Nutrition in the Lactating Cow

Dairy Section

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Energy and Fiber in Dairy Cow Rations and Utilization by the Modern High-Producing Cow

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Of the five major classes of nutrients (energy, protein, minerals, vitamins, and water) needed by the dairy cow, the nutrient most often limiting milk production is energy. A simple definition of energy is "the ability to do work." The basic energy unit is the calorie. A calorie is the amount of heat required to raise the temperature of one gram of water one degree centigrade. A gram of water is the amount contained in one milliliter, or one cubic centimeter (cc). A centigrade degree is 1.8 times as large as a Fahrenheit degree, which is more commonly used in the United States. The relationship of the calorie to other energy terms is shown in Table 1.

Table 1
Energy Terms

calorie (cal)	= heat to raise 1g. water 1° C
kilocalorie (kcal)	= 1000 calories = 1 Calorie
megacalorie (Mcal)	= 1000 kcal = 1,000,000 calories
B.T.U.	= 252 calories
Therm	= 1 Mcal = 1,000,000 calories

As can be seen in the table, a kilocalorie is 1000 calories. Unfortunately, nutritionists working with human diets have tended to cause confusion in the use of energy terms by using what they call a "large calorie" or "Calorie" (spelled with a capital C) to mean a kilocalorie. A megacalorie is equivalent to 1000 kilocalories, or one million calories. A British Thermal Unit (B.T.U.) equals 252 calories. The term "Therm," used extensively in older animal nutrition textbooks, is equivalent to a megacalorie. In order to stay away from very large numbers and also to avoid the confusion of large and small calories brought about by workers in human nutrition, the preferred energy term for evaluation of feeds for livestock is megacalories (Mcal).

Cows use energy for a variety of functions. A certain amount is used to maintain body tissues which are constantly undergoing many chemical processes which sustain life. In addition to maintenance requirements, a heifer needs more energy for tissue growth as she grows from calfhood to maturity. A pregnant cow needs additional energy for building the tissues of her unborn calf. A lactating cow requires still more energy to produce the milk which is being secreted by her mammary glands. A non-pregnant, non-lactating mature cow needs only enough feed each day to provide sufficient energy for maintenance. However, a pregnant, lactating, first-calf heifer would need much more feed each day to supply the energy required for growth, reproduction, and lactation in addition to that needed for maintenance.

Measures Used for Energy Allowances

There are several systems used for expressing livestock energy requirements. Each system has its advantages and disadvantages. Those in current use include total digestible nutrients (TDN), digestible energy (DE), metabolizable energy (ME), and net energy (NE). Accuracy of the methods in formulating rations increases in the order listed. However, difficulty in determining energy values of feeds according to the different systems also increases in the same order. TDN has been the most extensively used system in the United States. Limitations of this system, as discussed later in this paper, and more accurate evaluations of feeds and requirements have resulted in the net energy system being adapted as the official standard of the National Research Council (NRC) for ruminant energy allowances. A brief description of each system follows as all are used to some extent in various parts of the world.

Net Energy (NE)

Net energy is the most accurate for ration formulation. To determine net energy, measurements of the energy in the feed, feces, gases, urine, and heat produced by the cow must be made. The formula for determining NE is: NE = Gross energy — fecal energy — gaseous energy — urinary energy — heat increment.

An illustration of the use of energy in a feed is shown in Figure 1.

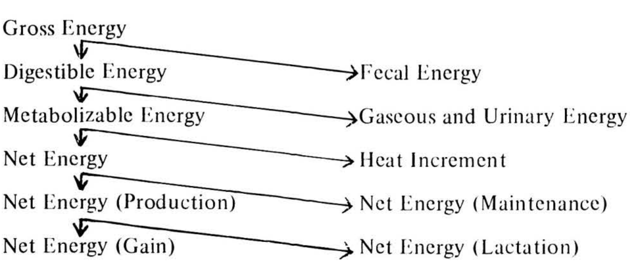


Figure 1. Utilization of energy consumed by a cow.

Gross energy is the total amount of energy a feed contains as measured by combustion in a bomb calorimeter. Not all of this energy is usable by the animal, however. Figure 1 shows where the losses occur. The first and largest loss is the energy contained in the feces. The remainder is called digestible energy. There is a further loss of energy in the gases that escape from the animal and in the urine. The remaining energy is called metabolizable energy. The last loss to the animal is the energy converted to heat as a result of microbial fermentation and nutrient metabolism of the ingested feed. This loss is called heat increment, or the specific dynamic action of a feed. Part of this net energy is used for maintenance of the animal and the remainder is used for productive purposes, such as growth and milk production.

The amount of energy that falls into the various categories shown in Figure 1 is variable depending primarily on the type of ration fed and level of milk production. Approximate percentages of the various energy components for a lactating cow fed a typical ration free-choice are shown in Figure 2.

Figure 2. Approximate percentages of gross energy represented by fecal, gaseous, urinary, heat increment, and net energy in a non-pregnant lactating cow. (Courtesy of W. P. Flatt.)

Fecal Energy (30%)	Urinary Energy (5%)	Gaseous Energy (5%)	Heat Increment (20%)	Net Energy for Maintenance (20%)	Net Energy for Production (Milk plus body tissue) (20%)

Only about 20% of the energy consumed by the cow is available for milk production or body weight gain. Another 20% is used for maintenance whereas about 30% is lost in the feces and 20% is lost as heat increment. Urinary and gaseous energy losses make up approximately 5% each on common rations.

Dairy cows use net energy with approximately equal efficiency for maintenance or milk production. Energy utilization for growth and fattening is lower, however. In order to account for this, current net energy nomenclature recommended by NRC is as follows:

Net Energy Nomenclature

NE_m	= Net energy for maintenance
NE_{gain}	= Net energy for gain
$NE_{lactation}$	= Net energy for lactating cows

Net energy for maintenance (NE_m) is the fraction of net energy expended to keep the animal in energy equilibrium. In this state the animal's tissues are neither gaining nor losing energy.

Net energy for gain (NE_{gain}) is the net energy required above maintenance used by growing cattle for body tissue gain.

Net energy for lactating cows ($NE_{lactation}$) is the total energy needed by lactating dairy cows for maintenance, milk production, and for pregnancy during the last two months of gestation. This would imply that the efficiency of energy utilization for maintenance, lactation, and pregnancy is the same, which is not exactly true. But they are close enough that they can be assumed to be the same for the sake of simplicity under practical dairy management. NE_m and NE_{gain} are used only for young, growing cattle.

Total Digestible Nutrients (TDN)

TDN has been the most popular measure for energy allowances in the United States. The formula for calculating TDN is as follows:

$$\%TDN = \frac{CP + CF + (EE \times 2.25) + NFE}{\text{feed consumed}} \times 100$$

where CP = digestible crude protein
CF = digestible crude fiber
EE = digestible ether extract
and NFE = digestible nitrogen-free extract

TDN is approximately the same as digestible energy but the method has several drawbacks. First, it is an empirical formula based upon chemical determinations not related to actual metabolism of the animal. Second, the result is expressed as percent or in some measure of weight (lb. or kg) whereas energy is expressed in calories. Third, TDN takes into consideration only digestive losses. It ignores gaseous and urinary energy, and losses due to increased heat production (heat increment). Heat increment losses approach digestive losses in ruminants. Fourth, TDN over-evaluates roughages in relation to concentrates, particularly low-energy forages. This is not important when comparing ingredients within a class, such as concentrates with concentrates, but is of major importance when comparing roughages with grains and other concentrate ingredients, as is done when formulating a practical and economical ration for a cow.

TDN gradually is being replaced in the United States by other energy evaluation systems, particularly net energy. However, voluminous TDN data on many feeds and long-standing tradition insure its continued use by many people for years to come.

Digestible Energy (DE)

Determination of digestible energy is similar to TDN in that all feed consumed and feces excreted must be weighed and analyses made on representative samples of each. However, only dry matter and combustible energy need be determined. The formula for calculating DE is: DE = gross energy consumed — fecal energy.

Digestible energy is expressed in calories and is not an empirical determination like TDN. However, it also considers only digestive losses and over-evaluates roughages as compared to concentrates. Consequently, it does not offer a significant improvement over TDN as an energy measurement.

Metabolizable Energy (ME)

Determination of metabolizable energy involves the subtraction of gaseous energy and energy lost in urine from digestible energy. It is considerably more tedious and requires more elaborate equipment than determination of digestible energy. Besides collection of feces, all urine must be collected and measurements of methane excretion must be made. The formula for determining ME is: ME = gross energy consumed — fecal energy — gaseous energy — urinary energy.

It is somewhat doubtful if the increase in precision of ME values over DE values justifies the greatly increased time and effort required to determine them. Gaseous and urinary energy represent only a small proportion of the gross energy consumed by ruminants, being about 5-7% each in most rations. Like DE, ME ignores heat increment which is the largest and most variable energy loss next to fecal losses. Therefore, ME also over-evaluates roughages compared with concentrates as does TDN and DE.

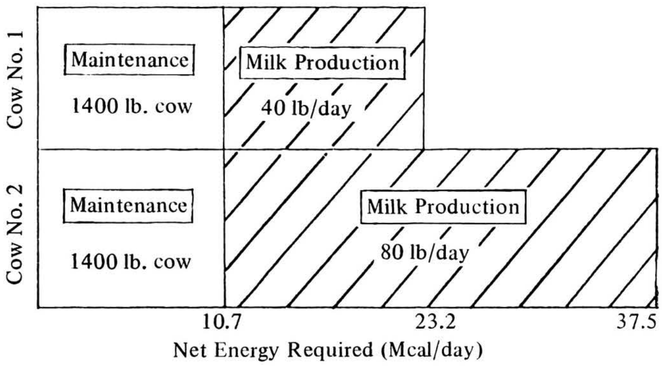
Energy Utilization

A dairy cow uses the available energy for maintenance and reproduction at the expense of growth and lactation when feed is restricted. Therefore, normal growth and high milk production require that adequate energy be supplied for growth and lactation requirements in addition to the needs for maintenance and reproduction.

To illustrate this point, the comparative energy requirements for two non-pregnant, mature, 1400-lb. cows, one producing 40 and the other 80 lbs. of milk per day, are shown graphically in Figure 3.

Cow No. 1 needs 10.7 megacalories (Mcal) of net energy per day for maintenance, represented by the left segment of the bar. In order to produce 40 lbs. of milk per day, an additional 12.5 Mcal are required, represented by the right segment of the bar, for a total of 23.2 units. Cow No. 2 requires the same amount of net energy for maintenance,

Figure 3. Net energy utilization for maintenance and milk production.



10.7 Mcal per day, because No. 1 and No. 2 are the same size. However, rather than only 12.5 Mcal for 40 lbs. of milk, Cow No. 2 requires 25.0 Mcal per day for production of 80 lbs. of milk, bringing the total to 37.5 Mcal per day. If she does not consume 37.5 Mcal of net energy per day, it is possible for her to produce 80 lbs. of milk daily only if she draws from her energy reserve, mainly in the form of body fat. When her body fat is used up, she uses the available energy first for maintenance. Energy left above the maintenance requirement can be used for milk production. If Cow No. 2 consumes only 23.2 Mcal per day, her milk production soon will drop to 40 lbs., the same as Cow No. 1. A drastic drop in milk production after two to three months of lactation often indicates the depletion of body energy stores because of an inadequate energy supply. From Figure 3 it can be seen that an increase in energy intake of approximately 62% is a very profitable investment because it results in 100% more milk from cows with this milk producing ability. This comparison serves to illustrate the efficiency of high milk production.

Energy From Concentrates

The above example illustrates the importance of energy in dairy cow rations. Because the capacity of the cow's digestive tract is limited, the only way to insure adequate energy intake is to feed high-quality forages and concentrates, and feed more concentrates to higher-producing cows. Elaborate concentrate feeding guides have been developed for this purpose and are used successfully in some herds. However, their use becomes more difficult as herd size increases. In a small herd, the owner will usually do the milking himself. He knows all of his cows, their present production levels, and can feed them all individually according to their needs. On the other hand, in a large dairy herd with 200 or more milking cows, they usually will be milked by hired milkers. In most cases, the milkers do not know the production level of individual cows. Therefore, they have no way of feeding according to production unless a simplified system is available.

A partial solution to the problem is the use of color-coding to identify cows according to production level. Once each month the colors should be changed according to the milkfat production of the cow as determined from the production test. Color coding different levels of production makes it possible for the feeder to know at a glance the amount of feed a particular cow should receive. Colored chicken rings on the neck chain, colored ear tags, or colored tape on the neck chain or attached to the tail are used with good results.

In some dairies, automatic feeders are operated from dials which regulate the amount of concentrates fed to a cow. A color-coding system can be used in this situation as well as for a hand-feeding method. Colored strips are placed on the dial to correspond with the desired feeding level. The feeder turns the switch to the colored strip on the dial which corresponds to the color marker on the cow, and the cow in that stanchion receives the desired amount of concentrates automatically. Using this method, a dairyman can feed his cows approximately according to production even in the largest herds. However, under large herd conditions, it may be more practical to divide cows into strings according to ranges in production levels and feed all cows the same amount within a string.

The amount of concentrate a cow should receive depends on many factors including body size, level of production, price and quality of roughage fed, price received for milk, and price of concentrates. To evaluate all of these factors simultaneously in a short time requires an electronic computer. However, a simplified system which has worked well under California conditions is illustrated in Table 2.

Table 2

Concentrate Feeding Allowances

		Lb Concentrates/Day With:		
Tag Color	Lb Milk Fat/Month	Avg. Roughage	Good Roughage	Excellent Roughage
Black	below 30	6	2	0
Red	31-43	14	10	4
Yellow	44-57	20	16	10
Green	56-68	26	22	16
Blue	69-80	32	30	24
White	above 80	free-choice	free-choice	free-choice

Using Table 2, a cow producing 50 lbs. of milk fat per month and receiving good quality roughage free-choice would be marked with a yellow tag and would be fed 16 lbs. of concentrates per day. All cows producing in the 44-57 lb. range would be marked and fed the same. This method is not so precise as feeding all cows exactly according to their production because the recommended amount of concentrates corresponds to that needed for production at the middle of the range (50.5 lbs.). However, it is much better than feeding all cows the same amount of concentrates regardless of production level, which is done in many large herds. Also, only the concentrate portion of the ration is fed according to production. Since there are large variations in voluntary roughage intake by individual cows, justification is lacking for making concentrate allowances more precise. The above system works well in dairies where cows are in the milking barn for a sufficient period to consume their allotted amount of concentrates. However, present emphasis on large dairies is on rapid milking in parlors to maximize the number of cows milked per man-hour. Under these condition, even if the correct amount of concentrates is given to a high-producing cow, she does not spend enough time in the parlor to consume her allottment. The left-over concentrate is available to the next cow that comes into the stall, whose production may or may not warrant it.

Some dairymen have attacked this problem by feeding a portion of the concentrates with roughage outside the milking parlor. A base amount of 5-15 lbs. per cow is fed outside daily and the remainder is fed in the milking parlor. Using this system it is possible to feed high-producing cows more closely according to their production. However, it does add another chore because concentrates have to be fed both in the milking parlor and outside with the roughage. Another disadvantage is that lower producing cows tend to be overfed when they receive concentrates both in the parlor and with the roughage.

Complete Rations

Many researchers have wondered why it is necessary to feed anything at all in the milking parlor. If all of the concentrates could be fed outside, it would eliminate the need for the milker to feed concentrates and he could concentrate on just milking cows. There would be less dust, defecation, and wasted feed in the parlor. Some dairymen insist that concentrates must be fed in the milking area in order to get cows to come in and remain calm while being milked. Others report that cows come in just as well and are calmer when no concentrates are fed.

It seems that the patience and skill of milkers in training cows to the concept of no feed during milking is more important than the ability of the cows themselves to adapt to this system. However, limited observations have indicated more difficulty in adapting this system to individual side-opening parlor barns than to other types, such as herringbone parlors, where groups of cows are moved together. Also, crowd gates improve cow movement when there is no feed in the milking parlor.

The most important question regarding feeding dairy cows in this manner is if they will produce as well when the production based concentrate allotment ordinarily fed in the milking parlor is mixed with roughage and group fed in mangers as a complete ration.

Milk production from cows fed complete rations depends on the amount and nutrient content of the ration, as is the case for any ration. When properly formulated and fed, production on complete rations has been at least as good as rations fed in the traditional manner. This has been demonstrated in experiments in many states, including California where average milk production is the highest in the nation.

In one California trial, cows fed a complete ration produced 3.1 lb. more milk daily than controls fed the same ingredients with roughages and concentrates fed separately. Fat test remained the same for both groups at 3.7%, but cows fed the complete ration produced milk with 8.94% solids-not-fat compared with 8.77% for the controls. Less feed wastage and better feed utilization probably account for the differences.

In another series of trials conducted at the University of California, Davis, a group of high-producing cows were obtained from commercial dairy farms all over the state. To qualify, a cow must have produced a 305-day record of at least 20,000 lbs. of milk on a mature equivalent basis. The cows were individually housed and fed a high-energy, complete ration containing 40% alfalfa hay and 60% concentrate. No concentrates were fed in the milking parlor.

Milk weights were recorded and milk samples were collected for analysis at every milking during the trial. Two other groups of cows with medium- and low-milk production potential were fed the identical complete ration in order to compare the performance of the "Super Cows" with average cows under controlled conditions. Results of the trial are shown in Table 3.

Cows in the high group averaged 24,241 lbs. of milk per lactation (308 days), with the highest cow producing 30,676 lbs. The medium group produced 15,310 lbs. and the low group 10,054 lbs.

Table 3

Performance of Cows Fed a Free-Choice Mixed-Ration with 40% Chopped Alfalfa Hay and 60% Concentrate

	Production Group		
	High	Medium	Low
Milk (lb/308 days)	24,241	15,310	10,054
Fat (%)	2.9	3.0	3.2
Fat (lb/308 days)	706	455	320
Dry matter intake (% of body wt.)	3.13	2.45	2.24
Body weight (lb)	1,434	1,446	1,391
Change in body weight (lb)	+106	+74	+130
Lb milk/lb feed	1.88	1.49	1.16
Energy efficiency (%):			
Total	42.1	33.9	26.7
Above maintenance	61.3	55.5	48 8

per lactation. All cows in these groups had free-choice access to the same ration during the trial. High-producers ate more feed dry matter (3.13 lb/cwt) than medium- (2.45 lb/cwt) and low-producers (2.24 lb/cwt). Average weights of cows in the three groups were similar as were weight gains during the trial.

Even though they ate more feed, efficiency of feed utilization was much greater for the high-producers which produced 1.88 lbs. of milk for each lb. of feed consumed. This compared with 1.49 and 1.16 lbs. of milk per lb. of feed for the medium- and low-producers. The high group converted 42.1% of their metabolizable energy intake into milk energy whereas only 33.9% and 26.7% were converted to milk energy by the medium- and low-groups. Similar differences were observed in energy efficiencies above maintenance requirements.

Restricting feed intake to less than free-choice intake had no significant effect on efficiency of milk production within the restriction levels studied. Cows within each production level group produced the same number of lbs. of milk per lb. of feed whether they were fed free-choice or were restricted to approximately 90% of their free-choice intake.

These experiments were conducted over a period of three years, with no concentrates fed in the milking barn at any time. With this type of production, there can be no question as to the ability of cows to produce well on complete rations. The milker reported this group of cows to be the calmest he had ever milked, despite no feed in the milking barn.

Fiber Levels

High levels of fibrous feeds (roughages) limit milk production by filling the rumen to capacity before all nutrient needs are met. Energy in the form of more concentrates in the ration must be increased in order to realize the full potential of high-producing cows. However, there eventually comes a point where it is impossible to increase energy any further without causing a depression in the fat content of the milk. A minimum amount of fiber in the ration is essential for normal ruminal function and production of milk with normal milk fat content.

Rations which contain high proportions of forages favor the production of acetate in the rumen. Acetate (CH_3COO^-) is the primary precursor of the fats found in milk. Feeding a ration high in concentrates tends to reduce the proportion of acetate and increase propionate (CH_3CH_2COO-). When the percentage of propionate is increased relative to the other ruminal volatile fatty acids, a depression in the percentage of milk fat often occurs. This is accompanied by an increase in body weight as a result of the deposition of fat in the cow. Factors other than acetate:propionate ratios also affect fat test, and more research is necessary before a complete understanding of this phenomenon is possible.

Not only is the level of fiber critical, but also its form. Milk fat percentage is decreased by hay which is finely ground and/or pelleted before feeding, even though the fiber level may be adequate. Heating and pelleting of concentrates and high levels of unsaturated fats in the ration also reduce the acetate-propionate ratio with resulting milk fat depression.

With present knowledge, a reasonable guideline to prevent milk fat depression is to supply a minimum of 17% crude fiber in rations for lactating cows. This is somewhat higher than the 13% crude fiber minimum listed in the 1971 edition of the NRC bulletin on Nutrient Requirements of Dairy Cattle. The 13% minimum is adequate to prevent depressed fat tests under some conditions but not in others. Therefore, in order to provide a safety factor under commercial conditions where fat test has a great influence on the price received for milk, the 17% minimum seems to be a more reasonable and safe level for lactating cow rations.

To insure the proper form of fiber, minimum roughage dry matter levels should be 1.5% of the body weight of the cow. For a 1400-lb. cow, this amounts to a minimum of 21 lbs. per day of dry hay, or its equivalent of other roughages which have not been finely ground. When this level of coarse roughage and the 17% crude fiber level are maintained, incidences of depressed fat test are very rare.

Acid-Detergent Fiber (ADF)

Crude fiber may not be the best indicator of the adequacy of fiber levels for maintenance of fat tests. Experiments with lactating cows at Cornell University indicated that acid-detergent fiber (ADF) was superior to crude fiber when relating dietary fiber fractions to fat percentage. This test was developed at the USDA in Beltsville and is based on the analysis of plant tissue for its cell wall constituents (CWC) and cellular contents (CC). Digestibility of CC always is very high. However, digestibility of CWC depends on the amounts of lignin and cellulose present. This lignocellulose is insoluble in acid-detergent, so it is called acid-detergent fiber (ADF). As ADF increases, digestibility of a plant decreases. Since ADF represents a better defined component of feedstuffs than crude fiber and is easier to determine, it probably *will replace crude fiber in the future as a* measure *of the potential of a ration for prevention* of milk fat depression.

Protein and Protein Replacers for Dairy Cattle

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Introduction

The common standards for feeding dairy cattle in the U.S. and Canada are those based upon the 1971 edition of **Nutrient Requirements of Dairy Cattle** (NRC— ISBN 0-309-01916-8), or, the 22nd edition of **Feeds and Feeding** (Morrison, 1956—no longer in print; 9th edition, abridged of same work, 1962, is still available and contains same tabular material). The NRC data is based upon consideration of the amounts of crude protein and digestible protein for dairy animals of various ages, physiological status, and production, whereas the Morrison values are based solely on digestible protein, on the same considerations.

It is well-known that a lack of protein will depress performance of animals, and in dairy cattle a severe lack will lower not only the yield of lactating cows, but also will affect the solids-not-fat content of the milk. A large excess of protein, on the other hand, is not toxic but is uneconomical, particularly at present-day prices for protein ingredients (or their substitutes). A high level of protein may increase milk protei slightly, but does not increase milk yield, provide the animals already receive required minimal levels.

In general, the present NRC requirements for milk production furnish about 150% of the amount of crude protein in the milk. The Morrison standards are not set figures but give range values, and these are about 130-165% of the protein in the milk produced.

Personally, my belief is that calculation of needs on the basis of DP is far superior to a system based upon CP.

When considering protein requirements of cattle it is necessary to remember that well-fed dairy animals have the ability to store protein, particularly during the dry period, and then they are able to catabolize body protein stores to synthesize milk during lactation. Naturally, the degree to which this is done is dependent upon many factors, but it is of critical value when high-producing cows are incapable of consuming enough feed to meet both their protein and energy needs during early lactation.

Determining DP Needs for Lactating Cows

An overall consideration of the results of the more recent and also the older experimental results suggests that the amount of DP needed in the ration per pound of milk produced is **not** constant, but that it is greater at high levels of milk output than it is at low yields. The two most obvious reasons for this are: (a) she uses stored body protein for milk production, as mentioned above, and (b) the amount of feed she consumes per unit of time affects the digestibility of protein.

The effects of inadequate DP are manifested earlier in the lactation period of the high producer than that of the low producer. Thus, the dairy clinician, faced with a fair number of cows which peak too quickly, and have "short-time" lactations,