EFFICIENCY OF LACTATION PRODUCTION

I.L. Mao

Department of Animal Science, Michigan State University, E. Lansing, MI 48824, USA

SUMMARY

Efficiency of lactation production is referred to in this paper as the efficiency of a lactating cow to convert energy intake to produce milk. Variation among cows is significant in each of the energy measures after the partitioning of energy intake, but variation due to genetic causes are not well understood. Establishing a data base to estimate efficiency on individual cows on farm by installing calorimetric instruments is not possible. Therefore, estimation of efficiency based on data collectable under normal farm conditions has been attempted. Given an accurate and meaningful measure, energetic efficiency can be improved by management and by genetic selection. All expressions of efficiency are measures of the balance or imbalance between the components in the metabolic complex in a cow. Thus, other approaches to improve efficiency could be a simultaneous consideration of, for example, intake, body weight and condition, yield, and efficiency.

Keywords: Efficiency, lactation, intake, energy conversion, genetic selection.

INTRODUCTION

As we strive to increase production per cow, the real goal that dairy scientists and industries are all trying to achieve is the efficiency in converting invested resources to saleable products. Fundamental to all definitions of efficiency is the minimization of inputs and the maximization of outputs. The distinction in scale, however, should be made between the macro- and micro-efficiency of production. For the macro-efficiency, or the efficiency of a production enterprise, inputs and outputs are weighed by costs and prices, respectively. It concerns the dynamics of economical parameters in labor, veterinary care, breeding, feeding, investments in housing and machineries, and returns in milk sales as well as in the selling of beef and breeding stock. The micro-efficiency, or the efficiency of a cow's productivity, deals with her biological ability to produce milk given an amount of feed intake. Both are complex problems, and the center of the problems is the difficulty in measuring either in a meaningful way, economically in the case of macro-efficiency, and biologically in the case of micro-efficiency. This paper deals with the efficiency of a cow to convert energy intake to produce milk.

BIOLOGICAL EFFICIENCY

Energy. In the context of biology for a lactating cow, both inputs and outputs are appropriately measured in units of energy. The relationship between inputs and outputs are dynamic consisting of a flow of energy through the biological system of a lactating cow starting with the energy from ingested feedstuffs, to the partitioning of the available energy into various usages to meet the requirement of body functions, to the conversion of energy to milk, and to the output of measurable milk. An ideal cow would be a producing cow which requires no feed. Somewhat less than ideal would be a cow which would convert every bit of the intake to produce milk. Realistically, however, a producing cow requires at least maintenance energy to be a living being first. Therefore, the best realistic expectation is for a cow to have the ability to partition a greater than average proportion of energy intake to produce milk, hence the definition of efficiency. A lactating dairy cow has the unique ability to go deep into negative energy balance during the peak production period, and for that one brief period, she turned into an almost ideal cow, although a following period of replenishment is necessary.

Partitioning of Intake Energy. The fundamental aspects of energy metabolism were described by results from several complete energy balance trials from calorimeters (e.g. Van Es and Nijkamp 1969; Moe and Tyrrell 1973). Much of these earlier work focused on proportions of partitioned energy intake by a typical, or an average cow. Potential sources of variation in energetic efficiency were reviewed (e.g. Bauman *et al.* 1985; Oldham and Friggens 1989), but lacking in these studies is a quantification of the variation. Saama *et al.* (1993) attempted to quantify the variation between cows in energy partitioning based on indirect calorimetric measures on 34 multiparous Holstein cows. They found coefficient of variation among cows ranged mostly between 10 to 20% in energy measures of intake, feces, urine, milk yield, methane, and heat production, and in gross energy intake, digestible energy intake, metabolizable energy intake corrected for nitrogen balance, net energy intake, body protein and fat, water intake, and efficiency of milk yield in ratios of various energy intake measures. Only measures involving energy balance had coefficients of variation greater than 200% in most cases. Sources of variation due to parity, season, body weight, and production levels were examined.

Unfortunately, Saama *et al.* (1993) could not estimate the genetic variation due to the small volume of data and with no parentage identification. The shortage of data base is inevitable, since the large scale use of calorimetric instruments on farm is not possible. Therefore, if efficiency measure is going to be examined as potential tools for management and criteria for selective mating, efficiency must be estimated from data obtainable from on-farm situations.

ON-FARM MEASURE OF EFFICIENCY

Variables. To estimate efficiency of energy conversion on a routine basis on commercial farms, certain data must be collected regularly. Minimally these include milk yield and its compositions which are relatively more readily collectable, and feed intake and body weight which would require special setups. Methods of recording and minimum necessary frequency of recording should vary depending on the variable observed, but would determine the usefulness of the data entering the estimation procedures for efficiency.

Obtaining individual intake data on a large scale on a continuing basis can be prohibitive under commercial conditions. If, however, total intake in a lactation is desired, Moore and Mao (1990) found that 10 days of intake information through a lactation had a .97 correlation with actual total intake. Daily milk sample and their compositions can be available easily with automated milking and recording system. Again, for lactation total, the conventional 30-day-equal-interval sampling procedure should give acceptable estimates (Anderson *et al.* 1989). Obtaining body weight data would require automated weighing system be established on farm. In analyzing up to 10 body weights a day recordings on each of a total of 115 lactating Holstein cows in different parities, Ngwerume *et al.* (1989) found that weights vary wildly over the course of a day, in the course of a lactation and between parities. Further work is needed to suggest a weighing schedule for the frequency and the timing of weighings for the purpose of efficiency estimation. For accurate estimation of efficiency, meaningful measures of body compositions would be essential. Such measures could come from a program of scoring body conditions, or more desirably, a system to physically measure body compositions. Also, information on reproduction status and health conditions would be useful in efficiency estimation. Data should be collected during multiple lactations as well as during dry period and transition period for a complete picture of energy intake and utilization.

Records collected would need to be adjusted in order to better approximate metabolical functions and the dynamics of energy flow in a cow. Walter and Mao (1989), for example, adjusted intake to reflect the delaying process of converting energy intake to usable energy, and adjusted daily milk yield to reflect the rates of milk secretion and milk removal from the udder. Body weight is frequently used for a constant conversion to approximate metabolic weight, and to approximate the rate of tissue gain or loss. The appropriateness of the constant for conversion and the variability between animals need to be further studied.

Efficiency estimation. There are basically three approaches:
(1) Gross efficiency (GREF). The GREF is simply the ratio of energy content in milk over the total energy input from feed. The GREF is relatively easy to calculate, but requires data on milk yield and feed intake and their compositions. Heritability estimates on GREF ranged from .36 to .86, phenotypic correlation with milk yield from .60 to .95, and genetic correlation with milk from .88 to .95 (e.g. Mason *et al.* 1957; Hooven *et al.* 1972; Freeman 1975; Blake and Custodio 1984). Because of the high genetic correlation, selection for GREF has been considered to be unnecessary because it is automatically improved via selection for milk yield. However, data used to compute the genetic parameters for GREF most likely came from dairy cattle fed concentrates according to milk production, thus forcing a high correlation. Also, the high phenotypic correlation could be due to the relative decrease in maintenance requirements for energy as milk production increases. The milk production depends not only on feed intake but also on body tissue losses or gains, a factor that is ignored in the calculation of GREF, which is the fundamental weakness of GREF.

(2) Residual efficiency (REEF). Residual intake is defined as the remaining energy from total energy intake after accounting for all identifiable energy usages (Brelin and Brannang 1982; Luiting 1987; Korver 1988). The idea of the residual intake as a measure of efficiency is that the greater the proportion of energy intake that can be accounted for, or smaller the residual, the less the waste, the more efficient is the animal and the higher the REEF.

Several methods were used to estimate REEF (Luiting 1987; Jensen *et al.* 1992; Svendsen *et al.* 1993). Ngwerume and Mao (1992) used the total energy intake as the dependent variable, which was fitted by a linear mixed animal model which contains covariates of metabolic body weight, yield of solid-corrected-milk, days-in-milk, and random effects of animal, permanent environment and residual. The resulting partial regression coefficients of the covariates were cross-animal net efficiency estimates, but the animal effects gave additive genetic effects of residual efficiency for individual animals.

The heritability value of REEF in lactating cows was found to be less than .02 (Ngwerume and Mao 1992; Svendsen 1993). The proportion of the phenotypic standard deviation due to REEF was high at 68% (Ngwerume and Mao 1992). This, together with a low heritability, indicated that variation in REEF in lactating cows is due to causes other than additive genetic effects. The heritability estimates for REEF in laying hen ranged from .25 to .40 (Luiting 1987), in growing bull was .28 (Jensen *et al.* 1992). Regardless of the estimation methods or species, the fundamental problem of REEF is that for a high REEF, or a low residual intake, animal, energy intake could have been spent for whatever purposes so long the expenditures could be accounted. The accountable expenditures, in addition to the energy for milk yield, include fecal and urinary energy and energy deposited for fat.

Had REEF been considered a selection criteria, selection results might not be desirable due to its close relationship to daily feed intake (Jensen *et al.* 1991, 1992). Selection for increased feed intake would increase residual intake and thus lead to less efficient animals (Jensen *et al.* 1992). However, selection for a decreased residual intake for more efficient animal would tend to increase fatness. (Jensen *et al.* 1991)

(3) Net efficiency (NEEF). The NEEF is the efficiency in synthesis of measurable amount of milk from the conversion of available energy intake after accounting for energy utilized for maintenance, changes in body reserve status, and other usages of available energy. The efficiency of energy conversion to support lactation in dairy cattle was quantified by, among others, Tyrrell *et al.* (1966), and Van Es and Nijkamp (1969), and Hashizume *et al.* (1965). Moe *et al.* (1971) used multiple regression models, pooling over all cows in the experiment, to explain the quantitative relationships between inputs and outputs in ruminant energetics. Since the units for the regression coefficients were energy input per energy output, the partial, or net, energy efficiencies of production are the reciprocals of the respective regression coefficients.

To obtain exact measure of NEEF of an animal, the partitioning of total energy intake into proportions for various usages must be determined first. This would require the use of calorimetric chambers which is impossible in practice. Of practical interest is a NEEF measure which allows the study of variability among lactating cows in NEEF under farm conditions. For that, Walter and Mao (1989) explored many statistical models that would permit the estimation of NEEF of individual lactating cows from data collectable on cows kept under normal farm conditions. For each of the 357 Holstein lactating cows in seven herds, a model was fitted regressing daily energy intake on several energy expenditures indicated by daily solid-corrected milk, metabolic body weight, body weight change, and pregnancy. The partial regression coefficient on yield gave the reciprocal of NEEF estimate of a cow. The approach is similar to what is now known as random regression. One such model was found to be particularly successful since it generated NEEF estimates on individual cows that on average approximated closely the reported average based on data from cows in energy chambers (NRC 1989). When the same model was used on a different population of cattle, the summary statistics of NEEF estimates were repeatable (Svendsen and Mao 1989).

To verify estimates of efficiency from field data, however, such estimates must be compared with exact measures from energy chambers on the same cows. Saama *et al.* (1992) showed that energy measures estimated from the field data, including estimated GREF, corresponded closely to, in both mean and variance, those from data collected on the same cows in energy chambers. They concluded that a data base on energy partitioning and energetic efficiency of individual cows from field data would be useful if such measures are needed for management or genetic evaluation of energetic efficiency. However, the data base used in their work had detailed content information of the feeds from a well managed experimental herd. The establishment of a data base such as theirs on a large scale on commercial farms would not be at all easy.

The comparisons between field and chamber results in NEEF need to take into account that the metabolic efficiency of cattle in partitioning energy in normal field conditions may be different from those kept in chambers. Although consistency in results did provide assurance in the validity of the model, but some discrepancies may not be entirely inappropriate. A optimum model for the estimation of NEEF for cows in field conditions should be one that would generate estimates that can best discriminate among cattle, that are most repeatable, highly correlated to control parameters from energy chambers, and most descriptive of the true variance components in NEEF.

IMPROVEMENT OF EFFICIENCY

For any of the efficiency measures, if it is going to be used in practice, sources of variation in the measure need to be identified. Based on the sources identified and their magnitude, ways to improve efficiency can be devised in both management and feeding practices and genetic selection programs.

Management. Management and feeding practices most certainly affect a cow's efficiency in converting energy intake for producing milk. Not only during lactation, but during transition period lasting from three weeks prepartum to three weeks postpartum, which is a critical period to maximize subsequent performance. Proper management and feeding during this transition period will decrease incidence of metabolic disorders, accelerate cows to peak yield, and enhance efficiency of production. In fact, the correlation between pre- and post-partum dry matter intake, both expressed as percent of body weight, was close to 60% (Emery and Beede 1997).

Genetic selection. The difficulty in considering feed intake or energetic efficiency in genetic selection of dairy cattle is in the most part due to the difficulty of establishing a sound data base. Installation of calorimetric apparatus on farms would be prohibitively expensive and impractical. Therefore, accurate approximation of energy efficiency using on-farm data is highly desirable. Given such estimates on individual cows are accurate, meaningful, and available, should cows and sires be genetically evaluated for efficiency and be considered as selection criteria in breeding programs?

A cow's ability to produce milk is the ultimate measure. For the trait of milk yield, the belief has been that efficiency is highly correlated with milk yield such that direct selection of efficiency is not necessary. This belief is perhaps not unfounded when the efficiency is defined as GREF, because of the high genetic correlations cited earlier. However, the NEEF estimates used by Buttazzoni and Mao (1989) had a heritability value similar to that of milk yield, a phenotypic correlation with yield of -.02 and a genetic correlation of only .56, which is approximately 60% of that between GREF and milk yield. Based on these numbers, cow's NEEF may be worthy for consideration as a selection criterion.

Blake and Custodio (1984) suggested that energy intake traits merit consideration in breeding programs for dairy cattle, since they saw no indication that efficiencies of nutrient utilization have been influenced by selection for milk yield.

In the advent of molecular genetics, genes marking major effects on energetic efficiency are worth exploring. Such exploration is more worth of the efforts than exploring marker genes for cow's productivity for milk. After the intense selection over many generations, the existence of a few single genes that are still in direct control of milk yield in a major way is unlikely. However, milk yield is controlled indeed by a collection of metabolical pathways, and some of these pathways may be controlled by single genes. I suggest that, for example, genes controlling fatty acid metabolism such as hormone sensitive lipase (HSL) are worth pursuing for their roles in energetic efficiency. They may very well play more of a significant role in energy efficiency than in volume of milk produced.

EFFICIENCY AND METABOLIC COMPLEX

Our ability, or the lack of it, to measure biological efficiency of a lactating cow on farm is the center of the problem in the whole issue of efficiency. Seeking a way to measure efficiency as a trait, and then simply attempting to improve the trait by management practices and genetic selection schemes is one approach. There may be other approaches.

Blake and Custodio (1984) concluded that efficiencies of nutrient utilization for milk production have not been influenced by selection for milk production, because they found no evidence in the literature for a pleiotropic pathway between milk production and dietary utilization. They, therefore, encouraged consideration of efficiency, in addition to milk yield, in genetic selection. They, however, also proposed to describe feed conversion as a composite trait, the "milk yield-tissue balance-appetite complex" in which milk yield was limited by energy input from tissue balance and appetite. One needs to consider hormonal regulation of tissue catabolism and the partitioning of energy as probable explanations for the improved feed efficiency following selection for milk yield. Hence, they proposed that the process of selection for improved feed conversion as selection for a composite trait involving milk yield, tissue balance and appetite. Svendsen *et al.* (1994) attempted to estimate the genetic (co)variance matrix for the components in the proposed "milk yield-tissue balance-appetite complex".

Much discussion has focused on alternative metabolic complexes and the balance between the components in a complex. One example is the complex of milk production-body weight-feed intake (Van Arendonk 1997), and the balance between efficiency, production and body frame. Another example is the efficiency-fatness-appetite complex (Emery and Beede 1997). If a balanced emphasis on the components of a complex is of biological importance and would result in significant gain in efficiency, perhaps a selection index approach for the genetic selection of these components would be appropriate.

Efficiency is defined in the context of economical balance and ecological balance on the macro scale, and of intracow metabolic balance on the micro scale. There are critical thresholds established by the nature for different variables in a complex in order to maintain the balance. A variable can be pushed to its threshold without disturbing the balance. The long term intense selection on milk yield has yielded astounding result. Holstein cows in U.S., for example, have increased per lactation yield by close to four times in the last 40 years. As we are pushing on yield, other biological functions responded, either favorably or unfavorably, due to pleiotropic genetic effects and metabolic and other forces in maintaining the balance in this complex biological complex within a cow. The consequences from selecting for milk are well known as evident by observing high producing cows. To manipulate efficiency is a closer and much more direct "tweaking" of the biological balance in a lactating cow. The task is challenging and the payoff could be handsome.

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