BEEF COW EFFICIENCY- REVISITED

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Introduction

It is comforting to address an issue with a historical signature, e.g., information addressing efficiency being presented by Armsby and Fries (1911). They observed that "type" of an animal affected the ability of that animal to convert feed to weight. Kleiber (1936) identified potential approaches that might affect the efficiency of food utilization by animals. At the symposium sponsored by the British Society of Animal Production with the topic of the relationship between size and efficiency, Robertson (1973) concluded that efficiency must be considered in terms of the function of the producing units. Dickerson (1978) aggregated components of the production cycle to define efficiency in a systems concept. In 1984, Michigan State University and Colorado State University sponsored the "Beef Cow Efficiency Forum" addressing issues such as definition of efficiency, both in biological and economic terms and identification of factors contributing to observed differences. A workshop implemented to evaluate the current awareness of efficiency of food utilization met in Armidale, Australia in May, 2000.

For the discussion today, the challenge is to consider the efficiency of the producing cow. In what context is the term "cow efficiency" to be used? Is this term to be applied at the system level? Can the view that production events occurring during the cow calf phase contributes more to phenotypic variation in beef production efficiency than the postweaning phase of the market animal be supported? If one defines efficiency as the conversion of feed energy resource to a marketable product, earlier results from the Meat Animal Research Center suggests that emphasis on the cow calf phase is appropriate. Feed energy consumption during the cow calf component of the production cycle involving breed crosses differing in genetic potential for post weaning growth, mature weight and milk yield, represented approximately 72% of metabolizable energy consumed during the period from conception to slaughter (Ferrell and Jenkins, 1982). Alternatively, does the industry need to be concerned about the effective use of feed resources by the individual producing female? If the latter, what traits should be identified to measure? Does sufficient phenotypic and genetic variation exist for selection to be effective? What is the relationship between feed efficiency during the postweaning period and cow efficiency? Should component trait improvement be made from within breed selection and efficient cows realized by the commercial producer through mating systems? More critically, is a biologically efficient cow an economically efficient cow? Are ratios such as progeny weaning weight to dam weight or dam weight to some power effective in identifying biologically efficient cows?

If ratios can be used, then do traits contributing to the phenotypic variation of the ratio of output relative to input need to be characterized? If the response to this is yes, then the issue may become more focused, namely partitioning the variation into its causal components, genetic and environmental. The anticipated presence of genotype by environment interactions for most traits contributing to the output of the cow calf operation (Butts et al., 1971) further complicates the partitioning of phenotypic variation in production efficiency into its component parts.

The role of the producing cow is to produce progeny of some weight by the end of a variable lactation period. For biological efficiency, productivity may be expressed relative to some measure of input; today a measure of food energy will be considered to be the input. The objective of today's discussion is to review work in the area of beef cow efficiency and identify traits that may contribute to differences in biological efficiency.

Experimental Evidence

To evaluate the conversion of feed to weight of calf at weaning under varying feed environments, a five year study was conducted involving nine breeds of cattle (Jenkins and Ferrell, 1994). These breeds varied in genetic potential for weight at maturity (at 25.0% fat, empty body weight), observed peak milk yield (Jenkins and Ferrell, 1992), post weaning gain and fat deposition potential (Gregory et al., 1994 a,b). Means for these traits are reported in Table 1. To evaluate production efficiency (lb calf weaned/lb dry matter consumed/cow exposed) dry matter intakes and measures of production were recorded for individual mature cows sampled from Angus, Braunvieh, Charolais, Gelbvieh, Hereford, Limousin, Pinzgauer, Red Poll and Simmental breeds of cattle. Four cows of each breed were assigned to one of four dry matter (DM) intake levels: 58, 76, 93, or 111 g DM/Wt$^{.75}$; the daily allotment of feed was established using the cow's initial weight on test. Individuals remained on their assigned feeding levels throughout the study. Calves had minimal access to feed resources other than their dam's milk supply. Calves were weaned at approximately 200 d of age. Component production traits measured included calf birth weights, milk yields, calving rates, weaning weights and cow weights. Breed means for five (5) years for these traits and dry matter intakes are reported in Table 2. On a dry matter basis, the composition of the diet was 77.5%, 17.5 %, and 5.0% of ground alfalfa, corn and corn silage, respectively.

The efficiency ratio in table 2 is mean weaning weight adjusted for conception rate. Output relative to dry matter intake did not differ among the breeds at mean yearly dry matter intakes. However, as reported by Jenkins and Ferrell (1994), feed availability effected the ranking for breed mean efficiencies. At lower feed availability, breeds that were moderate in genetic potential for growth and milk production (Angus, Red Poll, and Pinzgauer) were more efficient because of higher conception rates. Breeds with higher genetic potentials for growth and milk production were less efficient on the lower levels of intake because the cows did not cycle or conceive during the breeding season if they were nursing a calf. However, at the highest levels of feed intake, breeds with the highest genetic potentials for growth and milk production were the most efficient because feed availability was sufficient for the genetic potentials to be expressed. Cows of breeds with more moderate potential effect for milk or growth simply became fatter at the highest feed availability. If the same reranking occurs among cows within breeds, the problem of improving cow effiency becomes more complex.

Table 1. Breed means for traits of interest for nine breeds

Breed	Mature weight, lb[a]	Peak milk yield, lb[b]	Postweaning ADG, lb/d	Fat %[c]
Angus	1217	22.5	2.8	4.00
Braunvieh	1422	33.1	3.0	2.98
Charolais	1521	24.0	3.1	2.80
Gelbvieh	1380	26.0	2.9	2.76
Hereford	1338	19.8	2.8	4.00
Limousin	1300	21.4	2.8	2.65
Pinzgauer	1386	24.0	2.8	3.08
Red Poll	1113	24.5	2.8	3.83
Simmental	1440	29.5	3.1	2.86

[a] Weight adjusted to 25.0% empty body fat.

[b] Yield at time peak lactation as measured by weigh-suckle-weigh.

[c] Percentage fat 9-10-11 rib section at 450 days of age.

Table 2. Breed means for production traits pooled over intake levels and production years[a]

Breed	Cow weight, lb	Yearly dry matter intake, lb	Calving rate[b]	Survival[c]	Birth weight, lb	Weaning weight, lb[d]	Efficiencyl b/lb*100[e]
Angus	1179	8865	0.95(.22)	0.84(.37)	77	372	3.99
Braunvieh	1256	9640	0.82(.38)	0.87(.33)	108	436	3.71
Charolais	1488	9907	0.73(.45)	0.94(.22)	104	469	3.46
Gelbvieh	1285	9813	0.88(.32)	0.87(.34)	97	419	3.76
Hereford	1261	9052	0.81(.40)	0.90(.30)	82	357	3.19
Limousin	1247	9323	0.87(.33)	0.93(.26)	93	415	3.87
Pinzgauer	1179	9104	0.86(.35)	0.94(.24)	104	443	4.18
Red Poll	1045	8743	0.96(.19)	1.00(0)	86	427	4.69
Simmental	1300	9574	0.81(.39)	0.80(.40)	104	417	3.53

[a] Based on 16 observations/breed/year for 5 years (4 cows/intake levels within breed).

[b] Per cow exposed.

[c] Per calf born.

[d] Per calf weaned.

[e] (Lbs of calf weaned per cow exposed per lbs of dry matter consumed)*100.

Provided with this information that ranking among breeds varies with feed availability, it becomes readily apparent that a general discussion about genetic sources of variation on production efficiency becomes quite meaningless if considered in the context of a simple ratio. Production efficiency is a composite trait. Genetic variation expressed in this ratio represents a summation of the genetic variation among the constituents of this composite. This index, efficiency, is dependent upon the system. The definition and the partitioning of the observed phenotypic variation does not lend itself to a simple additive model. The question to be addressed is how do the four traits (mature weight, postweaning ADG, peak milk yield, and ability to fatten) used to characterize the breeds in the study reported affect cow efficiency and then identify other traits that may be considered as additional sources of variation.

Discussion of Traits of Interest

Mature weight and post weaning gain. Variation between and within breeds for asymptotic weight has been documented by numerous researchers (Brown et al., 1972; and Jenkins et al., 1991) and post weaning gain (Woldehawariat, 1977). Previous discussions considering the affect of size on efficiency have suggested that cow size per se does not does not affect efficiency directly but there can be indirect effects. Robertson (1973) concluded that the question of size and efficiency of dairy production was academic while Dickerson (1978) pointed out numerous ways that differences in body size may affect production efficiency. Among breeds of similar lactation potential, the preweaning gains of the Charolais and Limousin were greater than the more moderate size Angus and Hereford. The genetic correlation between weights at young ages and mature size is positive both between breeds and within breeds (Brown, Brown and Butts, 1972; Thiessen, 1986).

The positive genetic correlation between weight at maturity and birth weight negatively affect efficiency when excessive calf birth weights adversely affect reproduction. Cundiff et al. (1986a) reported significant breed of sire effects for gestation length, birth weights, calf survival and dystocia in a study involving 14 breeds of cattle. Higher birth weights, incidence of dystocia and lower calf survival rates were observed among breeds with heavier mature weights.

Factors that affect the energy required for production either directly or indirectly influence the efficiency ratio. Larger mature size is associated with greater daily energy requirement for maintenance, a direct influence. The energetic needs for production are increased. If energy availability is limiting in mature beef cows, low birth rate of cattle be further compounded by reduced reproductive performance, which may be attributed to greater energetic restriction resulting from larger body size and associated increased requirements for maintenance. This reduction in reproductive effectiveness represents an indirect influence on efficiency. As evidenced in the study reported here and the study of Morris et al. (1993), as the nutritional environment becomes limiting reproductive performance declines. The composite trait, calving rate, can be decomposed into traits such as postpartum interval, ovulation rate, conception, dystocia and postnatal survival. Nugent et al. (1993) characterized the nine breeds of this study according to mature weight and lactation potential to investigate the interaction between biological type and dry matter intake on postpartum interval. At the lower energy intake levels, extended postpartum intervals were observed for the biological types with heavier mature weights.

Lactation. Genetic variation for lactation traits has been managed to alter yield at time of peak lactation and total lactation yield both for breeds within the dairy and beef cattle industry. Provided adequate nutrition levels, the correlation between milk yield and efficiency was reported as 0.38 for beef cattle (Nedava 1970, as reported by Taylor, 1973). The direct effect of higher lactation yields is through the increase in weight of calf weaned.

As with increased genetic potential for mature size and post weaning growth, increased genetic potential for peak milk yield affects the efficiency ratio. This effect is mediated both through increased output and higher energy requirements; a readily apparent increase in energy requirement associated with higher yields plus an indirect increase associated with higher maintenance energy requirement that is expressed during lactation (Nelville, 1974). Additionally, higher maintenance requirements per unit metabolic size in non lactating cows characterized as having higher milk production potential have been reported (Ferrell and Jenkins, 1985; Taylor et al., 1986; and Montaño-Bermudez and Nielsen, 1990). This greater energetic need may affect the cow efficiency through introduction of an energetic constraint to reproduction by extending the post-partum interval and reducing fertility. Coupling large mature size and increased per unit cost associated with milk production potential creates a major constraint on the efficiency of production for a cow herd.

Available information suggests that increased milk production potential may offset part of the effect of increased mature size on component traits of reproduction. Morris et al. (1993) observed younger ages at puberty in Friesian cross females than for lower milking Chianina, Limousin, Charolais, and Blonde d'Aquaintaine crosses. Among cows characterized a having genetic potential for larger mature size, Nugent et al. (1993) reported the response to increasing dry matter intake on length of postpartum interval was more immediate for biological types with greater milk production potential.

Lean to fat. Cundiff et al. (1986b) reported differences in proportion of fat and lean yield among 19 breed crosses. Gregory et al. (1994b) documented breed variation exists for fat deposition at time of slaughter among the nine breeds reported earlier. Estimates of empty body composition from mature cows at various levels of dry matter intake indicate variation in the ability to deposit fat (Table 3). Observed breed differences in lean:fat at varying ages may be indicative of variation among breeds for appetite. Based on an evaluation involving 25 breeds, Thiessen et al. (1984) reported a genetic coefficient of variation for *ad libitum* intake of approximately 0.12 – 0.15 for cattle ranging from 12 to 72 weeks. Assuming that feed intake is proportional to mature weight to 0.73 power, then variation among breeds may be evaluated for animals fed *ad libitum* that are in weight equilibrium (Taylor et al., 1981). Using feed intake and weight data from the *ad libitum* animals at weight stasis during the second phase of the cow efficiency study this proportionality held among mature cows of the nine breeds; daily dry matter intake = $0.429Wt^{.73}$. The constant is an index of the relative food capacity of mature animals (Kleiber, 1961) and should characterize the genetic potential for appetite. Breed estimates of the regression constant ranged from a high of 0.493 for Angus to a low of 0.429 for Limousin suggesting substantial genetic variation in appetite. (Table 4).

Table 3. Body components relative to empty body for nine breeds fed at four intake levels (%)

	Feeding rate g DMI/kg$^{.75}$															
	58				76				93				111			
	Water	Prot	Fat	Ash	Water	Prot	Fat	Ash	Water	Prot	Fat	Ash	Water	Prot	Fat	Ash
Angus	58.5	15.7	20.0	5.6	45.8	15.0	34.5	4.7	52.1	15.1	28.0	4.8	48.2	14.3	32.9	4.6
Braunvie	642.	17.3	12.0	6.5	59.4	16.9	18.1	5.6	52.3	15.4	27.4	4.9	54.9	15.7	24.5	4.9
Charolais	62.3	17.5	13.7	6.5	60.2	17.2	16.8	5.8	51.0	15.1	29.3	4.6	58.3	16.7	19.6	5.4
Gelbvieh	64.4	17.6	12.2	5.8	58.2	16.8	19.5	5.5	58.9	17.3	18.1	5.6	55.7	16.4	22.9	5.0
Hereford	57.8	16.1	20.6	5.5	55.2	16.4	23.0	5.4	53.9	15.6	25.4	5.1	50.9	14.9	29.1	5.1
Limousin	66.4	17.7	9.8	6.1	59.6	16.8	18.6	5.0	56.0	16.2	22.9	4.9	58.1	16.9	20.1	4.9
Pinzgauer	60.5	17.0	16.6	5.9	56.2	16.2	21.8	5.7	49.9	14.8	30.8	4.5	49.7	14.4	31.1	4.8
Red Poll	66.7	17.3	9.1	6.9	59.1	16.6	18.5	5.8	51.7	15.3	28.1	4.9	51.0	14.7	29.6	4.7
Simmental	66.4	17.6	9.7	6.3	60.7	17.6	16.0	5.7	53.8	15.7	25.7	4.8	56.4	16.9	21.5	5.2

In general, breed ranking for body fat at 450 d (Table 1), was similar to the ranking among the breeds for appetite, with Angus, Hereford and Red Poll being of higher rank for appetite. The exception to this trend was Charolais who tended not to deposit fat during the post weaning period but whose estimate of appetite was similar to the Angus, Hereford and Red Poll. At the more restricted levels of dry matter intake, there was a tendency for those breeds exhibiting greater appetite potential at the *ad* *libitum* levels to exhibit greater reproductive success.

Table 4. Relative appetite differences among nine breeds of cattle (dry matter intake regressed on body weight to 0.73)

	Constant
Pooled	0.429
Angus	0.493
Braunvieh	0.423
Charolais	0.480
Gelbvieh	0.425
Hereford	0.454
Limousin	0.367
Pinzgauer	0.412
Red Poll	0.465
Simmental	0.409

[a] lb DM/Wt^{0,73}

Maintenance

Variation in cow production efficiency was demonstrated among nine breeds of cattle that differed in genetic potential for mature size and post weaning gain, lactation and fattening ability as the nutritional environment varied. Maximum efficiencies within breeds occurred at intake levels that did not limit reproduction of the cows, and provided sufficient energy for milk yields to meet the growth potential of the breed as expressed in the calf. At lower intake levels, differences among in the breeds in maintenance requirements contributed to differences in efficiency. Energy expended for maintenance is influenced by intake levels. Animals of greater genetic potential for productivity exhibited less ability to reduce maintenance requirements in response to reduced feed availability (Frisch and Vercoe, 1977; Taylor et al., 1986). Ferrell and Jenkins (1985) reported that during the postweaning phase Simmental were less efficient than Hereford at restricted levels but at *ad libitum* intakes more efficient. Jenkins et al. (1990) demonstrated that a breed with greater potential for mature size and lactation yield had greater daily heat production at restricted feeding rates than a breed with lower production potential. However, as rate of dry matter intake per unit weight increased, the ranking reversed between the two breeds.

If feed utilization is to be improved, reducing the amount of energy expended on maintenance without reducing appetite appears to be desirable. A measure of energy expenditure for maintenance, fasting heat production, has been shown to be moderately heritable (.25-.30; Nielsen et al., 1997a) in mice. By mating males of highest or lowest rank for fasting heat production, these researchers significantly changed the mean heat energy loss in the selected population by the fifteenth generation. As pointed out by the authors, the cost of measurement prevents this protocol from being adopted for use in an industry selection program. Byerly (1941) in poultry and Koch (1963) in beef cattle proposed adjusting feed intake of an animal for predicted requirements for performance and maintenance thus enabling individual animals of higher rank for efficiency to be identified. This approach, now referred to as residual feed intake, has been evaluated by poultry and dairy scientists, e.g.; Sabri et al., 1991 and Ngwerume and Mao (1992). Currently, a large study is being conducted in Australia to improve feed efficiency in beef cattle (see Feed Efficiency in Beef Cattle, 2000). Selection for residual feed intake (RFI) is applied during the postweaning period and favorable responses in feed efficiency have been reported for both the postweaning period and in the producing female.

An implicit assumption to application is the energy expenditure associated with maintenance is constant relative to a scaled measure of weight. As part of the 5-year study to evaluate production efficiency, the maintenance efficiencies (weight maintained per day per unit energy, Taylor et al., 1986) for the nine breeds were determined at the four feeding rates. Following the last calf crop, cows were allowed to remain open and continued to receive their assigned ration. Weight stasis (maintenance) was defined as a constant weight sustained for over 8-week period. A significant breed by feeding level interaction was observed for maintenance efficiency, the amount of weight maintained per unit of energy consumed. All breeds exhibited the highest level of maintenance efficiency at the most restrictive feeding rate, with the exception of the Red Poll, (Table 5). In general, as level of feed availability increased, the efficiency of maintenance declined. It is interesting to note that the breed most efficient at the lowest level of feed intake, the Red Poll, were the least efficient in maintaining body weight at the restricted level. As feed became more available, their maintenance efficiency did not change. This is significant because researchers selecting to lower the energy requirements associated with maintenance have reported unfavorable correlated responses in traits important to female performance. Among mice selected for lower fasting heat production during the postweaning period, Nielsen et al. (1997b) reported body mass similar to mice selected for high heat production, lower feed intake, greater empty body fat percentage, reduced ovulation rate and a decrease in litter size. These results imply that selection criteria to reduce the maintenance requirements of the producing females could have a negative effect on reproductive performance.

Table 5. Least squares means for maintenance efficiency by breed and feeding rate[a]

	Feeding rate (g DMI/kg$^{.75}$)			
	58	76	93	111
Angus	14.3	13.6	12.6	11.6
Braunvieh	15.7	11.5	11.2	14.3
Charolais	14.2	11.7	10.9	11.0
Gelbvieh	14.6	10.0	10.0	11.2
Hereford	14.6	11.9	11.9	12.0
Limousin	13.0	10.1	13.0	14.6
Pinzgauer	15.7	12.3	12.1	14.3
Red Poll	11.8	11.7	11.1	12.4
Simmental	14.5	11.3	9.3	12.5

[a] Maintenance efficiency = weight of cow (lb.) maintained per daily ME intake, Kcal.

Conclusion

Variation exists among cattle populations to improve the conversion of feed resources to a final product. A biologically efficient cow is one producing a calf each year she remains in the cowherd. The nutrition-reproduction axis may influence this success. Energy expenditure for maintenance may affect the reproduction of the cow. Energy expenditure for maintenance appears to be correlated to genetic potential for mature size and lactation. At restricted feed availability, an increase in maintenance efficiency among breeds with greater potential for size can be associated with longer postpartum periods for mature cows resulting in a lower reproductive rate thus lowering cow efficiency. At lower intakes, variation in milk production exists among breeds with higher milk production potential, resulting in lowered efficiency of gain for calves with higher growth potential.

Sufficient additive variation exists to alter fasting heat production in cattle, and selection criteria are being evaluated that allow “non-productive” energy expenditures to be reduced. More information to clarify the definition of an efficient cow, selection protocol, and potential correlated responses is needed. Genotype by environment interaction (abundant vs sparse nutritional testing environment) potential effects on cow efficiency requires investigation.

Rather than seeking to reduce energy requirements for maintenance, perhaps stabilizing these requirements over a wide range of nutritional scenarios is more desirable. Enhancing an animal’s genetic potential to conserve energy under sparse energy environments (feed resources and/or body fat) could be counterproductive to developing an efficient cow. Do other approaches to improving cow efficiency exist? With genomic information increasing every day, what phenotypes can we measure to associate with bovine gene map? Using genomics information, will we be able to identify heifers that are well suited to producing a calf every year within a defined production environment? An efficient cow for one producer may be ineffective under a different management program.

Literature Cited

Archer, J. A., R. M. Herd, and P. F. Arthur. 2000. Feed Efficiency in Beef Cattle. Proc. Feed Effic. Workshop., Univ. New England, Armidale, Australia.

Armbsy, H. P., and J. A. Fries. 1911. The influence of type and of age upon the utilization of feed by cattle. Tech. Bull. No. 128. USDA, Bureau of Anim. Ind., Washington, D.C.

Brown, J. E., C. J. Brown, and W. T. Butts. 1972. Relationships among weights, gains and earliness of maturing in Hereford and Angus females. J. Anim. Sci. 35:507.

Byerly, T. C., 1941. Feed and other costs of producing market eggs. *In* Bull. A1. Maryland Agriculture Experimental Station, Univ. Maryland, College Park, MD.

Butts, W. T., M. Koger, O. F. Pahnish, and E. J. Warwick. 1971. Performance of two lines of Hereford cattle in two environments. J. Anim. Sci. 33:923.

Cundiff, L. V., M. D. MacNeil, K. E. Gregory, and R. M. Koch. 1986a. Between- and within-breed genetic analysis of calving traits and survival to weaning in beef cattle. J. Anim. Sci. 64:27.

Cundiff, L. V., K. E. Gregory, R. M. Koch, and G. E. Dickerson. 1986b. Genetic diversity among cattle breed and its use to increase production efficiency in a temperate environment. Proc. 3rd World Cong. Genet. Appl. Livest. Prod. Vol. IX:271-274. Lincoln, NE.

Dickerson, G. E. 1978. Animal size and efficiency: basic concepts. Anim. Prod. 27:367.

Ferrell, C. L., and T. G. Jenkins. 1982. Efficiency of cows of different size and milk production potential. RLHUSMARC. Germ Plasm Evaluation Report 10:12.

Ferrell, C. L., and T. G. Jenkins. 1985. Cow type and the nutritional environment: Nutritional aspects. J. Anim. Sci. 61:725.

Frisch, J. E., and J. E. Vercoe. 1977. Food intake, eating rate, weight gains, metabolic rate and efficiency of feed utilization in *Bos taurus* and *Bos indicus* crossbred cattle. Anim. Prod. 25:343.

Gregory, K. E., L. V. Cundiff, R. M. Koch, M. E. Dikeman, and M. Koohmaraie. 1994a. Breed effects and retained heterosis for growth, carcass and meat traits in advanced generation of composite population of beef cattle. J. Anim. Sci. 72:833.

Gregory, K. E., L. V. Cundiff, R. M. Koch, M. E. Dikeman, and M. Koohmaraie, 1994b. Breed effects, retained heterosis, and estimates of genetic and phenotypic parameters for carcass and meat traits of beef cattle. J. Anim. Sci. 72:1174.

Jenkins, T. G., and C. L. Ferrell. 1994. Productivity through weaning of nine breeds of cattle under varying feed availabilities. I. Initial estimates. J. Anim. Sci. 72:2787.

Jenkins, T. G., and C. L. Ferrell. 1992. Lactation characteristics of nine breeds of cattle fed varying quantities of dietary energy. J. Anim. Sci. 70:1652.

Jenkins, T. G., C. L. Ferrell, and L. V. Cundiff. 1991. Differences among breed crosses of cattle in conversion of food energy to calf weight during the preweaning interval. J. Anim. Sci. 69:2762.

Jenkins, T. G., M. Kaps, L. V. Cundiff, and C. L. Ferrell. 1991. Evaluation of between- and within-breed variation in measures of weight-age relationships. J. Anim. Sci. 69:3118.

Jenkins, T. G., J. A. Nienaber, and C. L. Ferrell. 1990. Heat production in mature Hereford and Simmental cows. In: C. Wenk, and M. Boessinger (Ed.) Proc. 12th Symp. Energy Metab. Farm Anim. Kartause Ittingen, Switzerland. EAAP 58:296.

Kleiber, M. 1936. Problems involved in breeding for efficiency of food utilization. Page 236 in Proc. Amer. Soc. Anim. Prod.

Kleiber, M. 1961. The Fire of Life. John Wiley and Sons, New York and London.

Koch, R. M., L. A. Swiger, D. Chambers and K. E. Gregory. 1963. Efficiency of feed use in cattle. J. Anim. Sci. 22:486.

Montaño-Bermudez, M., M. K. Nielsen, and G. H. Deutscher. 1990. Energy requirements for maintenance of crossbred beef cattle with different genetic potential for milk. J. Anim. Sci. 68:2289.

Morris, C. A., R. L. Baker, S. M. Hickey, D. L. Johnson, N. G. Cullen, and J. A. Wilson. 1993. Evidence of genotype by environment interaction for reproductive and maternal traits in beef cattle. Anim. Prod. 56:69.

Nelville, W. E. 1974. Comparison of energy requirements of non-lactating and lactating Hereford cows and estimates of energetic efficiency of milk production. J. Anim. Sci. 38:681.

Ngwerume, F. and I. L. Mao. 1991. Estimation of residual energy intake for lactating cows using an animal model. J. Dairy Sci. 75:2283.

Nielsen, M. K., L. D. Jones, B. A. Freking, and J. A. Deshazer. 1997a. Divergent selection for heat loss in mice: I. Selection applied and direct response through fifteen generations. J. Anim. Sci. 75:1461.

Nielsen, M. K., L. D. Jones, B. A. Freking, and J. A. Deshazer. 1997b. Divergent selection for heat loss in mice: II. Correlated responses in feed intake, body mass, body composition, and number born through fifteen generations. J. Anim. Sci. 75:1461.

Nugent, R. A. III, T. G. Jenkins, A. J. Roberts, and J. Klindt. 1993. Relationship of post-partum interval in mature beef cows with nutritional environment, biological type and serum IGF-1 concentrations. Anim. Prod. 56:193.

Robertson, A. 1973. Body size and efficiency. Proc. Br. Soc. Anim. Prod. 2:9.

Sabri, H. M., C. J. Wilcox, H. R. Wilson, and R. H. Harms. 1991. Measurements of genetic variation in residual metabolizable energy intake of laying hens. Poultry Sci. 70:222.

Taylor, St. C. S. 1973. Genetic differences in milk production in relation to mature body weight. Proc. Br. Soc. Anim. Prod. 2:15.

Taylor, St. C. S., R. B. Thiessen, and J. Murray. 1986. Inter-breed relationship of maintenance efficiency to milk yield in cattle. Anim. Prod. 43:37.

Taylor, St. C. S., H. G. Turner, and G. B. Young. 1981. Genetic control of equilibrium maintenance efficiency in cattle. Anim. Prod. 33:179.

Thiessen, R. B. 1985. Inter age correlation of body weight, weight gain, and food intake between and within breeds of cattle. Anim. Prod. 40:23.

Thiessen, R. B., E. Hnizdo, D. A. Maxwell, D. Gibson, and St. C. S. Taylor. 1984. Multibreed comparisons of British cattle. Variation in body weight, growth rate and food intake. Anim. Prod. 38:323.

Woldehawariat, G., M. A. Telemantes, R. R. Pettit, and T. C. Cartwright. 1976. A summary of genetic and environmental statistics for growth and confirmation characters of beef cattle. (2nd Ed). Dept. Tech. Rep. 103. Texas A&M Univ., College Station.