cattle were not able to meet their energy requirements for maintenance and for growth or reproduction in this harsh environment, therefore body condition suffered and the ability to conceive also suffered.

Postpartum interval

Postpartum interval plays a vital role in herd efficiency. If cows are continually late in breeding, the calving date gets pushed back or cows don't get bred that season. Short et al. (1972) found that removal of calves after birth will shorten the postpartum

interval and mastectomy will further reduce the postpartum interval over allowing calves to suckle the dam even when nutrient intake is adjusted for lactation status. However, these practices are impractical. Apparently, lactation in the cow inhibits estrual activity and ovulation without affecting follicular development (Short et al., 1972). Oxytocin injections to the cows that are mastectomized or intact 3x per day for 35 d following calving did not change the postpartum length.

Freetly et al. (2000) found cows that cycled prior to and after parturition did not have a difference in the number of cows diagnosed as being pregnant with their second calf, although it was cautioned that cows that lost body condition until lactation were numerically the lowest in percentage pregnant for the second term. In their study, nutritional treatments were imposed to either have the cow maintain body condition during pregnancy, lose body condition during the second trimester and then regain it during the third, or lose body condition during the second and third trimesters and regain it after 28 d of lactation. All cows would be at the same body condition for breeding.

Freetly and Cundiff (1998) found postpartum interval to differ ($P < 0.001$) by sire breed with heifers of Brahman, Boran and Tuli sires having the longest postpartum interval and Angus, Hereford and Belgian Blue sired heifers to have the shortest. Hereford was not different than Brahman, and Belgian Blue was not different than Brahman. This may be due to the different times at which the heifers expressed their period of full (highest) lactation. Postpartum interval did not differ due to heifer breed group or nutritional treatment.

Calf Weaning Weights

Clutter and Neilsen (1987) state that in beef production, development and survival of a calf are to a large part dependent upon the maternal environment provided by the dam. If a dam provides colostrum directly after birth, cleans the calf up after birth (this is especially important in cold weather), provides an adequate supply of milk and teaches the calf how to forage, the calf has a good chance at surviving.

Milk Production of the Dam

Neville (1962) and Rutledge et al. (1971) say that among beef cattle, 66% of the variation in weaning weight is accounted by milk production of the dams. Holloway and Butts (1984) stated calves on high quality pastures did not consume more milk than calves on low quality pastures. However, there was a difference in growth rates. Calves on high quality pastures appeared to consume more nutrients from forage, which would account for their increased growth rate. Clutter and Nielsen (1987) stated that the greater regression for the lower milking (.032, .032 and .053 kg/kg for high, medium and low milk groups, respectively) group suggests better use was made of the milk available. On average 31.25 kg of milk was required for 1kg of gain in the high and moderate milk groups while the low group required 18.87 kg of milk for 1 kg of gain. This suggests the calves receiving less milk are making up for the difference in other ways or are making better use of the available milk. Grings et al. (1996) found efficiency of production to increase with increasing milk production. Calf weaning weights were larger for the cows that produced more milk and this more than made up for the difference in forage intake by the cow.

Boggs et al. (1980) found calves born from March 21-31 consumed more milk than those born from March 1-20. This may be a result of forage quality differences at these times and the ability of the dam to convert forage to milk. They also found milk intake to have a negative effect on grass intake by calves 2-6 mo old. Each increase of 1 kg of milk consumed decreased .03 kg/d less grass in 2 mo old calves ($P < 0.05$). Six mo old calves consumed .02 kg/d less forage for every 1 kg increase in milk consumption ($P < 0.05$). It was also determined that each additional kg of milk/d added 7.20 kg of 205 d adjusted weaning weight and .34 kg/d of average daily gain.

Calves not receiving adequate milk from the dam may try to compensate by consuming more forage. Boggs et al. (1980) found that during the first 2 mo of life grass intake and ADG were negatively related indicating that calves were not able to compensate for the decrease in milk by consuming forage. However, during the 3rd through 5th month, added grass tended to improve gain ($P < 0.10$). Each 1 kg of grass yielded .02 kg/d of additional gain during this time. Rumen function for calves at this later stage is probably better so better use of the available forage was probable. Clutter and Nielsen (1987) indicate that as lactation progresses, the importance of milk production for calf growth declines.

Baker et al. (1976) found calves gained 81 g/kg of milk provided during the time calves were housed and milk was the only source of feed. After calves were grazing the gained 50 g/kg of milk provided. In a subsequent study (Le Du et al., 1976) found calves on restricted milk intake consumed more forage per unit body weight than those not being restricted on milk intake. It was determined that calves not being restricted in milk intake grew faster from birth to weaning, but after weaning, these calves had a lower

forage intake for a period of time than calves on restricted milk intake, causing no difference in live weight a few weeks after weaning.

Forage intake by the calf

Le Du and Baker (1979) found that forage intake was depressed by milk intake but total ME consumption and growth rate were enhanced. This is similar to Ansotegui et al. (1991) who found fecal output to be negatively correlated with milk intake in July ($r = -.62$; $P < 0.05$) and August ($r = -.56$; $P < 0.05$). Ansotegui et al. (1991) suggested that forage intake of calves may be under metabolic control rather than being limited to rumen fill due to similar ADG and DE intake each year even though forage consumption and milk consumption were different each year. Milk intake in 1985 was higher ($P < 0.05$) (817.6 ± 42.1 kg) than 1984 (534.8 ± 77.7 kg).

According to Ansotegui et al. (1991) calves nursing low milk producing cows consume more forage than those calves nursing high producing cows. A strong negative relationship between the amount of milk the dam produces and forage DMI by the calf was reported. Data presented by Ramsey et al. (1994) with sheep supports this observation. Clutter and Neilsen (1987) state that calves from low milk producing dams rely earlier in lactation and to a greater extent on alternative food sources of lower nutritional value than milk. Ansotegui et al. (1991) found calves to consume approximately the same amount of DE whether receiving high amounts of milk or low amounts of milk, suggesting that forage intake by suckling calves may be under metabolic control rather than being controlled by rumen fill. Miller et al. (1998) found higher fecal outputs by calves from low milk producing cows than moderate or high milk

producing cows, suggesting more forage intake by these calves. Le Du et al. (1976) agrees with this finding, calves on restricted milk intake consumed more forage than calves not restricted. When looking at calf weights, this increase in forage intake was not enough to make up for the lost milk, however, after weaning these calves were able to continue consuming large quantities of forage while those on high milk had a difficult time converting strictly over to forage consumption. After several weeks of grazing, calves from both groups weighed the same.

Horn et al. (1979) found diets selected by calves to be higher in nitrogen than diets selected by cows during certain months. Grings et al. (1995) also found that calves selected diets of higher quality than mature steers early in the summer when calves were receiving much of their nutrient intake from milk, but not at a later time. This differential effect may be caused by learning behavior, changes in forage quality or increased forage intake by calves. Calves may have more time to be selective in their foraging due to the consumption of milk; a high quality food. As milk intake decreases or calf growth requires more than milk can provide, forage intake will increase, therefore there is less time for the calf to be selective.

In a study by Boggs et al. (1980) milk intake had a negative effect on grass intake by calves that were 2 to 6 mo old. They also found a negative relationship between grass intake and calf performance through the entire preweaning period and grass intake and ADG for the first 2 months. However, from days 60 to 150 the added grass tended to improve gain, each additional 1 kg of grass eaten per day resulted in about .02 kg/day more gain. It was also found that calves born later in their study, March 21-31, consumed less DM ($P < 0.05$) than those born before March 21st. Monthly forage DM

intakes represented .62, 1.46, 1.51, 1.75 and 2.20 % of the calves body weight for May, June, July Aug and Sept.

Sowell et al. (1996) found that restricting milk intake by blocking the rear udder quarters did not affect ($P > 0.10$) forage OMI of calves grazing blue grama, a low quality forage, during any time even though the calves consuming less milk spent more time ($P < 0.05$) grazing in June. Weaning weights were adversely affected by restricting milk intake for 4 weeks. Grings et al. (1995) found similar results when forage quality was poor. However, when forage quality was good, calves consumed diets that were 21% higher in crude protein and contained 5% less ADF when compared to mature steers. It seems that when forage quality is good and milk production is adequate, calves will be highly selective in their forage intake. However, if milk intake is limited and/or forage quality is poor, the calf does not have the ability to be selective and will consume more forage in an attempt to meet energy requirements.

Animal Requirements

Maintenance requirements have been shown to account for 71 to 75% of the ME required by the cow during a production cycle (Ferrell and Jenkins, 1987). For this reason alone it is important to study and understand maintenance requirements and the differences among breeds with regard to their maintenance requirements. According to Ferrell and Jenkins (1987), about 70% of the variation in maintenance requirements is associated with the variation in milk production among breeds.

Maintenance Requirements: Size and body condition

According to Holloway and Butts (1984) animals consume different amounts of forage depending upon the type of forage in question. Large framed cows grazing a fescue-legume pasture consume more DE than smaller framed cows, however the opposite tendency was noted for animals consuming fescue alone. The use of breeds or breed crosses of greater genetic potential for performance to improve output can increase the nutrient requirements of the producing females (Jenkins et al., 1991). Data presented by Lemenager et al. (1980) suggests that weight alone cannot be used to accurately determine the energy requirements of the larger breeds or breeds with higher milk production potential.

Dickerson (1978) stated that biological adaptation of body size to climatic, seasonal grazing and feed resource environments and to specialized crossbreeding systems can be important. Ferrell and Jenkins (1985) reported maintenance requirements per unit metabolic body size to differed little due to weight per se but that genetic potential for milk production was positively related to maintenance energy requirements and these differences are expressed in the non lactating female. Conversely, Buttazzoni and Mao (1989) studying dairy cows, state that energetic expenditure for maintenance per unit of metabolic weight is independent from milk yield. Results from Barlow et al. (1988) are in agreement; genotypes with higher potential for milk production did not have higher maintenance requirements per unit metabolic live weight.

Russell and White (1983) noted that maintenance per unit of size decreased with increasing body condition and this is in agreement with Dickerson (1978). Ferrell and Jenkins (1985), citing Turner (1974), reported that Charolais and Hereford maintenance

requirements increased proportionally to metabolic body weight. However, when they compared several different studies and scaled back milk production at a value of 1.06 Mcal ME/kg milk, variation in maintenance requirements were found to exist beyond those associated with size or milk production.

Marshall et al. (1976) concluded larger cows apparently produce enough additional calf weight to balance their greater nutrient requirements. Reid et al. (1991) calculated MEM values for eight breeds or breed crosses. Red Poll cows had the highest MEM while Brahman x Hereford had the lowest.

Maintenance requirements: Pregnancy and Lactation

According to NRC (1996) animal heat production increases with pregnancy. This increase in heat production can be assumed to increase the energy requirements of beef cattle. According to Barlow et al. (1988) and Kress et al. (1996) crossbred cows have a higher milk production than their straightbred counterparts. The percent hybrid vigor for milk yield is 6% in dairy cattle (Bourdon, 1997). Under grazing circumstances, crossbred cattle consumed more DMI than did straightbred cattle when grazing poor quality forage (Barlow et al., 1988). Conversely, when forage quality was high, crossbred cattle consume less DM. Ferrell and Jenkins (1985) suggest crossbred cows have greater nutrient requirements than straight-bred animals; this is a result of the greater lactation yields rather than any differences in live weight. The lactating animal has higher visceral organ weights than the non-lactating counterpart (Ferrell and Jenkins, 1985). The more milk produced by an animal, the larger the increase in visceral organ weight

(Ferrell and Jenkins, 1985). This corresponds to an increase in energy requirements during lactation.

The estimated ME requirement for lactation is 1.06 Mcal/kg of milk (NRC, 1971). Montano-Bermudez et al. (1990) calculated the energy required to produce 1 kg of milk to be $1.0 \pm .13$ Mcal for their experiment. There seems to be an antagonistic relationship between milk production and ME requirements. Anderson et al. (1986) found a 53% increase in intake for animals during lactation. It is also noted that intake differences during lactation of different biological types is related to levels of milk production and that seasonal differences or yearly differences in forage quality can influence intake levels of different biological types of cattle. Lemanger et al. (1980) found average TDN consumption ratios during lactation to be 100, 112, 112 and 132 for HH, AH, CH and SH cows respectively. The visceral organs, lungs, liver, kidneys and heart, consume a large amount of energy, any increase in their size corresponds to an increase in the energy required by the animal.

Maintenance requirements: Previous plane of nutrition

Ferrell and Jenkins (1985) found sheep on a high plane of nutrition had an increased maintenance requirement over sheep on low planes of nutrition. It was also found that the weights of the heart, lung, liver, and kidney to be greater in ad libitum versus restricted diets for cows in feedlots. This suggests maintenance requirements for the ad libitum fed animals would be higher than those on a restricted diet.

Ferrell and Jenkins (1985) state that maintenance is related to body composition, primarily with the body lean or protein mass. The correlation of maintenance with body

fat mass is low. Holloway and Butts (1984) found rumen capacity as a percentage of body weight and in total capacity is inversely related to fatness. Ferrell and Jenkins (1985) also state that maintenance requirements differ due to nutritional treatments prior to evaluation. Lambs on a high plane of nutrition had maintenance requirements that were 32% higher than those lambs from the low nutrition plane. A portion of this increase in maintenance requirements can be attributed to the increase in organ size (Barlow et al. 1988). This is in agreement with Ferrell and Jenkins (1985) Friesian steers had a higher proportion of visceral organ weight than did Herefords and had a higher maintenance requirement. They believe this is a result of the genetic potential of the Friesian breed to produce large quantities of milk.

Biological Efficiency

Biological efficiency has become a large topic of interest. With the introduction of the continental breeds in the early 1970's, a rancher can choose a large variety of cattle or crossbreds. To choose the best animal for any given area, one needs to consider a vast array of factors including but not limited to, climactic conditions, forage resource availability and animal size. In essence, genotype x environment interactions need to be explored and understood to get the most efficient animal type for a given range. According to Dickerson (1978), biological efficiency would be improved more in beef and lamb than in any of the other meat animals with an increase in reproductive rate.

Biological efficiency is a term used to describe the relationship between inputs and outputs. Ferrell and Jenkins (1994) define biological efficiency as the ability of a cow to convert feed resources to calf weight at weaning. This allows breeds or individual

animals within a breed to be ranked for biological efficiency by measuring cow intake, or cow feed energy consumed and by measuring calf weights at weaning.

Calculations for biological efficiency are often of the sort presented by Kattnig et al. (1993):

$$\text{Biological efficiency} = \frac{\text{calf weight}}{\text{OMI}}$$

To calculate biological efficiency while including reproductive measures, Doornbos et al. (1987) proposed the following formula:

$$\text{Biological efficiency} = \frac{\text{Adjusted calf weaning weight/cow exposed}}{\text{OMI}}$$

In a 4-yr study conducted by Doornbos et al., (1987) using straightbred Herefords (HH), 50%Angus x 50%Herefords (AH), 25% Simmental x 75% Hereford (1S3H), 50% Simmental x 50% Hereford and 75% Simmental x 25% Hereford (3S1H) it was determined that matching genotypes to the environment is important for biological production efficiency. This study was conducted in the foothills region of northern Montana with precipitation ranging from 20 cm to 41 cm during the study years. Average annual precipitation is 46 cm, this study was conducted during a severe drought. Production efficiency always favored the larger cattle with higher milk production. However, during the years with low rainfall, biological efficiency tended to favor an intermediate in both size and milk production. In this particular environment, the large genotypes with high milk production could not eat enough to support maintenance and

heavy milk production. It was decided the intermediate genotypes were the best for this environment.

Jenkins et al. (2000) indicate that breed and (or) breed crosses differ in peak and total milk yield with differences being expressed among breed crosses as well. "The greater genetic potential for milk production would increase the ME cost for maintenance per unit metabolic size." In this case biological efficiency was more dependent upon breed potential for calf preweaning growth and milk production. The growth of calves from dams with lower genetic potential for milk production was not fully realized during their 170 d test period. This resulted in fewer kilograms of marketable product and lower biological efficiency when related to total DMI consumption.

Kattnig et al. (1993) found overall efficiency to decrease with increasing cow hip height ($P < 0.05$) under semidesert range conditions. Organic matter intake and efficiency were not affected by the estimated genetic potential for milk while cow BW had a positive effect ($P < 0.01$) on calf body weight from late spring through weaning in mid-autumn. On average, the weaning weights of calves increased by .18 kg/kg of cow body weight.

Organic matter intake generally increased with cow BW in a study by Kattnig et al. (1993). Efficiency was negatively related to cow body weight indicating that under semidesert conditions, smaller cow types are more biologically efficient. Even though the larger cows weaned heavier calves, their OMI was high enough to offset the benefit gained from weaning a heavy calf. Solis et al. (1988) reported that cows that have the potential to store fat are more efficient when energy is limited, whereas cows that have larger protein stores are more efficient when energy is not limited. Under semidesert

conditions and energy deficiency may be a common event, lighter, small framed cows may be able to store more fat during times of plenty due to a reduction in maintenance requirements.

Contradictory to this is that taller cows tended to maintain more condition on average than their shorter counterparts (Kattnig et al., 1993). Average condition scores increased by .05 units for every additional cm in cow hip height. Biological efficiency was negatively related to cow hip height and efficiency decreased by .3 kg/kg for each 1-cm increase in cow hip height. This would indicate that maintenance requirements of the large framed cows may have been too high under these conditions.

Increasing milk production increased the OMI of the cows only during the late summer (mid-lactation) ($P < 0.04$) (Kattnig et al., 1993), cow condition was not affected by increasing milk production ($P > 0.10$). The quadratic relationship between milk production and efficiency during early lactation indicated efficiency increases initially with increased milk production potential, than attains a point of diminishing returns. No relationships between milk production and efficiency were observed during any other time of the year. It was concluded that optimal biological efficiency may be achieved using cows that are small in stature and weight under semidesert conditions. Genetic potential for calf growth preweaning did not affect efficiency ($P > 0.20$) within the range of their data, which implies that cows with more genetic potential for preweaning growth tended to consume more forage overall and the increased calf growth from these cows balanced the greater intakes. However, the potential to produce milk could become a large problem under poor environmental conditions.

Montano-Bermudez and Nielsen (1990) defined biological efficiency as “the ratio of estimated kilograms of calf weight weaned by a herd of 100 first-cross cows to estimated metabolizable energy (ME) intake by the cows and preweaning non-milk intake by the calves”. This study was conducted in a drylot setting in Nebraska. Biological types represented included Hereford x Angus, Red Poll x Angus and Milking Shorthorn x Angus, which represented low, medium and high levels of milk production respectively.

The energy required by the cow herd was 10 and 12% higher for the medium and high groups respectively and maintenance requirements represented 64 to 67% of the total energy required by the cowherd. Energy required for lactation was 32 and 43% higher for the medium and high milk groups respectively when compared to the low group. Energy requirements for the calves followed a similar trend. Calves in the medium group required 8% more energy than calves in the low group and high calves required 14% more energy. The weaning weights were 201 kg, 211 kg and 212 kg for low, medium and high milk groups respectively (Montano-Bermudez and Nielsen, 1990).

Efficiency of production to weaning was highest for the low group, the higher outputs in the medium and high groups were more than offset by the higher energy requirements for maintenance (Montano-Bermudez and Nielsen, 1990).

Reid et al. (1991) used breed group means for weight of calf weaned per mature female exposed to breeding and divided this by the yearly MEm requirements to estimate efficiency. In doing this, estimates of energy requirements for gestation and lactation were not considered nor was ME intake of the calves from non-milk sources considered. The conclusion reached is that breed types vary in efficiency at different stages in the life

cycle and evaluating efficiency by weaning weight alone may be misleading. Moderate body size *Bos taurus* crosses that are medium in body size and milk production have the highest biological efficiency in a dry, temperate climate.

Jenkins et al. (1991) in a study conducted in the drylot, found a significant sire breed of dam effect on output (calf weaning weights). Progeny weight gains from Brown Swiss- and Maine Anjou- sired F1 cows were greater ($P < 0.05$) than weight gains of progeny from Angus/Hereford- sired F1 cows. Weight gains of breed crosses with moderate potential for either size or milk yield did not differ ($P > 0.05$) from other high or moderate potential breed crosses.

Differences among the breed crosses for the conversion efficiency seem to contrast breed crosses with genetic potential for moderate mature size with breed crosses of greater potential for mature size (Jenkins et al., 1991). Angus/Hereford- and Red Poll- sired dams' efficiency ratios were greater ($P < 0.05$) than the ratios for Gelbvieh (large size and high milk production) and Chianina (large size) but did not differ ($P > 0.05$) from those for the Maine Anjou (large size) or the Brown Swiss (high milk production).

Jenkins et al. (1991) concluded that the variation in efficiency seems to be more dependent upon ME consumption of the dam rather than that of the calf. Calves showed no differences ($P > 0.05$) in their level of creep intake in this study. The breed types with a higher milking ability required more ME intake and the difference in calf weight was not enough to offset this increase in ME intake, therefore efficiency ratios were less desirable.

Evidence indicates the cows with moderate mature weights and levels of milk production have the potential to be more biologically efficient. If these moderate cows are mated to sire breeds with greater genetic potential for growth, the resulting complementarity effects would be expected to be positive for efficiency during the preweaning period for a production system (Jenkins et al., 1991).

Grings et al. (1996) found calf growth potential was not a significant factor affecting efficiency due to an increased intake of forage of these high growth potential calves. However, when converted to intake per unit BW, forage intake did not differ ($P > 0.10$), indicating the increased forage consumption of high growth potential calves was a result of increased BW. This is in contrast to Jenkins et al. (1991) who, in the drylot, found high growth potential calves to consume the same ME levels of lower growth potential calves.

Milk production was found to be a significant adjustment factor for efficiency ($P < 0.05$) with greater milk production being associated with greater efficiency (Grings et al., 1996). Growth potential of the calves sire did not influence efficiency of production to weaning even though calves from high growth sires had greater weaning weights in some years. It was determined that no extra nutritional demand was place on the cow. Cow size influence intake of the cow but not efficiency of production. Indicating that larger cows ate more but weaned enough extra kg of calf weight to compensate for this increase in intake.

Davis et al. (1983a) evaluated lifetime biological efficiency. Calf weaning weight and cow salvage value were included as the outputs while progeny creep feed and the dams lifetime feed consumption were the inputs. It was determined that dams receiving

low energy diets generally had lifetime efficiencies equal to or superior of those fed high energy diets in spite of the older ages at calving. It was also found that dams of beef breeding were the most efficient followed by a beef x Holstein cross and then straight Holstein. Even though Holstein cows weaned the heaviest calves and had the highest salvage values, the ME consumption was so much greater as to outweigh these benefits. It was concluded that dams of smaller size tended to be more efficient than those of large size.

Davis et al. (1983b) found that weights, heights and weight:height ratios of the dams at 240 d of age were not correlated significantly with subsequent efficiency. This indicates that selection of dams on these traits would not be advisable if one is selecting for lifetime cow efficiency. However, more efficient weight gains from 240 d to first calving tended to be related to dams lifetime efficiency.

A dam's weight at the weaning of her calf was found to have a significant negative correlation with efficiency (Davis et al., 1983b). This indicates that smaller dams or dams with lower BCS were more efficient over the dam size and BCS in their study. However, it was mentioned that this advantage may in part be due to these dams being mated to sires that had larger body sizes relative to their own. This trend was much stronger when the cows salvage value was excluded from the model. Feed consumption of the cow appears to be the most important factor influencing actual lifetime efficiency.

Decreased age at calving had a large favorable relationship ($P < 0.01$) with actual lifetime efficiency. This would indicate that dams that calved earlier or rebred sooner

after parturition had a reduced feed intake prior to weaning a calf than those who took longer to conceive.

Correlations between efficiency and change in weight:height ratio from calving to weaning were positive indicating an increase in BCS during the post-partum interval increased efficiency.

Nazzie et al. (1999), studying life cycle herd efficiency in a simulation study, defined efficiency as the ratio of total output (steer lean meat equivalent) to total input (feed equivalent) over a specified age at disposal of the herd. In this study, an assumption of unrestricted feed intake was made.

Nazzie et al. (1999) determined that efficiency could be maximized by selling offspring to the feedlots at weaning when the offspring was 31 to 35% mature. Life cycle efficiency tended to be higher the slower the breed matured. It was found that the slowest maturing group (dairy synthetic) was the most efficient. This is probably due to less intake, since the animal is not carrying fat all the time and it is still growing. If maturity rate is increased, efficiency is decreased due to feeding the mature animal for longer. The longer the cow was in the herd, life cycle herd efficiency was decreased, however, after 6 yr of age, the decline in efficiency was minimal and in some cases it began to recover (Nazzie et al., 1999).

Marshall et al. (1976) defined efficiency as the ratio of calf weaning weight to total TDN intake by the cow and calf. This study was conducted in the drylot with feeding levels altered to allow for monthly weight changes that were similar to the average of their contemporaries in pasture. Angus, Charolais and the F1 reciprocal cross were mated to a single Hereford sire each year.

It was determined that cow weight affected ($P < 0.01$) all TDN measures and progeny weaning weight but did not affect efficiency ($P > 0.25$). Cow weight, condition, and milk production did not affect reproduction. However, both crossbred and Angus cows were more fertile ($P < 0.05$) and weaned more calves ($P < 0.05$) than Charolais cows. Dickerson (1978) stated that an approximate 10% improvement in biological efficiency could be expected in lamb or beef cattle as a result of a 20% increase in the number of offspring produced due to genetic improvement. It was also suggested that factors associated with size, such as lactation and gestation, dystocia, and post weaning rate of gain, preclude size itself from having a major effect on life cycle production efficiency.

Milk production accounted for 23% of the variation in efficiency while cow condition and weight only accounted for 1% (Marshall et al., 1976). Milk production was moderately associated with weaning weight ($r = .44$) and efficiency ($r = -.52$). Cows that produced more milk had heavier calves at weaning and tended to be more efficient. Ferrell and Jenkins (1985) found increasing milk production increased maintenance requirements. However, Marshall et al. (1976) found total intake to have essentially no relationship with efficiency even though cow TDN intake was influenced ($P < 0.01$) by breed, age of dam and calf age effects. Heavier cows consumed more food but produced more kg of calf weight, thus counterbalancing one another and explaining why efficiency did not differ with cow weight. Increasing BCS negatively affected both weaning weight and efficiency in this study. It was determined that heterosis for reproductive performance is the major advantage of the crossbred cow.

Green et al. (1991), studying input/output differences among nonpregnant, lactating *Bos indicus* x *Bos taurus* and *Bos taurus* x *Bos taurus* F1 crossbred cows in south central Nebraska, found in general the *Bos indicus* x *Bos taurus* groups to be more efficient. Measuring efficiency as calf gain over cow ME feed intake during an 18-wk lactation portion of the production cycle, while omitting calf creep intake and being independent of milk production, determined that efficiency was 7.5% higher for *Bos indicus*-X groups ($P < 0.10$). This in part could be due to ignoring calf creep intake and *Bos indicus*-X groups had lower creep intakes ($P < 0.10$). When calf gain was related to feed consumption of both the cow and calf, independent of any measures of milk production, an 11% advantage of the *Bos indicus*-X groups was found over their *Bos taurus*-X counterparts ($P < 0.05$). Differences between the two *Bos indicus*-X groups were negligible, as was the difference between the two *Bos taurus*-X groups. A portion of the advantage seen by the *Bos indicus*-X groups may be attributed to an increase in heterosis.

Miller et al. (1999) studied the effect of milk yield on biological efficiency of three biological types of cattle. Purebred Hereford, small rotational (cross of Tarentaise, Pinzgauer, Gelbvieh, and Angus) and large rotational (cross of Charolais, Simmental, and Maine Anjou). Cows were housed and fed a silage based diet to maintain condition through a production year.

Increased milk yield was associated with an increase in efficiency in Hereford ($P < 0.01$) and small rotational cattle ($P < 0.10$), with no effect found in large rotational cattle. This is in contrast to the relationship found across breed groups found by Van Oijen et al. (1993). They found differences in inputs to contribute more to variation in

efficiency than those in outputs. Miller et al. (1999) reported increasing milk yield tended to improve biological efficiency to weaning for two of the three breeds of cattle studied. Even though increasing milk yield increased intake during lactation, calf weaning weights were enough to compensate for this increase.

Types and Methods of External Markers

There are several different methods for estimating forage intake, digestibility and measuring total fecal output. Under controlled feeding programs in which a known type and amount of forage is fed, internal markers can work very well. However, for the animal grazing pasture, internal markers do not quantify an animal's intake, forage digestibility or fecal output effectively. According to Sunvold and Cochran (1991) citing Galyean et al. (1986) and Cochran et al. (1987) erratic results have been attained from internal markers used under range conditions. Different laboratories and different forage types affect the results from an internal marker. Under these circumstances an external marker needs to be used.

Pond et al. (1987) defines an external marker as something that is not a natural constituent of the forage and is not digested or absorbed. These markers are either given daily or are given in a bolus that has a constant release to maintain steady state equilibrium in the digestive tract. There are several types of external markers available for use; these include rare earth markers, chromic sesquioxide (Cr_2O_3), peristaltic-infusion pumps and the Cr_2O_3 constant release bolus.

Rare Earth Markers

Rare earth elements include ytterbium, lanthanum, cerium, europium, samarium, neodymium, dysprosium, erbium, terbium, lutetium, hafnium and scandium Pond et al. (1987). Commonly, the element is mordanted to the fiber and then fed to the animal. Under grazing conditions this method is not an alternative. A Pulse dosing method can also be used. According to Paterson and Kerley (1987) there are pitfalls to this method of administration. The most common problem is the constant sampling that is required with this method. Animal grazing behaviors can be greatly disturbed, therefore inaccurate fecal outputs, estimates of intake and digestibility can be obtained.

Chromic Oxide

Chromic sesquioxide, commonly called chromic oxide, is the most commonly used external marker (Paterson and Kerley 1987). It is fairly cheap and can be analyzed by atomic absorption spectrophotometry. Its main disadvantage is that it doesn't flow with either the solid or liquid phase of the digesta and is therefore subject to diurnal variation (Pond et al., 1987; Paterson and Kerley, 1987; Momont et al., 1994; Brandyberry et al. 1991). It is recommended to allow five days after initial dosage to allow steady state equilibrium to occur before collecting any fecal samples from the animals. Many methods of administration have been used with Cr_2O_3 . These include mixing with feed, gelatin capsules of powder administered daily, paper impregnated with Cr_2O_3 inside of a gelatin capsule, constant release pellets and boluses, and mordanting to fiber at 6-8% as suggested by Pond et al. (1987). The last three methods are attempts at decreasing diurnal variation of marker concentrations in the feces.

