THE UTILIZATION OF ENERGY BY LACTATING DAIRY HEIFERS

by

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ABSTRACT

Six lactating Ayrshire heifers were used to study the utilization of energy and the energy requirements for milk production at different stages of lactation and at different levels of production.

The heifers produced an average of 5175 kg 4% FCM during lactation. Gross energetic efficiency of milk production declined from 47.58% at the beginning of lactation to 29.93% at the end of lactation. The over-all gross energetic efficiency was 36.42 ±5.55%. There was a highly significant ($P < .01$) positive correlation ($r = 0.91$) between gross energetic efficiency and 4% FCM production.

High net energetic efficiencies of milk production were associated with early stages of lactation or high levels of production. The over-all net energetic efficiency was 64.22 ± 5.20%. This was equivalent to a requirement of 1.187 ±0.089 megacalories digestible energy /kg 4% FCM or 270 ±20 grams TDN/kg 4% FCM. These requirements were significantly ($P < .01$) lower than NRC recommendations. There was a highly significant ($P < .01$) difference between heifers in their daily net energetic requirements. A highly significant ($P < .01$) positive correlation ($r = 0.88$) was found between net energetic efficiency and 4% FCM production.

Total energy balance trials were conducted. By using an assumed maintenance requirement of 131 kcal $ME/W_{kg}^{.75}$ to calculate the efficiency of ME utilization for milk production, the efficiency with which ME was converted to milk decreased gradually from 55.37% in early lactation to 52.11% in late lactation. Higher efficiencies of ME utilization in early stages of lactation were attributed to tissue mobilization. A significant ($P < .01$) difference between heifers in their efficiency of ME utilization for milk production was observed, while period effect was non-significant. By either simple linear regression analysis of ME available for milk plus maintenance on milk energy or multiple regression analysis of dietary ME on milk energy, tissue loss and metabolic body size, the efficiency of ME utilization for milk production was estimated to be 69.2 to 70.0% with a maintenance requirement of 183.5 to 184.5 kcal ME/$kg^{.75}$. Multiple regression analysis showed that tissue energy was utilized for milk production with an efficiency of 98.5%.

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I

INTRODUCTION

It is a recognized fact that a good number of children in developing countries suffer from severe protein malnutrition (Kwashiorkor); a large number of these children die young as a result of this condition. It is also recognized that the average man in a less-developed country consumes much less animal protein in his diet than his counterpart in a developed country (146). Thus, one of the greatest problems facing a developing nation today is the provision of food of adequate quality, especially animal protein, to its people.

One of the cheapest sources of animal protein and the most complete food provided by nature is Milk. If the developing nations must eradicate kwashiorkor in children and produce future generations with mental and physical well-being then the inexpensive production and consumption of milk have to be intensified.

As a result of increasing urbanization and industrialization the number of farmers responsible for agricultural production is rapidly decreasing in most countries all over the world. If the requirements of the growing population must be met, the farmers left in the production sector must produce efficiently. The level of milk yield per cow must be sufficient to cover the costs of input such as feed, labour and other essential services. Thus, increasing the level and efficiency of milk production is the primary aim of good dairy farmers. The continued success of the dairy industry will depend upon how efficiently milk is produced as to make it worthwhile for the farmers to remain within the industry.

Increasing the level of milk production depends not only on the genetic potential of the dairy cows but also on the nutrition of the animals and on how efficiently the animals convert the feed offered into milk. While proteins, fats, minerals and vitamins are necessary ingredients in a ration, the energy becomes the dominant factor when feeding lactating dairy cattle. Thus, many recent studies have been geared towards evaluation of the efficiency with which dairy cows convert feed energy into milk energy. This is of considerable economic importance. The nutritive value of feeds and the energy requirements of the cows for various levels of production should be known in order to supply adequately the energy requirements of these animals as economically as possible. In attempts to achieve this, feeding standards for milk production have been listed in different parts of the world. In America, feeding standards have been published by National Research Council (NRC) (143) and Morrison's "Feeds and Feeding Tables" (140). These two standards are based chiefly upon the early studies of Haecker (73) in which cows of low production were used. The cows of today produce much more milk than those of Haecker's time. Thus, feeding standards based on low producing cows will not adequately meet the requirements of high producing cows. In fact, in many cases it has resulted into high producers being underfed and low producers being overfed. It, therefore, becomes necessary to evaluate the utilization of energy for milk production by the present-day dairy cattle so as to supply more adequately the energy requirements of these cattle.

The evaluation of the efficiency of energy utilization for milk production has been mainly limited to dairy cows and relatively few trials have been conducted with lactating dairy heifers. The heifers of today become the cows of tomorrow. Therefore, it is necessary that the efficiency of energy utilization and the requirements of energy for milk production by lactating dairy heifers should be known. This will aid the practical farmer in exercising judgement over the keeping or otherwise of certain heifers in his herd as the future cows. Since economic consideration is a major item in the dairy industry it is also of importance to know the economic returns right from the early stages of the animal's productive life.

This thesis is a study of the energy utilization by lactating dairy heifers and the energy requirements for milk production at different stages of lactation and at different levels of production. In addition, the returns over and above feed costs from the milk produced were considered.

II

LITERATURE REVIEW

A. The Nutritive Value of Forages and Concentrates as Sources of Energy in Dairy Cattle Feeds

It is now recognized that the requirement of an animal for energy exceeds all of its other nutrient needs combined. It is obvious, therefore, that in practical feeding of farm animals a primary consideration must be the adequacy of the energy supply. It is also obvious that a knowledge of the nutritive value of feeds as sources of energy is of importance especially when it is recognized that the greater proportion of the feed consumed by ruminants comes from forages. In order to evaluate the nutritive quality of these feeds a simple yet accurate measure of their energy value is of necessity. To accomplish this, various systems of feed evaluation have been proposed and used for many years all over the world but there is by no means agreement among farmers, feed manufacturers, teachers or research workers as to which method is most desirable. The data presented by such workers as Blaxter (13), Reid (151), and Huffman (93) illustrate the discrepancies which may occur when various methods are employed in assessing the energy value of feeds. For instance, Blaxter (13) in his review of the nutritive value of feeds, compared some of the feed evaluation systems using artificially dried immature grass and mature rye grass hay. He observed that the variations in the superiority of the immatre dried grass over the mature rye grass were quite enormous. The various superiortity values obtained for the different systems were: Total Digestible Nutrients (TDN) 29%, Estimated Net Energy (ENE) system 46%, Kellner's Starch Equivalent (Germany) 75%, Modified Starch Equivalent (U.K.) 46%, and Fodder Unit System (Scandinavia, France, Israel) 86%. As was pointed out by Blaxter (13), "All these estimates cannot be correct; yet economic and other considerations are made on the assumption that any particular one of them does, in fact, reflect the true nutritive worth of the material considered."

1. Definition of Nutritive Value of a Feed

Blaxter (13) defined the nutritive value of a food in regard to any nutrient as a measure of its ability to promote or sustain some group of metabolic activities in the animal body. Thus, nutritive value is a biological measurement and not a physical or chemical one. This means that the value obtained in any experiment reflects the intrinsic efficiency of the test animal. The net energy value as determined calorimetrically with an adult steer is, in effect, the net efficiency of the animal in converting unit weight of food to calories of body fat. It, therefore, follows that if two animals differ in their net efficiency of feed utilization, then the one animal will provide a higher estimate of the nutritive value of the food than the other.

The nutritive values of foods may also differ according to the physiological function to which they are put. For example, lactation involves metabolic demands different from those of growth and fattening. Lactation, in general, has been demonstrated to be a more efficient process than fat deposition. This indicates that a food will have a higher absolute value as an energy source for lactation than for fattening the same animal when dry. Since the nutritive value of a feed is not a constant, it, therefore, varies depending upon the species considered, the type of production it supports, the amount of it which is given and its physical state.

2. Criteria for Evaluating the Nutritive Value of Feeds

The starting point in estimating the energy value of a feed is the determination of its gross energy content (GE) which represents the heat given off when the feed is completely burned in a bomb calorimeter to its ultimate oxidation products. As a measure of nutritive value, GE is of no value because in the processing of feeds by the animal, variable quantities of energy are lost in the form of gases, faeces, urine and heat. The various energy categories used herein are those suggested by Harris in 1966 (78) in the first revision of the National Research Council (NRC) Bulletin on energy terms and are illustrated in Figure 1.

Deducting the energy lost in faeces from the GE gives the Digestible Energy (DE) content of the feed. This quantity of energy less that contained in fermentation gases is absorbed from the gastro-intestinal tract and metabolized further resulting in losses by way of urine. The energy left after accounting for urinary and gaseous losses is the metabolizable energy (ME). This is the energy utilized by the animal for various body functions as maintenance, tissue gain, milk production or work. However, part of the ME is lost as waste heat. That portion of the ME remaining after deducting the heat loss is the Net Energy (NE). This

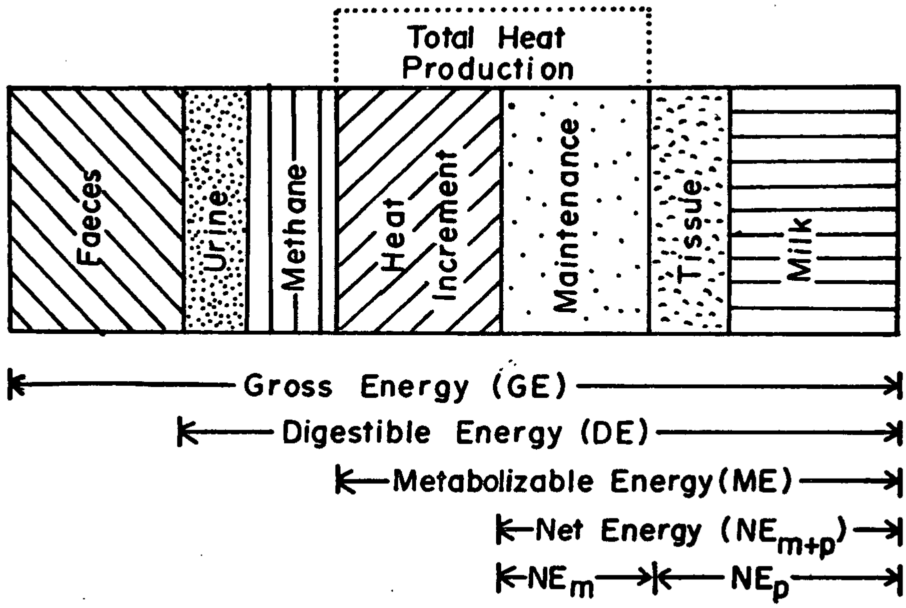

Figure 1. The Total Heat Production and Energy Utilization of a Lactating Cow (adapted from data of W. P. Flatt [Harris (78)])

is that portion of the gross energy that is actually utilized for body tissue gained, milk secreted or work done.

Based on these categories of energy, various systems of feed evaluation have evolved.

(a) Systems Based on Digestibility: The three measures of nutritive value representing differences between the feed consumed and the faeces voided are Digestible Dry Matter (DDM) (or Digestible Organic Matter, DOM), Total Digestible Nutrients (TDN) and Digestible Energy (DE). In essence, all of these measure essentially the same thing, namely, the proportion of ingested matter that disappears as the feed traverses the intestinal tract. Because of this fact Reid (150) and Swift (171) reported that these criteria are highly correlated one with the other. Swift (171) pointed out that DE is the preferred measure of the nutritive value of a feed because it is more direct and accurate than TDN and because it is "free from empirical procedures and assumptions." Hardison (74) in his review concluded that since with the usual rations fed, relatively constant proportions of ME are put into such functions as milk production, maintenance and body increase and since faecal energy loss is the most significant loss of energy, the simplest and the best practical measure of the productive value of feeds would be that based on DE. In the determination of DE only one source of energy loss (faecal energy) is accounted for hence this measure of nutritive value of a feed is fraught with considerable error as shown by the data of Blaxter and Graham (18). DE fails to account for gaseous energy losses, which are actually digestive losses, in effect regarding them as digested energy, consequently, the reason why DE overevaluates feeds is not far fetched.

The systems of feed evaluation commonly in use in America are the TDN and the Estimated Net Energy (ENE) systems. In the TDN system, animal requirements and the value of feeds in meeting these requirements are expressed in terms of the weight of digested materials in the feed.

The development of the calculation of TDN came about gradually. The final step was taken in 1910 when Hills *et al.* (84) and Woll and Humphrey (186) added digestible protein to digestible carbohydrates and fat, multiplied the latter by 2.25 and called the sum "TDN." This conventional system of calculating TDN has been criticised by a number of workers. Lofgreen (116) contended that the conventional procedure of computing TDN would result in inaccuracies of TDN values because in the method one has to assume that all the proteins and carbohydrates in all feeds are of equal value and that all fats have an energy value of 2.25 times that of carbohydrates and proteins. In the determination of digestible energy (DE) heats of combustion are determined on the feeds and faeces and the digested energy is obtained as a difference. This means that the bomb calorimeter automatically assigns to the various constituents their proper energy value. The fat in the total feed consumed as well as that in the digested portion is given a value of approximately 2.25 times that of the carbohydrate portion. This is not true in the calculation of TDN where only the digested fat is given the extra value while the fat in the feed consumed is given the same value as carbohydrates and proteins. This would result in a discrepancy between DE and TDN which would increase as the fat content of the ration increased. Therefore, in order to express TDN on the same basis as DE, Lofgreen

(116) proposed that the DE should be multiplied by a conversion factor computed as:

$$F = \frac{OM}{100} \times \frac{100 + (EE \times 2.25) - EE}{100} \quad \text{where}$$

F = Conversion Factor

OM = % organic matter in the feed

EE = % Ether Extract in the organic matter.

Thus, it is possible to calculate a value equivalent to TDN by the use of bomb calorimeter rather than the determination of the complete proximate composition of the feeds and faeces. Such a procedure would simply involve determination of moisture and energy on the faeces, calculation of the apparent DE, calculation of the conversion factor by the formula and multiplication of the apparent DE by the conversion factor to obtain the TDN value. Lofgreen (116) concluded that the TDN content calculated by the calorimetric procedure would be more accurate as a measure of the energy of the feed than the TDN content determined by the conventional method because it is free from assumptions as the bomb calorimeter would give the various nutrients their proper heat of combustion. The average heat of combustion of the various nutrients reported by Atwater in 1899 [cited by Lofgreen (116)] are: protein 5.65 kcal/g, nitrogen free extract (NFE) 4.15 kcal/g, ether extract 9.40 kcal/g and crude fibre 4.25 kcal/g. The method has the advantage that the conversion factor is specific for each feed or combination of feeds. By comparing TDN values obtained by the conventional method with those obtained by the calorimetric method in 23 digestion trials, Lofgreen (116) observed small differences that were not significant between the two systems, thus indicating that the assumptions made in the determination of TDN by the conventional method may not necessarily lead to serious errors in most cases.

Maynard (123), in like manner, pointed out several discrepancies in the present-day computation of TDN. He suggested that to summate TDN on an equivalent carbohydrate basis (in terms of gross energy value) digestible protein should be multiplied by the factor 1.36 (5.65/4.15) because the gross energy value of protein is 5.65 kcal/g and that of carbohydrate is 4.15 kcal/g. This suggestion has not yet been adopted by nutritionists. Like DE, this procedure for calculating TDN ignores both methane and heat of fermentation which are actually digestive losses, in effect, including them as part of digestible nutrients.

Many practical feeding experiments have been conducted with dairy cattle to evaluate the relative utilization of TDN derived from roughage and TDN derived from concentrates. In 1906, Beach (11) using two steers observed that 4.5 lb TDN from 6.25 lb of corn meal was equivalent to 7.1 lb TDN from 13.15 lb of hay for maintenance, when both feedstuffs were fed by themselves. He concluded that the digestible nutrients from concentrated feeds are more valuable pound for pound than digestible nutrients from roughages.

In 1918, Woll (185) in an investigation involving 9 pairs of dairy heifers determined the nutritive value of alfalfa when fed as the sole feed as compared to mixed rations consisting of alfalfa hay, silage and a fair amount of concentrates. The animals were fed the rations from about 1 1/2 years of age to freshening and during their first and second lactations. The average daily dry matter consumption of the all-alfalfa ration was 24.9 lb and in the mixed ration 28.6 lb. The average daily production from the all-alfalfa ration was 17.6 lb of milk and 0.71 lb butterfat and on the mixed ration 22.7 lb milk and 1.0 lb butterfat. That is, each one hundred pounds of dry matter in the all-alfalfa ration produced 70.7 lb milk and 2.82 lb butterfat, and in the mixed ration 74.4 lb milk and 3.50 lb butterfat, an improvement of 12% and 23% in the production of milk and butterfat respectively. Using Armsby's standards, Woll (185) calculated the NE of the feeds and found that the all-alfalfa ration supplied 9.9 megacalories (Mcal) of NE whereas the mixed ration supplied 15.4 Mcal of NE. Therefore, 1 Mcal from all-alfalfa ration produced 1.78 lb of milk and 1 Mcal from the mixed ration produced 1.47 lb of milk. However, in the latter case, greater weight gains were observed in the animals fed the ration. Woll (185) concluded that the production of good dairy-bred heifers can be appreciably increased by feeding a variety of feeds and that the body development of both calves and young dairy stock is, in general, improved by this system of feeding. This is supported by the observations of Reed *et al.* (149). Woll's conclusion would indicate that greater advantages are to be derived from feeding TDN from hay supplemented with grain than by feeding TDN from hay alone.

Haag *et al.* (72) in their physiological investigations with dairy cows fed solely on alfalfa hay observed that cows in early lactation were generally in positive calcium balance, in negative nitrogen balance, and always in negative phosphorus balance, an observation they found difficult to interpret. They also observed that the milk production of the animals restricted to alfalfa hay was one half as much as that to be expected if the animals were on regular herd ration of hay and concentrates; and suggested that the observed milk production must have been limited by the intake of TDN. The report by Jones *et al.* (102) indicated that low production on alfalfa alone was due to insufficient consumption of TDN and phosphorus thus confirming the suggestion by Haag *et al.* (72). The work of Headley (82) in 1930 and Graves *et al.* (71) in 1938 seem to indicate that there was little or no difference in the utilization of TDN for milk production whether derived from alfalfa alone or from mixed ration of grain, hay and silage. In contrast to this, Huffman in 1938 (92) reported evidence from a long-term alfalfa hay feeding experiment that suggested that the TDN of alfalfa had a low feeding value. He suggested a method to facilitate the study of various supplements to alfalfa hay. Cows were placed on alfalfa hay ration which was considered a "depletion" ration until milk production and live weight changes became minimal. Then a portion of the TDN of the alfalfa was replaced by an equal amount of TDN from the supplement. The substitution on a TDN equivalent basis of corn, cottonseed meal or corn gluten meal into an all-alfalfa hay ration resulted in increased milk production. Similar lactation responses were observed by Smith *et al.* (163). The results demonstrated the inferiority of TDN from alfalfa as compared to TDN from concentrates. From the results of their series of work published between 1944 and 1952, Huffman *et al.* (94, 95, 96, 97, 98) in Michigan concluded that the increased milk production noted when concentrates were substituted for alfalfa hay on an equal TDN basis was evidence of the presence of "unidentified lactation factor(s)" in grain. The actual nature of these "unidentified factors" has not been demonstrated. However, Saarinen *et al.* (158) showed that if the data of the Michigan workers were re-calculated to a net energy basis, the increase in milk production resulting from concentrate substitution into an all-alfalfa ration could be explained by the increase in net energy intake. Perhaps the "unidentified lactation factors" suggested by Huffman *et al.* (97, 98) were nothing more than increases in net energy intake resulting from concentrate substitution for alfalfa. The results of Huffman *et al.* have been interpreted by Breirem (22) and Blaxter (13) as evidence of the inadequacy of TDN as a feed evaluation system since it fails to predict animal performance on different types of feeds. This fact in addition to its failure to include energy losses in forms other than faeces have been regarded as the shortcomings of the TDN system of feed evaluation.

(b) Metabolizable Energy System of Feed Evaluation: Both the DE and TDN failed to account for such energy losses as urine, methane and heat of fermentation (resulting from microbial digestion). Reid (150) and Hardison (74) have reviewed these losses and found that urinary energy loss is between 4 - 6% (rarely more than 5%) of the GE of the feed. Blaxter *et al.* (17) have briefly reviewed the various attempts made to estimate the heat of combustion of ruminant urine from its more easily measured N content. They (17) also showed that urinary energy varies according to the amount of crude protein content of the diet consumed, and developed a regression equation for predicting urinary energy from the crude protein content of the diet.

Reid (150) and Hardison (74) in their review found that gaseous energy losses as methane vary between 5 - 12% (with an average of about 9%) of the GE of the feed and tends to decrease with increasing levels of feeding above maintenance as shown by Forbes *et al.* (57, 59), Mitchell *et al.* (127) and Flatt *et al.* (54, 55). Various equations have been developed to predict methane production by ruminants. Kriss (112) developed an equation which showed that methane production of cattle was linearly related to the dry matter consumption. Bratzler and Forbes (21)proposed a regression equation to predict the amount of methane produced based onthe amount of digested carbohydrates. The equation of Axelsson of 1949 based on dry matter intake was modified by Blaxter and Clapperton in 1965 (16). These workers analysed data from many calorimetric investigations with sheep and cattle and developed a regression equation which related methane production to the apparent digestibility of the energy of the feed. Their equation showed that as the apparent digestibility of the feed increases, methane production increases markedly at the maintenance level of feeding, but at feeding level of 3 times maintenance it falls thus confirming the findings of other workers (54, 55, 57, 59, 127).

Hardison (74) estimates that heat of fermentation represents about 10 - 15% of the total heat increment while Reid (150) states that 1.5 to 11% of the gross energy (GE) of mixed rations is lost as heat of fermentation. Blaxter (14) by employing stoichiometric relationships of the fermentation reactions which occur in the rumen, arrived at a range of 4 - 12% of the energy of the feed as heat of fermentation. To account for both methane and heat of fermentation losses, it was proposed that the factor 1.8 X methane energy be used implying that heat of fermentation is 80% of methane energy. These various estimates indicate that a sizeable proportion of the GE of the feed is lost as urine, methane and heat of fermentation. Therefore, a system of feed evaluation such as DE, or TDN which does not take these various losses into account would overestimate the productive energy value of feeds. Metabolizable energy (ME) takes into consideration energy losses as methane and urine; i.e. metabolizable energy (ME) is equal to the gross energy (GE) of the feed minus the energy of the faeces, urine and methane; but does not account for energy lost as heat of fermentation so that ME does not truly represent the energy which is capable of being metabolized within the animal as the name implies. This notwithstanding, ME is a better measure of food value than DE and TDN and is an entity which can be measured directly without the empirical assumptions of the TDN system. Thus the basic differences in ME and TDN are the deductions for methane and urinary losses. These losses have been shown to be similar for forages and mixed rations (16, 150). Therefore, the major difference in productive value of forages and concentrates would appear to be in the utilization of the metabolizable energy from the respective rations.

The experiment by Cook, Stoddart and Harris (31) clearly illustrates one of the cases where metabolizable energy provides a much better measure of feed value than does TDN. Wether sheep were equipped with faecal bags and urinals and grazed in enclosures of pure stands of important desert plants. The digestibility of the forage was determined by the lignin ratio technique and the TDN calculated; the gross energy of the urine was determined and the energy lost as methane estimated from the digestible carbohydrates using a suitable equation. From these data, the metabolizable energy of the forage was determined. Their result indicated that forage species high in essential oils had high gross energy and high TDN values but were relatively low in metabolizable energy because the oils, though absorbed, were not metabolizable, and were lost as extremely large quantity of energy through the urine and hence did not represent available energy for animal use. Cook *et al.* (31) concluded that an accurate appraisal of the nutritive energy furnished by many range forage plants can be assessed only by determining their metabolizable energy.

The superiority of metabolizable energy over TDN or DE led Blaxter (14) to propose the use of metabolizable energy to replace TDN or DE in feed evaluation; and described useful methods for estimating net energy from metabolizable energy (15). He proposed that the measurement of metabolizable energy of a feed should be made at the maintenance level of nutrition because the estimation of its determinants, the loss of energy in faeces and urine requires only relatively simple equipment, a metabolic cage or stall, and the loss of energy as methane can be estimated with little error. Earlier, Colovos (29) remarked that metabolizable energy system of feed evaluation is no better than DE system if losses of energy as methane and urine are estimated rather than directly determined.

Blaxter (14) indicated that methane losses can be predicted with such low errors that only when the metabolizable energy of the food falls below about 2 kcal/g as in straws and poor quality hays does the error attached to metabolizable energy approach ±1% of the amount actually present. With regard to urine Blaxter *et al.* (17) stated that the heat of combustion of urine expressed as a percentage of gross energy of the feed can be predicted with 95% confidence limits by an equation such as that obtained by these workers which relates urinary energy to the crude protein content of the diet. They concluded that if this prediction equation for urine energy is combined with that of methane (16), the ME of diets can be predicted from results of trials in which the apparent DE and N content of the diet have been the only measurements made.

The limitations of ME by way of the use of an expensive and complicated apparatus, a respiration chamber, for measuring energy losses as methane, and the involvement of much labour and technical skill have resulted into the actual determination of ME of only a few feeds. However, the metabolizable energy of a large number of feeds has been estimated by converting TDN or DE (which are relatively easy to measure) to ME using suitable conversion factors. Forbes and Kriss (62) suggested that 1 lb TDN is equivalent to 1616 kcal of ME; NRC (143) in converting TDN to ME assumes 1 kg TDN is equivalent to 3,740 kcal ME. Blaxter *et al.* (17) calculated various conversion factors (ME as a percentage of DE) for rations of varying energy digestibility and crude protein content. They observed that the ratio of metabolizable energy to digestible energy was not constant but varies little from an average value of 82%; and suggested that DE of most rations can be converted to ME with errors not exceeding ±3% (1) by simply multiplying the apparent DE by 0.82, a procedure that has been recommended and adopted by NRC (143) for estimating ME from DE for a number of feeds.

Graham (70) recently analysed data from various workers to find the relationship between ME and DE of rations fed to sheep and cattle. A synthesis of the regressions of ME on DE gave the following equation:

M = (37.5)I x d - U where

M - Metabolizable Energy (kcal/day)

I = Organic Matter Intake (kg /day)

d = Digestibility of Organic Matter (%)

U = Urinary Energy for a fasting animal (70 and 500 kcal/day for sheep and cattle respectively).

Graham's equation has the advantage of being applicable to both sheep and cattle; and encompasses a wide range of diets, digestibilities and levels of feeding. In his analysis, Graham (70) observed that ME was not a constant fraction of DE but varies ranging from 70 - 85% depending on level of feeding and digestibility, an observation which agrees with that of Blaxter *et al.* (17).

The premises on which ME system is based are that the measurement of ME of a feed is uncomplicated by any variation due to age, species or physiological function of the ruminant animal used; and that the values for individual feeds can be added together to obtain the metabolizable energy of a mixed ration. This is in contrast to ENE (98).

The second premise implies a rejection of all associative effects on the digestibility of food. These effects do exist as evidenced by the work of Forbes *et al.* (58, 60), Harris *et al.* (79), Reid (150), Swift (171) and Ward *et al.* (182). However, Reid (150) and Reid [cited by Hardison (74)] indicated that this is seldom greater than 5 percentage units of TDN or 10% of the digested energy particularly if enough time is allowed for an equilibrium to be established between the microflora of the gut and the diet. Thus, the magnitude of the associative effect is not large enough as to invalidate the usefulness of ME system for assessing the value of feeds.

Metabolizable energy system also assumes that the ME of all feeds is used equally efficiently for maintenance. Evidence are well documented which indicate that ME of all feeds is not in fact equally efficiently used for maintenance purposes, the efficiency tending to decline as the feeds given become more fibrous (68) and less digestible (47). The assumption of equal efficiency of ME utilization for maintenance seems to involve too wide an extrapolation of the results of experiments with rumen infusions of pure volatile fatty acids. In effect it implied that a constant proportion of the ME of feeds of widely different digestibilities is absorbed from the rumen volatile fatty acids. Armstrong (5) has suggested that, with decreasing digestibility in a series of feeds, an increasing fraction of ME is lost as heat of fermentation thus resulting in a lower proportion being absorbed as useful energy. Besides distinguishing between efficiencies of utilization of ME for maintenance and productive purposes, the ME system also includes a relationship to allow for the reduction of the ME of feed that may occur with increasing level of intake due to a depression in digestibility.

(c) Existing Net Energy Systems of Feed Evaluation: Because of the shortcomings that have been observed in the TDN system and other systems based on digestibility, the ENE has been used as an alternative in North America. Similar to it are the Starch Equivalent System (SE) in the United Kingdom and the Scandinavian Feed Unit System (SFU) in Scandinavia. These forms of net energy system have been based on the premise that they actually measure the productive response of the animal. That is, they are directly proportional to the level of production, a function which the TDN system failed to accomplish. In the acceptance of ENE various practical feeding experiments were conducted with dairy cattle to compare the relative merits of TDN and ENE systems of feed evaluation.

In 1951, Saarinen *et al.* (158) conducted their experiment in which the ENE intake was held constant during the control and experimental periods. Eight cows were fed from the 56th to 154th day (14 weeks) after calving according to Morrison's (1948) higher net energy standards on either alfalfa hay alone or in combination with a purified carbohydrate, or carbohydrate and fat mixture. Replacement of the purified mixtures with corn did not result in any changes in milk production, an observation that could not be explained on the basis of the calculated net energy intake. This result indicated that the increase in milk production resulting from substituting concentrate into an all-alfalfa hay ration could be explained on a net energy basis. The work of Saarinen *et al.* (158) was supported by the result of the experiment of Irvin *et al.* (100) in which a portion of the net energy of an all-alfalfa hay ration was replaced with either ground corn, a cellulose mixture, a carbohydrate mixture, corn distillers dried solubles, or soybean oil meal. By plotting actual milk production against that expected from TDN and calculated net energy intakes, it was observed that actual milk yield more nearly approached that expected from net energy than from TDN intake. This observation supports the premise on which net energy system is based, namely, prediction of actual performance of an animal. It also supports the contention that TDN system tends to over-evaluate the feeding value of roughages relative to concentrates for productive purposes, a fact that has long been observed even by Wolff in 1888 [cited by Elliot and Loosli (43)], the originator of TDN system. It was also observed that the higher the quality of the hay, the more closely TDN system approached net energy system. Thus Blaxter (13) in his review remarked that TDN and ENE systems are not the same especially when forages are compared with concentrates, the poorer the quality of the feed, the wider the discrepancy between TDN and ENE.

In 1955, Loosli *et al.* (118) compared the lactation performance of cows fed forage alone or forage plus concentrates supplying equal TDN and ENE according to Morrison's (140) values. Consistently greater milk yield was observed from the TDN over the ENE system of feeding thus reflecting the fact that ENE more accurately predicted the productive energy value of the feeds used than did TDN values. These workers remarked that the TDN values have been obtained under conditions of maintenance, growth and fattening, so that their inaccuracy with regard to lactation should not be unexpected. The work of Teichman *et al.* (172), Elliot and Loosli (43) and Zeremski *et al.* (187) lend support to the superiority of ENE over TDN in accurately evaluating feed energy for production.

Although some studies such as those of Martin *et al.* (122) did not show any superiority of ENE system over TDN system when comparing forages and concentrates, the majority of reports to date recognize the fact that the DE and TDN systems overrate roughages relative to concentrates and that ENE system more accurately predicts the actual response.

Inspite of its disadvantages the TDN system is still in use in North America for two main reasons: its ease of determination and the large mass of feed data accumulated in terms of TDN. In contrast, due to the difficulty and expense involved (which Colovos (29) described as "Calorimetrophobia") in determining net energy, the absolute net energy of only a few feeds is known. However, attempts have been made to establish the relationship between TDN and net energy of feeds, so that if the TDN is determined, its inaccuracies may be rectified by converting it to ENE using suitable equations.

Several plans for converting TDN to ENE have been proposed. Forbes and Kriss (62) by adopting 3.563 Mcal ME/kg TDN of mixed rations, and 57.5% as the fraction of net availability of ME for fattening, arrived at a value of 2.049 Mcal NE/kg TDN. Haecker's (73) standard and Morrison's (140) table of requirements gave a value of 1.870 Mcal NE/kg TDN.

In 1953, Moore *et al.* (138) showed that a linear relationship exists between ENE and TDN values of feeds. These workers obtained energy-value data derived from experiments involving several animals and various classes of feeds and developed a general regresssion equation of the ENE/TDN relationship. This regression equation showed that the net energy value of feeds decreases at a faster rate than the TDN value such that there could be as much as 100% difference in the net energy value of a pound of TDN, depending upon whether it comes from a concentrate or a poor quality forage. They suggested that in feeding experiments, the experimenter should not change the proportions of grain and forage on a TDN basis but only on ENE basis. Moreover, in using the equation for calculation the experimenter should keep within the limits of data used in developing the regression line (about 30 - 100% TDN). Although Moore *et al.* (138) felt that the use of regression of ENE on TDN might offer a means of approximation and serve as a guide to establishing more accurate productive values (this is undoubtedly so), they doubted whether the regression equation could be used to calculate the ENE value of a specific feed. On the basis of this, Kane in 1962 (106) developed regression equations for the relationships between TDN and ENE for individual classes of feeds using data from Morrison's 21st and 22nd editions (140). He observed that all the feed classes had regression coefficients that differ significantly from the general regression for the combined classes. His general regression equation for the combined classes was similar to that obtained by Moore *et al.* (138). The feed classes, except silage, were found to have similar slopes for their ENE/TDN relationships while the general regression line was significantly different because the feed classes operated at different levels of energy. Regression equations obtained from data of Morrison's 21st edition agreed satisfactorily with those of 22nd edition. Kane (106) concluded that in converting TDN to ENE values using Morrison's data, the appropriate feed class regression appeared to be more accurate than a general regression. In the present-day system of dairy cattle feeding roughages and concentrates are fed in varying proportions to constitute a mixed feed, rather than feeding roughage alone or concentrate alone. In the concept of use of appropriate individual feed class regression for calculating ENE for a particular class of feed postulated by Kane (106) it, perhaps, would have been appropriate to calculate ENE of each feed and sum up to obtain the ENE of a mixed feed. This approach is nullified by the result of the investigation by Huffman *et al.* (98) which indicated that ENE and SE values of individual feeds are not additive. This non-additivity has been termed "Associative Effect." The full explanation of non-additivity is not clearly understood, although it is likely that at least a portion of this effect is due to one or both ration components in a mixed feed being nutritionally imbalanced when fed alone. Thus the general regression equation developed by Moore *et al.* (138) would appear to be more appropriate in predicting the ENE value of mixed feeds. However, in investigations in which sole alfalfa or any type of roughage is fed, the use of the feed class regression equation of Kane (106) for predicting ENE might, perhaps, be appropriate.

(d) The New Net Energy System of Feed Evaluation: The existing net energy systems (ENE, SE, SFU) which have been used to replace the TDN system have all been based primarily on the net energy value of individual feeds for fattening. It has been established by Armsby (4), Kriss (113) and Armstrong and Blaxter (7) that the use of dietary energy is more efficient in lactating animals than in fattening, non-lactating animals. On this basis, the energy values of feeds expressed in terms of net energy value for fattening cannot be directly applied to lactation. Although, the existing net energy standards of Morrison (140) and that recently proposed by Lofgreen and Garrett (117) have been based on fattening, Morrison's (140) net energy standards in particular have been applied to the lactating dairy cow by adjusting the net energy requirement for milk production downward to compensate for the higher efficiency of lactation as compared to fattening. This, as stated by Moe and Flatt in 1969 (129) has resulted in the anomaly of 660 kcal ENE being required for the production of one kilogram of milk containing 740 kcal. Attempts to resolve this discrepancy and to obtain net energy value of feeds for lactation were recently initiated by Moe and Flatt (129) in Beltsville. These Beltsville workers employed calorimetric procedure using lactating dairy cows in complete energy balance trials to evaluate the net energy value of feeds for lactation (NE_{milk}). Their procedure was not totally free of some assumptions. For instance, by regression of milk energy production on ME intake, the energy required for maintenance was estimated to be 0.085 Mcal milk/$kg^{.75}$, and described as 0.085 Mcal $NE_{milk}/kg^{.75}$. This value was assumed as the maintenance requirement per kilogram of metabolic body size of the animals and was regarded as constant. There is undoubtedly some variation among animals in their individual maintenance requirements as indicated by Van Es (45). From the results of their trials, Moe and Flatt (129) have developed a table of feed composition listing several expressions of energy value including NE_{milk} for the 21 diets they have so far evaluated. The table showed that NE_{milk} of concentrates is higher than that of roughages. They have also developed tables of NE_{milk} requirements of lactating dairy cows for maintenance and milk production. The applicability of this new system of feed evaluation in rationing diets for lactating dairy cows and the limitations of the system are well discussed by these workers.

In 1970, Moody (136) using the equation of Moore *et al.* (138) and % TDN as listed by Morrison (140) calculated the ENE values for the 21 feeds evaluated by Moe and Flatt (129) and compared these values with NE_{milk} obtained by these workers. He observed that the differences between ENE and NE_{milk} were in the order of 30%, thus reflecting the more efficient use of energy for lactation than for fattening and the inaccuracy of rationing diets for lactating cows on the basis of ENE. This new system has not been widely adopted due to paucity of information regarding NE_{milk} for many diets.

B. Energy Requirements for Lactation

The existing Morrison's (140) and 1958 NRC (142) standards set forth an allowance of 0.31 to 0.32 kg TDN/kg of 4% FCM produced by cows, in addition to the allowances for maintenance, growth and pregnancy. These allowances were based on Haecker's (73) experiments in which the average yield per cow was only 11 kg (24.4 lb) per day and even the highest producing cow gave only about 20 kg (42.6 lb) of milk per day. The assumptions underlying the requirements are (a) that metabolizable energy (ME) is utilized with approximately 70% efficiency for milk production; (b) that the utilization of ME remains constant regardless of the percentage of the total ration consumed as concentrate or roughage; (c) that the digestibility of the ration does not change with increasing levels of intake; and (d) that the maintenance requirement remains constant whether a cow is dry or lactating. Wagner and Loosli (179) have shown that differing efficiencies in the utilization of ME for milk production would yield TDN requirements per kg of 4% FCM produced of 0.305, 0.329, 0.356, 0.397 and 0.438 kg if the utilization of ME for milk production was 70, 65, 60, 55 or 50% respectively.

The levels set forth by these standards (140, 142) have been regarded low by, among others, Reid *et al.* (156). Moe *et al.* (133) and Wagner and Loosli (179). The bases of this view have been enumerated by Moe *et al.* (133) as:

(1) The cows employed in the feeding trials on which the earlier standards were based were low producers.

(2) The present-day milk output per cow is generally higher than in the past.

(3) Most herds have at least a few cows whose production exceeds 27 kg (60 lb) per day for at least two months of the lactation period.

(4) The proportion of mixed rations which is digested decreases as the amount of ration ingested per day increases, yet

rationing is based on TDN values of feed determined at low levels.

(5) The hereditary ceiling on milk yield appears to be much higher than the yield produced by the average cow.

As a result of the criticisms on the existing standards, the present-day energy standards for milk production as recommended by NRC (143) are about 10% higher than the earlier levels for average production and 25% more for the highest milk yields. Better cows might even consume more feed than the tables suggest. The present NRC (143) prescribed 0.33, 0.37, and 0.42 kg TDN/kg. of 4% FCM produced for cows producing less than 20 kg, 20 to 35 kg and above 35 kg of 4% FCM per day respectively thus recognising the fact that the requirement of energy for lactation is greater at higher levels of milk production than at low levels. These requirements are equivalent to 1.46, 1.63 and 1.85 Mcal DE or 1.20, 1.34 and 1.52 Mcal ME/kg 4% FCM for cows producing less than 20 kg, 20-35 kg and above 35 kg 4% FCM per day respectively. Although, the energy requirements above maintenance increase per unit of milk produced as the daily yield becomes higher, gross efficiency continues to increase with higher production because a small proportion of the total energy is used for maintenance.

Based on calorimetric experiments it was found by Moe *et al.* (133) that the TDN requirement at the mammary gland level is 0.3 kg TDN/kg 4% FCM, a value quite close to the requirements set forth by Morrison (140) and NRC (142). This requirement at the mammary gland level does not represent the requirement at the dietary level or even at the gut level which obviously will be higher than at the mammary gland level. This is, perhaps, one of the reasons why NRC (143) has increased the existing standards by as much as 10 - 25%.

The results of feed input-milk output experiments by Jensen *et al.* (101) indicate that cows producing 5000 to 5454.5 kg (11000 to 12000 lb) of 4% FCM per annum require above maintenance allowance approximately 0.5 kg TDN/ kg 4% FCM produced. Although, a part of this energy appears to have been used for the gain of body tissue, the size of the apparent requirement suggests that at the level of feed intake needed to produce as much as 5000 to 5454.5 kg (11000 to 12000 lb) of 4% FCM per annum, a given quantity of TDN must have a milk-producing value per unit of weight of about 66% of that which it would have when the same source of TDN is fed at a level slightly above that of maintenance.

Reid (150, 152, 153) and Blaxter (14) have discussed the inadequacies of the existing feeding allowances for milk production. They suggested that the three main factors involved in the increasing need for dietary energy per unit of milk produced are the result of (a) decreasing digestibility with increasing levels of feed intake, i.e. a progressive reduction in absorption as the feed intake increases; (b) an increasing tendency to fatten with additional feed; and (c) the relative inefficiency with which energy is used for fattening as compared with milk production (fattening is 83% as efficient energetically as milk production).

The TDN values of feeds recorded in tables of feed composition and nutritive value were determined largely with steers and wethers fed at low levels of intake, usually at levels of intake only slightly above that of maintenance. The studies of Moe *et al.* (130, 133) and Wagner and Loosli (179) indicate that the TDN value of a given feed is not a constant, but that it depends upon the level at which the feed is ingested. Thus, Wagner and Loosli (179) showed that with decreasing TDN as the level of intake in multiples of maintenance increases, the requirement of TDN for milk production increases. In order for a high-producing cow to attain a high level of milk output, she requires a large feed intake which is accompanied by a large percentage loss of energy in the faeces. However, as her feed intake increases, she absorbs a greater absolute amount of energy of which a progressively smaller part is required for maintenance. This represents a gain in lactational efficiency. Moe *et al.* (133) indicated that since the labour, space and equipment costs are not much different for a high milk yield than for a low milk yield, the increase in economic efficiency of a large output of milk over a low yield of milk is greater than that indicated by a mere comparison of the ratio of feed input to milk output. This aspect is of particular relevance to the study reported in this thesis.

C. Efficiency of Energy Utilization for Milk Production

Brody (23) states that the efficiency complex involves innumerable genetic and environmental, as well as physiologic and economic factors. This statement indicates that the interactions of a host of factors are involved in determining the efficiency with which dairy cows utilize feed energy for lactation.

Efficiency does not necessarily mean maximum production, rather, it is the proportion of the input which is recovered as a useful product. Thus, the biological efficiency of milk production is the proportion of the feed energy ingested that is recovered as milk energy.

Armsby and Moulton [cited by Stone *et al.* (168)] in 1925 defined efficiency on two bases:

Net Efficiency, when the maintenance costs are excluded, i.e.,

$$\text{Net Energetic Efficiency(\%)} = \frac{\text{Milk calories produced}}{\text{Digestible feed calories consumed} - \text{Calories for maintenance}} \times 100$$

and Gross Efficiency, when the maintenance costs are included, i.e.,

$$\text{Gross Energetic Efficiency(\%)} = \frac{\text{Milk calories produced}}{\text{Digestible feed calories consumed}} \times 100.$$

This expression does not remove the fixed maintenance charge or take into consideration any changes in body weight. Flatt *et al.* (56) have shown data from calorimetric studies which illustrate the ability of a dairy cow to gain and lose large quantities of body tissue without reflecting the magnitude of these changes by body weight changes. Therefore, corrections for maintenance and body weight change would involve some assumptions regarding the caloric changes applicable to a specific cow. These assumptions may lead to errors in determining the actual net energetic efficiency of milk production. Kleiber (110) expressed gross efficiency and net efficiency as Total Efficiency and Partial Efficiency respectively. Using these definitions, Brody (23) determined the gross efficiency of milk production for a large number of cows. His results indicate that the average dairy cow has a gross energetic efficiency of 28-34% and that there is a difference among cows in their efficiency of feed utilization for milk production. Similar differences in efficiency among cows have been reported by Blaxter (13), Forbes and Voris (63) Edwards (41), Hooven and Matthews (89), Stone *et al.* (168), Jumah *et al.* (104), Smith and Rice (164).

In the conversion of feed energy into milk, a good proportion is lost as faeces. Armstrong (6) and Baumgardt (10) indicated that the make-up of the resulting digestible or absorbed energy (Volatile fatty acids, glucose, amino acids, etc.) varies with the type and physical form of the ration. As reviewed earlier (page 6), metabolizable energy is the portion of the gross energy left circulating in the bloodstream for such functions as maintenance, milk production by the mammary gland and body tissue deposition. Van Soest (176) in his review suggested that the pattern of metabolites absorbed from the gut and presented to the tissue (mammary gland and adipose tissue) can influence the direction of their usage as well as the efficiency of use at the tissue level. Thus, the process of conversion of feed energy into milk energy can be divided into three phases: intake, digestion and metabolism. Variations in each of these phases can influence the efficiency of energy utilization for lactation.

1. Influence of Level of Feed Intake on Efficiency

Brody (23) and Reid *et al.* (156) have showed that increasing feed intake results in increased milk production, consequently gross efficiency also increases (but at a decreasing rate) because the maintenance requirement becomes an increasingly smaller proportion of the total feed intake. This is the major reason for the interest in high feed intake. Reid *et al.*

(156) have explained the diminishing returns effect on the basis of (a) digestibility depression and (b) increasing proportions of dietary energy being diverted to the production of new body tissue consequently reducing the maintenance cost. The relationship between metabolizable energy input (at body-energy equilibrium) and milk energy output has been shown by Hashizume *et al.* (80) to be linear at feed inputs up to three times maintenance or even four and a half times maintenance as shown by Flatt (49). This indicates that the efficiency of the mammary gland does not change with increased milk output, but tells nothing about digestibility or diversion of metabolites for other uses.

That increased level of feeding does cause a depression in digestibility has been shown by Moe *et al.* (130). This effect is more marked in the case of high-concentrate mixed diets than all-forage diets as indicated by Brown (24) and Tyrrell *et al.* (174). Thus, if digestibility is determined at the level of intake applicable to the efficiency trial and the value obtained is used in the denominator of the gross efficiency calculation, any depression in digestibility due to high intake will not result in a lowered gross efficiency. But, if digestible energy (DE) determined at maintenance level of intake is used in the denominator, gross efficiency will be relatively low because DE obtained at maintenance level will be higher than that determined at higher levels of intake where depression in digestibility probably has a marked effect. Since the latter situation often occurs, Reid *et al.* (156) concluded that gross efficiency depends mainly on two opposing conditions (a) digestibility depression and (b) dilution of the maintenance cost. Dilution of the maintenance cost is the dominant condition and the gross efficiency increases at least up to a daily output of 100 lb of FCM when the rate of depression in digestibility does not exceed 4% per increment of intake equivalent to that of maintenance. When the digestibility depression is 5 and 6%, the gross efficiency is maximal at 4% FCM outputs of about 85 and 70 lb per day, respectively.

The diminishing-returns effect has also been based on increasing proportions of dietary energy being diverted to the production of new body tissue. Since milk energy is considered the only output, i.e. no allowance being made for maintenance or change in body weight, diversion of part of the absorbed energy into body weight gain or contribution to dietary energy by tissue loss, can have a marked effect on the efficiency value. The latter case is probably responsible for higher efficiency observed in most lactating cows in early lactation when they are mobilizing large quantities of body fat for productive purposes. This suggestion is supported by the finding of Moe and Flatt (128) which showed that body tissue reserves were used for milk production with an efficiency of approximately 85% in dairy cows.

2. Influence of Digestible Energy Concentration on Feed Intake and Efficiency

The possibility that ruminants possess the ability to regulate energy intake was investigated by Montgomery and Baumgardt (134). These workers fed four all-pelleted alfalfa meal: corn rations to Holstein heifers under *ad libitum* conditions. The rations were composed of 100%

alfalfa meal, 80% alfalfa and 20% corn, 60% alfalfa and 40% corn, 40% alfalfa and 60% corn. It was observed that the digestible energy concentration increased with increasing corn proportion but feed dry matter intake decreased as the digestibility of the rations increased. The net effect of these changes was that the animals voluntarily maintained the same digestible energy intake for the rations. Similar results were obtained when these rations were fed to sheep. Since gastrointestinal tract fill did not appear to be the factor limiting dry matter intake in rations containing higher proportions of corn, Montgomery and Baumgardt (134) hypothesized that the regulation of food intake must be due to the changing nature of the mechanisms involved as a result of ration characteristics. This hypothesis is in general agreement with the results of Conrad *et al.* (30). Due to the nature and characteristics of high-roughage rations, feed intake by ruminants may be limited by distension of the gastro-intestinal tract while the genetic and physiological demand may be the limiting factor in the intake of highly digestible rations. The hypothesis of Montgomery and Baumgardt (134) was also supported by their later work (135) which suggests that digestible energy intake can be increased by increasing the digestible energy concentration in the ration through supplementation of roughage with concentrate. If this is so, it can be of major significance in designing rations for the greatest efficiency of milk production.

Since gastrointestinal tract fill appears to limit intake on high-roughage diets it seems likely that the quality of the forage would have an effect on the efficiency of milk production. Dawson, Kopland

and Graves (39) reported the effect of cutting alfalfa at three stages of maturity on efficiency of milk production. The alfalfa was cut and made into hay at initial bloom, half-bloom and full-bloom stage and was fed as the sole ration to milking cows over a twelve-month lactation period. Their result indicated a decrease in crude protein content and an increase in crude fibre with advancing maturity. The effect of these factors was a decrease in daily 4% fat-corrected milk (FCM) production and gross efficiency and a decrease in daily dry matter consumption. Later work by Reid *et al.* (155) and Spahr *et al.* (166) supported the result of Dawson *et al.* (39). Spahr *et al.* (166) calculated that about 65% of the reduction in caloric intake of the forages associated with advance in maturity was due to reductions in dry matter consumption, while only 35% was due to changes in per cent digestible energy. This is in agreement with the findings of Crampton *et al.* (36) which indicate that about 70% of the variation in Nutritive Value Index is associated with relative intake, while 30% is associated with digestibility of energy. The studies of Reid *et al.* (155) and Spahr *et al.* (166) did not provide enough data to estimate the efficiency of milk production. However, it can be assumed that if the cows were in a favourable stage of lactation and of a genetic make-up to convert additional energy into milk rather than body fat, the efficiency of milk production would be higher with the early-cut forage. Moore (137) in his excellent review, pointed out that no one quality characteristic accurately reflects the appetite of the animal for a particular forage or can predict the efficiency of utilization of the forage for growth or milk production.

However, it is evident that the stage of maturity and curing methods have an effect on the quality of forages and in turn play a part in the efficiency of utilization. Thus increased forage nutritive value should improve the efficiency of milk production.

There are few experiments in which high-producing cows were truly fed *ad libitum* quantities of all parts of their ration. In most cases roughages are fed *ad libitum* and concentrate fed in proportion to production. Various workers including Beach (11), Huffman *et al.* (96), Irvin *et al.* (100), Loosli *et al.* (118) have shown that the addition of a grain or concentrate mixture to roughage alone almost invariably results in increased milk yields, but the size of the response depends upon the nature of the roughage, the kind of supplemental grain mixture, the stage of lactation and the genetic ability of the cow as indicated by Bloom *et al.* (19). To what extent should grain be added to roughage to increase milk yield and yet prevent depression in gross efficiency? Attempts to answer this have been put forth by a number of workers. Putnam and Loosli (147) fed 12 Holstein cows with three rations containing 20%, 40% and 60% as concentrate and the rest made up of a mixture of hay and silage fed at a ratio of 1 kg hay to 3 kg silage. *Ad libitum* feeding was allowed with the restriction that the forage: concentrate ratios be maintained as specified, thus, roughage intake dictated concentrate levels. The result showed an increase in dry matter and digestible energy consumption and 4% FCM production as the proportion of concentrate increased. However, there was a slight decrease in gross efficiency of milk production with the values being 35.6%, 33.0%, and 32.8%

for rations containing 20%, 40% and 60% concentrate respectively. These results indicate that increases in milk production might be expected by increasing the concentrate proportion in dairy cow ration, but at the same time there is little or no improvement in gross efficiency.

In a total energy balance experiment with design similar to that of Putnam and Loosli (147), Flatt *et al.* (54) fed three rations containing 40%, 60% and 80% concentrate and the rest as wafered alfalfa hay to six high-producing dairy cows. The experiment was replicated twice. The digestible energy concentration under *ad libitum* feeding conditions was 69.7%, 73.5% and 76.6% for rations containing 40%, 60% and 80% concentrate respectively. It was observed that as the energy concentration increased with increasing proportions of concentrate, dry matter and digestible energy intakes declined, milk fat test was depressed, and milk energy produced actually declined with the increasing energy concentration. The efficiency of milk production in terms of milk energy/ digestible energy intake declines from 33.8% to 32.3% to 26% as the percentage of concentrates in the diet increases. Similar decreases in fat test and gross efficiency of milk production have been reported by Ronning (157), Hooven and Plowman (91) and Swanson *et al.* (170). Thus, Van Soest (176) in his review article concluded that the efficiency of milk production does not form a linear function with the hay: grain ratio, but exhibits a maximum at some point, probably near the hay: grain ratio where milk fat test begins to be depressed. Certainly this hypothesis is in accord with the experimental results of the workers cited above. Thus, a ration which contains so high a proportion of concentrates as to cause milk fat depression is not as efficient for milk production as one containing less grain but which still meets nutrient requirements.

Flatt *et al.* (54) examined the effects of the different diets over different stages of lactation and found that cows given rations containing 40% and 60% concentrates produced more milk in early and mid lactation than those given 80% concentrates. Since significant differences in metabolizable energy intake (35.6, 36.5 and 33.0 Mcal ME/day for 40%, 60% and 80% concentrate ration respectively) were not observed between cows given the different diets, this would suggest that either the cows given 40% and 60% concentrates were mobilizing body fat or those given 80% concentrates were storing body fat or both factors were operating. Flatt *et al.* (54) reported that the cows given 40% concentrates drew upon 10.1 Mcal body tissue per day while those given 60% and 80% mobilized 7.0 Mcal and 3.5 Mcal of body fat respectively. Thus, when forage was restricted and the cows were forced to consume 60 to 80% of the dry matter as concentrates, they mobilized less body fat and secreted less milk. In effect, the cows on the high-concentrate rations had less energy available for milk secretion than did those fed 40% concentrate and 60% alfalfa hay ration because they did not draw upon their body stores to supplement the dietary energy. This might explain the depression in efficiency observed with increasing proportions of concentrate in the diet.

3. Influence on Varying Metabolites (Volatile fatty acids) On Efficiency

The volatile fatty acids (VFA) are important end-products of digestion and excellent source of energy in ruminants. Carroll and Hungate (26) in an *in vitro* study, estimated that a ruminant animal could receive from 61 to 71% of the available energy in its ration as volatile acids. The molar proportions of the volatile fatty acids present in the rumen are known to be influenced by the composition of the diet consumed (8, 9, 169). The acetic acid content was found to be closely related to the fat content of the milk of dairy cows in studies conducted by Tyznik *et al.* (175). In these studies, they showed that by adding acetic acid or sodium acetate to rations which normally produce low fat milk, that is one low in roughage or one where the roughage was finely ground, the per cent would be increased to normal. When sodium acetate feeding was discontinued the fat percentage dropped immediately. No response was obtained when sodium acetate was added to a normal long hay ration.

Restricted roughage-high concentrate rations were found to reduce significantly the milk fat in cows and goats by Van Soest and Allen (178). The decline in fat test was associated with a significant increase in propionate concentration in the rumen, and decrease in blood acetate levels. The experiments conducted by Elliot and Loosli (44) and Coppock *et al.* (34) showed that as the proportion of concentrate in the ration increased, the molar proportion of acetate to propionate (A:P) in the rumen and fat test declined. Since fat test of milk is related to its energy content (129), a depression in fat test resulting from a decrease in acetate: propionate ratio will result in a decrease in actual total milk energy produced and consequently a decrease in gross efficiency. Thus, Elliot and Loosli (44) and Coppock *et al.* (34) observed a depression in gross efficiency by feeding rations high in concentrate. The data of these workers suggest that maximum gross efficiency would occur when concentrate formed 40 - 60% of the ration resulting into ruminal acetate: propionate ratio of between 2.5 and 3.0. This is in general agreement with the studies summarized by Blaxter (14).

Although, workers like Hinders and Owen (85), Bell *et al.* (12), and Zeremski *et al.* (187) by feeding rations with varied hay: concentrate ratios based on ENE system did not observe differences in gross energetic efficiency of milk production, it is the opinion of most investigators that increasing the proportion of concentrate in the ration results in decreases in gross efficiency. It appears that the efficiency of conversion is influenced by whether increased energy intake is reflected in elevated milk production and whether the per cent milk fat is depressed.

D. Energy Balance Studies with Lactating Cows and the Utilization of Metabolizable Energy for Maintenance and Milk Production

The utilization of metabolizable energy (ME) by lactating dairy cows has been of much interest to nutritionists since the beginning of this century, but relatively few complete energy balance trials have been carried out to evaluate the utilization of dietary energy by dairy cows. Since Kellner's balance studies of 1911 [cited by Coppock (32)] involving three cows, a number of balance trials have been reported though not necessarily to evaluate the utilization of ME for lactation.

In 1964, Flatt *et al.* (51) and Flatt (48, 49) reported that from 1904 to 1961 only 110 complete energy balance trials involving 38 lactating dairy cows including all replicates were conducted while in 1965 the Japanese workers, Hashizume *et al.* (80) reported the 26 balance trials they carried out between 1961 and 1963. Since then, more balance trials have been conducted in U.S.A., the Netherlands and Japan.

The present-day balance trials involving the use of dairy cows are mainly designed to evaluate the utilization of ME for maintenance, lipogenesis and lactation. Coppock (32) has outlined the procedure for calculating the efficiency with which ME is converted to milk energy as shown in Table I.

The maintenance cost of 131 kcal ME/kg$^{.75}$/24 hrs. by Kleiber *et al.* (111) was used as maintenance requirement of lactating cows. The factors 1.61 and 1.43 of Van Es (45) were used to adjust the ME consumed for tissue gained or tissue lost respectively.

Table I: Procedure for Calculating the Efficiency of Conversion of ME to Milk using Data from Kleiber *et al.* (111) [Coppock (32)]

Cow No.	1007
Weight (kg)	463 (99.81 kg $^{.75}$)
Date	12/4-22/39
Total ME consumed	21,530 kcal
Heat Production	- 15,880 kcal
Energy Balance	= 5,650 kcal
Milk Energy	- 8,320 kcal
Energy derived from Tissue	- 2,670 kcal
X Factor for Energy Loss	X 1.43
Equals the ME available from Tissue	= 3.818 kcal
Plus the ME consumed	+ 21,530 kcal
Equals ME available for Milk plus maintenance	= 25,348 kcal
Minus the Maintenance Cost	- 13,100 kcal
Equals ME available for Milk	= 12,248 kcal
Energy in Milk 8,320 kcal	= 67.93%
Divided by ME available for Milk 12,248	
Equals the Efficiency of converting ME to Milk	= 67.93%.

1. <u>The Utilization of ME for Maintenance</u>

Among the early contributions to the energy requirements for maintenance of cattle determined in respiration experiments are those of Henneberg and Stohmann in 1860 which formed a part of the basis of Wolff's standard in 1874 [cited by Reid (153)] and Armsby in 1917 (4). Studies of live-weight maintenance were made by Armsby in 1898, Haecker in 1903 and Eckles in 1911 [cited by Reid (153)]. According to Armsby's calculations of 1917 (4), the average maintenance requirement of a 1000-pound cow was 5.9 Mcals per day for the respiration experiments he performed and 6.2 Mcals per day for the experiments based on the maintenance of live weight.

The present-day maintenance requirements for cows as listed by the National Research Council (NRC) in 1966 (143) and Morrison (140) have been assumed to be the same for both dry and lactating cows. Such an assumption has been accepted and used primarily because of the technical and theoretical difficulties involved in making direct determinations. Evidence are well documented to show that the requirements of energy of dry and lactating cows for maintenance are not the same. A dry cow uses the ME consumed for maintenance, tissue gains and pregnancy, whereas, a lactating cow has an additional requirement for producing milk. It is, therefore, logical to expect a lactating cow to have a higher maintenance requirement than a dry one.

Various workers have obtained different maintenance requirements for dry and lactating cows. Savage (159), Haecker (73), Gaines (66) and Morrison (140) allowed 7.92 lb TDN per 100 lb of live weight for a non-lactating cow. Assuming 1 lb TDN is equivalent to 1616 kcal ME, (62) this requirement for maintenance is equivalent to 130.1 kcal ME/kg$^{.75}$. Forbes and Kriss (62) obtained 5.55 and 5.97 lb TDN per 1000 lb live weight (91.1 and 98.0 kcal ME/kg$^{.75}$) for non-lactating and lactating cows respectively. Using multiple regression analysis, Brody (23) estimated the maintenance requirement of lactating cows to be 8.2 lb TDN/1000 lb body weight (134.6 kcal ME/kg$^{.75}$) as compared to 6.9 lb TDN/1000 lb body weight (110.8 kcal ME/kg$^{.75}$) for dry cows.

In the investigations by Thomas and Moore (173) the energy requirements for maintenance were determined in constant-weight, feeding-trial experiments on non-pregnant Jersey cows. Their result indicated that a 1000-pound non-pregnant Jersey cow required 13.0 lb dry matter alfalfa for maintenance. If the TDN value of alfalfa is 56.5% of the dry matter, this requirement is equivalent to 7.35 lb TDN (120.7 kcal ME/kg$^{.75}$). Garret, Meyer and Lofgreen (67) using the slaughter-energy balance technique determined the maintenance requirement of cattle. The range in the TDN requirements observed by these workers (67) and Thomas and Moore (173) was 6.8 to 7.35 lb per day. Kleiber *et al.* (111) had reported earlier that the ME requirement of cows is 131 kcal ME/kg$^{.75}$. The TDN equivalent of this value for a 1000-pound cow (7.98 lb) appears to be only slightly above the range determined by Thomas and Moore (173) and Garret *et al.* (67). Van Es (45) in 1961 observed 11,697 kcal for a 1000-pound cow (118.8 kcal ME/kg$^{.75}$). Hutton (99) partitioned organic matter intake into fractions associated with live-weight gain, milk production and maintenance. Three groups of cows were stall-fed pasture for four months. One dry group was fed to maintain body weight, a second dry group was full-fed and a third lactating group was full-fed. The result indicated that the maintenance requirement was almost twice as high for lactating cows as for dry cows, with the respective values being 236.5 and 126.5 kcal ME/kg$^{.75}$. Wallace (180) observed a value of 211.9 kcal ME/kg$^{.75}$ in lactating cows. This value was determined on grazing cows and thus included energy for activity.

In the Netherlands, the requirement for maintenance frequently adopted for an animal of 500 kg is 2.67 kg Starch Equivalent or 3.45 kg TDN, equivalent to 12,500 kcal ME (118.2 kcal ME/kg$^{.75}$). However, Van Es (45) in his 237 balance trials obtained an average requirement of 11,500 kcal ME (108.8 kcal ME/kg$^{.75}$). The difference of 1000 kcal between the value of 11,500 and the standard 12,500 kcal is due to the fact that a safety margin has been included in the latter to cover ration and between-animal variations. In Great Britain (1) the value for maintenance of a cow of similar weight is slightly higher being 2.90 kg SE or 13,578 kcal ME or 128.4 kcal ME/kg$^{.75}$.

From the results of their balance trials, Van Es and Nijkamp (47) found that the maintenance requirement apparently increases as the ration digestibility decreases or the per cent protein in the ration increases. They observed that for each unit increase in digestibility and for each unit decrease in the percentage of digestible crude protein in the dry matter of the ration, the requirement of energy for maintenance decreased by 100 kcal ME. This observation was a confirmation of the earlier findings of Blaxter (14) and Armstrong (5). In the balance trials by Van Es and Nijkamp (47) the maintenance requirement ranged from 8.97 to 13.66 Mcal ME/500 kg (average 11.56 Mcal) equivalent to 84.8 to 129.2 kcal ME/kg$^{.75}$ (average 109.3 kcal ME/kg$^{.75}$); while in another series of trials Van Es (45) found the requirement for maintenance to be 12.6 Mcal ME/500 kg (119.2 kcal ME/kg$^{.75}$). By feeding dry non-pregnant cows with early-cut alfalfa hay pellets, late-cut alfalfa hay pellets and late-cut grass hay pellets, Flatt *et al.* (50) showed that the maintenance requirements vary from 100 - 128 kcal ME/kg$^{.75}$/24 hrs. depending on the ration. The results of these various workers seem to indicate that the maintenance requirement of dry non-pregnant cows varies between 100 to 128 kcal ME/kg$^{.75}$/24 hrs.

Evidence are now available indicating that the maintenance requirements of pregnant cows are higher than those of non-pregnant dry cows. Van Es (45) found an increase of 10% (or 1200 kcal ME) in the last 2 months before calving and of 30% (or 3,600 kcal ME) in the last month of pregnancy. Similar increases were found by Graham (69) with pregnant and lactating ewes. Flatt *et al.* (52) in 1967 fed three rations with 60%, 40% and 20% of the dry matter supplied as alfalfa and the rest as concentrate and observed that the maintenance requirements of non-pregnant cows were affected by ration composition with maintenance requirement decreasing with increasing proportion of concentrate in the ration.
The values 11.28, 10.72 and 9.96 Mcal ME/500 kg (106.7, 101.4, and 94.2 kcal ME/kg$^{.75}$) were obtained with rations containing 60%, 40% and 20% alfalfa respectively. However, when the cows were pregnant the influence of advancing stages of lactation was greater than the differences due to

rations. During this stage the overall mean maintenance requirement was 12.36 Mcal ME/500 kg (116.9 kcal ME/kg$^{.75}$), a value quite close to NRC (143) standards of 12.5 Mcal ME/500 kg.

Recently Moe *et al.* (132) showed that there is a difference in the maintenance requirements of lactating cows according to whether the animal is in positive or negative tissue energy balance. By multiple regression analysis of dietary ME intake as the dependent variable and metabolic body size ($W_{kg}^{.75}$), milk energy, body tissue energy gain and body tissue energy loss as independent variables, these workers observed that the requirement of ME for maintenance was higher for lactating animals in negative tissue energy balance than for lactating animals in positive tissue energy balance with the respective values being 128 kcal and 118 kcal ME/kg$^{.75}$.

The maintenance requirement per kg metabolic weight ($W_{kg}^{.75}$) of young animals is generally thought to be higher than that of older animals. With veal calves given only a liquid milk replacer, Van Es and Nijkamp (47) found a requirement of 110 kcal ME/kg$^{.75}$, a value that is indeed high for a non-ruminating calf consuming a feed with energy digestibility as high as 97%. Blaxter (14) in trials with calves fed cow's milk found a value of 130 kcal ME/kg$^{.75}$. The difference between Blaxter's and Van Es and Nijkamp's figures may be explained by the fact that Blaxter's animals were younger and found a higher efficiency (80 - 85%) of utilization of ME for gain than was found by Van Es and Nijkamp (65 - 70%).

The various maintenance requirements observed by the various workers indicate that the maintenance requirement of dairy cattle is not a constant value but varies according to whether the animal is engaged in activity, dry and non-pregnant, pregnant, lactating with positive or negative tissue energy balance or growing. In his thesis, Van Es (45) indicated that the within-animal variation in the requirement of ME for maintenance was about 7% and the among-animal variation within breeds was about 8 - 10%. Since the maintenance requirement is not a constant value, differing efficiencies in the utilization of ME for milk production would be obtained depending upon the magnitude of the maintenance requirement employed in the calculation. For instance, in the procedure outlined by Coppock (32) and shown in Table I, the assumed maintenance requirement was 131 kcal ME/kg$^{.75}$ (111). If a lower maintenance requirement for a lactating cow such as 98 kcal ME/kg$^{.75}$ suggested by Forbes and Kriss (62) had been used in the calculation, the efficiency value would have been 53.5% instead of 67.93%. Thus the higher the maintenance requirement employed in the calculation, the higher would be the efficiency with which ME is converted to milk.

2. The Utilization of ME for Milk Production

As early as 1901, Jordan, Jenter and Fuller (103) showed that from 49 - 64% of the ME consumed above maintenance was converted to milk. By using a large number of lactation records Haecker (73) found a range of 50 - 66%. In 1924, Fries, Braman and Cochrane (64) reported energy balance studies with lactating cows in which the available ME was converted to milk with an efficiency of 68.5%. Two years later, Forbes *et al.* (61) found the average utilization of ME for milk production to be 72.2%, 70.4% and 74.7% for the three cows used in their investigation. Their result showed a greater efficiency of utilization of feed energy for milk production than for body increase and seemed to show a tendency toward a more efficient utilization of the available feed energy in the later stages of lactation when efficiency of ME for milk production rose up to 79.6%. They indicated that the average rates of utilization of energy of the ration for maintenance, lactation and body increase follow the ratio 1 (as standard): 0.985:0.761. Even though attempts have been made since 1901 (103) to evaluate the utilization of ME for lactation, Blaxter (14) cited Møllgaard as being the first to employ systematic approach in evaluating the use milking animals make of the energy in their food for lactation. Møllgaard's result [cited by Blaxter (14)] showed that the utilization of ME for fat deposition relative to lactation was 86%. In 1932, Forbes and Kriss (62) compared fattening and lactation and concluded that ME was used with an efficiency of 57.5% for fattening and 69.3% for milk production.

Blaxter (14) in his review of available data hypothesized that the efficiency of utilization of ME for lactation varies depending upon the relative proportions of volatile fatty acids in the rumen. The influence of ration composition on the proportions of volatile fatty acids in the rumen has been among others demonstrated by Balch and Rowland (9), Storry and Rook (169) and reviewed by Balch (8). When roughages were substituted for concentrates, acetic acid formed the greater proportion of the total volatile fatty acids in the rumen. By combining data from several sources Blaxter (14) proposed that the ME of food given in excess of maintenance needs would be maximally converted to milk (approximately 70%) when rations resulting in 50 to 60 molar per cent acetic acid in the rumen were fed, and would theoretically decline outside this range.

In 1962 Reid (153), by assuming Kleiber's value of 131 kcal ME/kg$^{.75}$ (111) for maintenance, recalculated the efficiency of utilization of ME for milk production and fattening from the data of Forbes *et al.* (1926), Fries *et al.* (1924), Kellner (1911), Kleiber *et al.* (1945) and Møllgaard *et al.* (1929) involving 59 complete energy balances and representing 27 lactating cows. From the result of his computations Reid (153) concluded that ME was used for milk production with an efficiency of 70.2 ±4.0% and with a coefficient of variation of 5.7% on mixed rations and that ME for fattening is on the average 83% of that for milk production (58.4 ±3.5%) with a coefficient of variation of 6%. Coppock *et al.* (33), by assuming maintenance requirement to be 131 kcal ME/kg$^{.75}$ (111) and using the procedure outlined in Table I, calculated the efficiencies of utilization of ME for milk production from the data of various workers. Tissue gain or loss was corrected to zero using Van Es's factors of 1.61 for gains and 1.43 for losses (45). The various values obtained are shown in Table II below.

Table II - Summary of Lactation Balance Trials of Different Workers for Efficiency of Conversion of ME to Milk [Coppock *et al.* (33)]

Reference	No. of Cows	Balance Experi- ments	Efficiency %	S.D.*
Kellner & Fingerling (1956)	10	36	68	±7.1
Fries *et al.* (1924)	3	6	81	±5.8
Forbes *et al.* (1926)	3	8	107	±20.1
Møllgaard & Lund (1929)	9	27	76.5	± 7.10
Ritzman & Benedict (1938)	4	8	63	±15.4
Kleiber *et al.* (1945)	4	14	79.1	±15.8
Van Es (1961)	2	4	81.4	± 7.8
Mean	35	103	75.5	±15.9

* S.D. = Standard Deviation

Using the same procedure for calculation, Coppock (32) reported differences in the utilization of ME for milk production depending upon the percentage of the total ENE supplied as concentrates. He obtained efficiencies for utilization of ME of 54.95%, 61.09% and 65.21% for rations containing 0, 25 and 50% ENE as concentrates respectively. Linear regression analysis of the same data using ME available for milk plus maintenance versus milk energy resulted in estimates of efficiencies of 57.5, 58.8 and 62.9% with maintenance requirements of 141.6, 127.7 and 124.6 kcal ME/kg$^{.75}$ for rations containing 0, 25 and 50% ENE as concentrates respectively. From the result of the regression analysis Coppock (32) suggested that a difference might have existed in the maintenance requirements of the cows when on the all forage ration as well as a difference in the efficiency with which ME was converted to milk.

In the studies of Hashizume *et al.* (80) complete energy balances were determined with milking cows fed three diets containing 31.6, 56.4 and 33.2% of concentrates and at levels up to 2.8, 2.6 and 3.4 times the maintenance level respectively. Their computations revealed that the mean rates of ME utilization for lactation were 71.3, 68.7, and 68.3% respectively, with coefficients of variation of 4.3, 5.8 and 6.9%. In these calculations, it was assumed that the maintenance requirement is 116.3 kcal ME/kg$^{.75}$ and that the net utilization of ME for body energy gain is 62%. The variations in the utilization of dietary ME for lactation observed by Reid (153) and those observed by the Japanese workers (80) seem to indicate that the amount of variation in the utilization of ME for milk production is quite small in cattle and that this variation is smaller than the variation in ME utilization for fattening. This observation was supported by the recent findings of Moe *et al.*(131). The small variation in the utilization of ME for lactation would suggest the great capacity of the ruminant to maintain homeostasis even when widely differing rations were being fed under varying conditions.

Flatt (48) studied the utilization of ME for milk production when 40, 60 and 80% of the ration was supplied by concentrates, with the remainder being supplied as alfalfa hay. An efficiency of approximately 65% was obtained regardless of the percentage of concentrates in the ration. However, relatively large corrections for tissue losses were required for many of the trials. The utilization of ME above maintenance remained linear up to levels of input equal to 5 times maintenance. In 1967, Flatt *et al.* (54) fed similar rations as were fed by Flatt (48) in 1964. By simple linear regressions of Energy Balance/ $kg^{.75}$ as dependent variable and ME intake/$kg^{.75}$ as independent variable or ME intake/$kg^{.75}$ as dependent variable and Energy Balance/$kg^{.75}$ as independent variable, the estimates of efficiency of utilization of ME from rations containing 40 to 80% concentrates for production of milk plus body tissue were 66 to 68% with a maintenance requirement of 140 - 145 kcal ME/$kg^{.75}$. The high apparent maintenance requirement observed by these workers was suggested to be due to such physiological functions as pregnancy, lactation and tissue mobilization. Recently, Moe *et al.* (132) by multiple regression analysis indicated that the efficiency of utilization of dietary ME for milk production is higher when the animal is in negative tissue energy balance than when in positive tissue energy balance. His estimates were 66.1 and 63.5% when the animal was in negative tissue energy balance and when in positive tissue energy balance respectively. The estimate of the partial efficiency of milk production from tissue energy was 84%. This observation would partly explain the higher efficiency generally observed in early stages of lactation when most cows are in negative tissue energy balance.

III

EXPERIMENTAL PROCEDURE

A. Animals

Six Ayrshire heifers ranging from 27 to 35 months of age and well advanced in gestation were selected from the University herd and used as experimental animals. Calving dates of these animals ranged from December 1969 to June 1970. Information about the animals is given in Table III.

Table III - Animal Information

Animal No.	Date of Birth	Freshening Date	Age at Freshening (months)
67007	Oct. 20, 1967	Feb. 20, 1970	28
67130	Apr. 7, 1967	Mar. 15, 1970	35
67133	June 14, 1967	Dec. 2, 1969	30
67138	Dec. 6, 1967	Apr. 16, 1970	28
68002	Feb. 21, 1968	June 11, 1970	28
68004	Mar. 23, 1968	June 11, 1970	27

Immediately after freshening the animals were kept indoors in separate box stalls in the conventional stanchion barn provided with individual mangers and watering cups and remained in these stalls throughout the entire experiment which constituted the lactation period of the animals. Wood shavings were used as bedding.

The animals were milked twice daily at 4:00 A.M. and 4:00 P.M. and milk weights were recorded at each milking to the nearest 0.05 kg. Body weights were taken at 10:00 A.M. every Saturday throughout the experiment. The data were summarized by ten 30-day periods beginning 2 days after calving; body weight for any 30-day period was generally an average of four or five weights and was used in the analyses of the changes in body weight during the experiment.

B. Feeds and Feeding

The feeds used for this experiment were good quality hay of alfalfa (*Medicago sativa*) mixed with brome grass (*Bromus spp*), dried beet pulp and a 16% Dairy Cattle concentrate.

Two days after freshening, the animals were placed in separate box stalls and individually fed with 5 kg hay and 4.55 kg dried beet pulp daily. That is, 1 kg of hay and approximately 1 kg of dried beet pulp per 100 kg of body weight, respectively. Concentrate was fed at the rate of 1 kg concentrate to 2.5 kg of milk produced. All feeds were offered 2 times per day with half of the feeds offered in the morning at 3:00 A.M. and the other half in the afternoon at 3:00 P.M. That is, all feeding was done before milking. Occasionally there were some refused feeds which were removed from the manger before the next feeding and weighed in order to know the actual amount of feed consumed. Daily feed consumption by each animal was recorded. The heifers had free access to water at all times while in the box stalls and trace mineralized salt was also available at all times in the manger. Data, on feed consumption were summarized by 30-day periods and the mean daily feed consumption for each period was calculated.

C. Sample Collection

1. Feed Sampling

Samples of approximately 500 g of hay fed were taken weekly from the core of the bales of hay meant for feeding for that week. Similarly, samples of approximately 500 g of dried beet pulp and concentrate were taken weekly. Each sample of feed was ground to pass the 1 mm sieve using the C & N Laboratory Mill Size 8".[1] At the end of each 30-day period, the four weekly samples of each feed were composited and thoroughly mixed with the Hobart Don Mills Mixer Model No. A200.[2] From the mixed composite sample, subsamples were taken and stored in screw-cap bottles ready for analysis.

2. Milk-Sampling

On Tuesday evening and Wednesday morning of each week throughout the lactation period, approximately 120 cc (4 oz.) of milk were taken

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[1]Manufactured by Christy & Norris Ltd., Chelmsford, England.

[2]Manufactured by The Hobart Don Mills Manufacturing Company Ltd., Ontario.

from the milk produced by each experimental animal, stored in 180 cc (6 oz.) plastic screw-cap vials and then sent to the British Columbia Government Milk Testing Laboratory for analysis with the Infra Red Milk Analyser (I.R.M.A.). Each sample was analysed for fat, protein and lactose. The mean composition of the Tuesday evening and Wednesday morning milks was taken as the composition of milk of each animal for that week. At the end of each 30-day period, the average of the four or five weekly milk composition was taken as the monthly milk composition. The average monthly fat per cent was used in the calculation of 4% fat-corrected milk (FCM) using Gaine's formula (65).

D. Digestibility Trials

The primary objective of this phase of the current study was to determine the digestibility of the various nutrients especially energy in the diet fed the experimental animals and thereby to provide information which can be used to estimate the digestible energy consumed by the animals throughout their entire lactation period. From the knowledge of this the efficiency of milk production would be determined.

Because of its accuracy and simplicity chromic oxide has generally been accepted as one of the most reliable external indicators used to measure digestibility of ruminant rations. The major shortcomings of this indicator are its diurnal variation reported to occur in its excretion rate (105, 108) and the incomplete recovery of the indicator in the feces resulting in highly variable results, lower digestion coefficients or both. It is, therefore, the secondary objective of this phase of the present study to compare the digestibility of nutrients obtained using the chromic oxide technique with the conventional total collection method and to study the fecal excretion pattern of the indicator.

1. Experimental Procedure

Digestibility trials were conducted two times using two of the experimental animals, one of them in her late stage of lactation and the other in her mid stage of lactation.

The first digestion trial involved the use of the conventional total collection method. In this method, the animals were placed in specially constructed metabolism crates and held in place with the stanchion. Rubber mats were used instead of wood shavings for bedding to prevent additional roughage consumption. Plastic webbing (supplied by Fisher Scientific Company) was cemented to the pelvic area of the animals with the 3M Bull cement EC 1578.[3] One end of a gooch tubing 9 cm in diameter and 2.3 meters long was shaped in such a way as to fit directly and tightly the vulva of the animal so that there is no leakage when the animal urinates. It was secured by tieing it to the cemented plastic webbing. This set-up is illustrated in plates I and II.
A preliminary period of seven days was allowed for the animals to adjust to the metabolism crates during which it was observed that the animals consumed their feeds normally and milked normally. During the digestion

[3] 3M Minnesota Mining and Manufacturing of Canada Ltd., London, Canada.

trial, the daily feed allowance for each animal which had been determined at the start of the trial was held constant for the 7-day preliminary period and the subsequent total collection period. Water and mineral licks were available to the animals at all times.

2. Feed Sampling

At the beginning of the preliminary period, the quantities of feeds - hay, dried beet pulp and concentrate - that would be sufficient for feeding the animals during the preliminary and collection periods were kept separate from the herd's total feed supply. From the quantity of dried beet pulp and concentrate offered, samples were taken daily and composited during the preliminary and collection periods. Core samples of hay were obtained from at least one half of the bales used during the preliminary and collection periods. At the end of the trial, the composite feed samples were finely ground and prepared for analysis as previously described. The animals were milked twice daily as usual and milk production recorded for each day.

Plate I

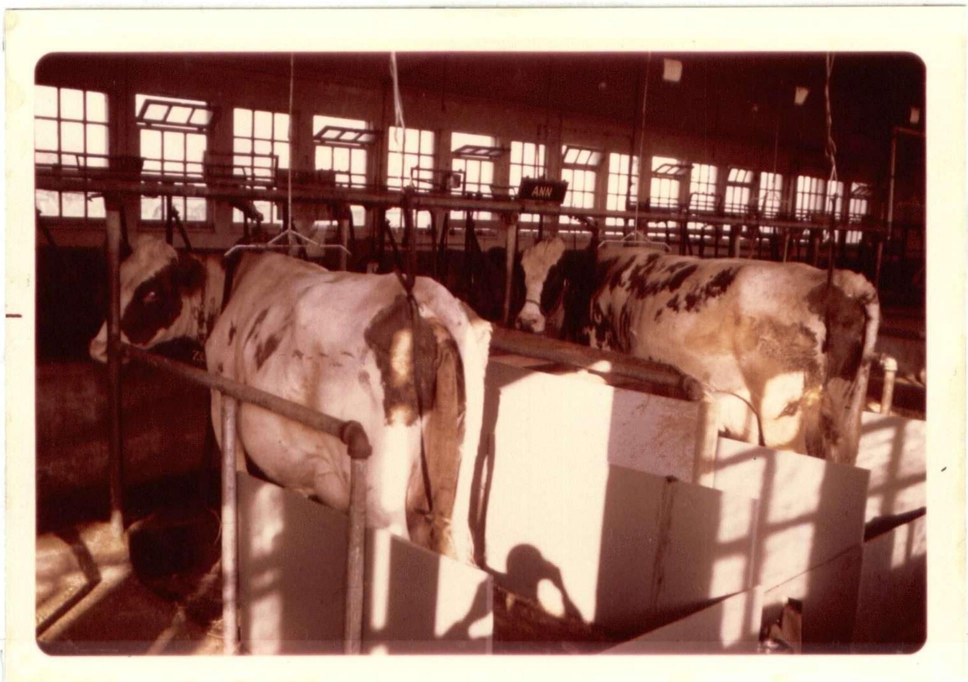

Plate II

Plates I & II: Heifers in their metabolism crates during the digestibility trials

3. Fecal Collection

Staples *et al.* (167), King *et al.* (109) and Clanton (27) have showed that there is little or no advantage in extending collection periods beyond seven days; therefore, in the present study, total collection was made during the last seven days of the trial. Faeces was collected in a specially constructed wooden box painted with rubberized paint. The box was placed at the basement directly behind the animal and was lined with previously weighed polyethylene sheets to make fecal collection easy without going into the trouble of scraping feces adhering to the box which would have been the case if the feces had come into direct contact with the box. Electrical stall trainers were used to make the animal stand back and defecate directly into the collection box. Total collection of feces was done each morning at 9:00 A.M. The total feces voided per day was thoroughly mixed within the collection box and then weighed to the nearest 0.05 kg along with the polyethylene sheet. The weight obtained minus the weight of the polyethylene sheet gave the weight of feces voided for that day. From the thoroughly mixed wet feces, grab samples of about 500 g were taken and kept in water proof plastic bags.

From the grab samples, representative samples of about 60 g were weighed into glass petri dishes and dried at 80° C in a forced draft oven for 48 hours. The rest of the grab samples were kept in the freezer at -10°C. At the end of 48 hours the petri dishes plus samples were cooled in a desiccator and then weighed and from this the partially dry matter of the feces determined. The partially dried fecal samples were kept in plastic bags until the end of the trial when they were ground to pass the 1 mm mesh using the C & N Laboratory Mill Size 8", composited and stored in screw-cap brown bottles until analysed.

4. Urine Collection

The urine from each animal was channelled through the gooch tubing and collected in a 16-liter small mouthed stainless steel milk pail to which it was connected. The urine pail was emptied twice daily.

The second digestion trial was run two weeks after the completion of the first trial. In this trial, both the conventional total collection method and the indicator method were simultaneously employed using the same animals as were used in the first trial. Chromic oxide (Cr_2O_3) was the indicator employed. Earlier report by Smith *et al.* (162) had indicated no difference in accuracy of the estimated output of faeces when Cr_2O_3 was administered either in capsules or mixed with concentrate feeds; therefore, in this study the Cr_2O_3 was administered in capsules.

Twenty grams of Cr_2O_3 were prepared in capsules and administered orally by means of the balling gun twice daily throughout the experiment. A capsule containing 20 g Cr_2O_3 was administered just shortly before feeding at 3:00 A.M. and another at 3:00 P.M. so that each animal received 40 g Cr_2O_3 per day. In 1959, Hardison *et al.* (76) reported a stable excretion rate of Cr_2O_3 within 4 days after the initial dose in Holstein heifers and lactating Holstein cows, while in 1969 Hoogendoorn *et al.* (88) reported maximum percentage recovery and steady state of Cr_2O_3 excretion within three days after initial dose. Therefore, in this experiment, four days were allowed as preliminary period followed by a five-day collection period for digestibility determination. Cr_2O_3 was given each day of the preliminary and collection periods, with the exception of the last day of the collection period.

In order to obtain the excretion pattern of Cr_2O_3 throughout the entire experimental period, fecal sample collection started 24 hours after the first dose and continued until the end of the experiment. On the 4th day of the collection period the intraday excretion of Cr_2O_3 was determined over a 24-hour period. Samples of about 250-400 g were taken at 3:00 A.M., 9:00 A.M., 1:00 P.M., 5:00 P.M., and 9:00 P.M. Sampling of feeds, collection, sampling and preservation of feces and urine were as described for the first trial. Partially dry matter determination was as described for the first trial.

E. Energy Balance Studies

Energy balance studies were carried out for each 30-day period throughout the lactation. These studies were based on estimations of digestible energy intake, methane energy, urine energy, heat production, milk energy and metabolizable energy intake using appropriate regression equations.

F. Observations

The chief difficulties encountered during the experimental period were (a) inability of the heifers to consume all of the feed offered in early lactation and (b) occasional digestive disturbances resulting into bloat and reduced feed intake. However, this did not always result in depression in milk production.

G. Analytical Methods

1. Dry Matter Determination

Dry matter determinations were made on the feeds and pre-dried feces by drying to a constant weight in an oven. A known weight of each sample was placed in aluminium dishes and dried in the oven at 105°C for approximately 24 hours after which the dishes were cooled in a desiccator and reweighed. The weight of the dry sample expressed as a percentage of the initial sample weight gave the percentage dry matter of the sample.

2. Gross Energy Determination

Gross energy determinations were made on feeds and feces using the Gallenkamp adiabatic bomb calorimeter[1] and expressed as kcal/g of dry matter.

3. Nitrogen Determination

Nitrogen determinations were made on feeds and feces using the A.O.A.C. macro-Kjeldahl method (3). Nitrogen content in the feeds and feces was converted to crude protein by multiplying by 6.25 and expressing it as a percentage of the initial sample on a dry matter basis.

4. Acid Detergent Fibre Determination

Acid detergent fibre (ADF) was determined on feeds and feces according to the method of Van Soest (177). Crude Fibre was estimated from ADF using the following regression equations developed by Van Soest

[1]Gallenkamp Adiabatic Bomb Calorimeter Manufactured by A. Gallenkamp & Co. Ltd., Christopher Street, London E.C. 2.

in 1964 [cited by Flatt *et al.* (51)]

(i) For forage and feces

% Crude Fibre = 3.56 + 0.750 ADF;

(ii) For concentrates,

% Crude Fibre = 0.03 + 0.658 ADF.

5. Ash Determination

Ash was determined on the feeds and feces by heating a known weight of the sample in a muffle furnace at 600°C for 4 hours [A.O.A.C. (3)]. The ash content was calculated as the residue remaining after this treatment, and expressed as a percentage of the sample dry matter.

6. Ether Extract Determination

Ether Extract was determined on feeds and feces according to A.O.A.C. (3). A known dry weight of the sample was put in a thimble and extracted with ether in a Soxhlet extraction unit for 16 hours after which the extract was dried, cooled in a desiccator and weighed. The ether extract content was expressed as a percentage of the sample dry matter.

All determinations of dry matter, gross energy, nitrogen, acid detergent fibre, ash and ether extract were made in triplicate and the mean calculated.

7. Chromic Oxide Determination

Chromic Oxide in the feces was determined by the colorimetric method described by Schürch *et al.* (160). A standard curve from which Cr_2O_3 concentrations in the feces were read was prepared as described by Schürch *et al.* (160) using known quantities of Cr_2O_3 in control fecal material. The Cr_2O_3 concentration was plotted against 1000 times the reciprocal of the observed per cent transmittance. The resulting curve is shown in Appendix Figure 1.

H. Calculations

1. Apparent Digestibility

(a) Conventional Method of Digestibility Determination: The apparent digestion of dry matter, energy, protein, crude fibre, ether extract and nitrogen free extract (NFE) was calculated as the difference between nutrient intake and feces excretion, expressed as a per cent of nutrient intake. Since no corrections were made for fecal components of endogenous origin, it was assumed that the feces represented residues of dietary origin only, and thus the term apparent digestibility would describe all such coefficients calculated in this experiment. The following formula was used to calculate digestibility:

$$\text{Coefficient of Digestibility (\%)} = \frac{[(W_o \times A_o) - (W_1 \times A_1)] \times 100}{(W_o \times A_o)} \quad \text{where}$$

W_o = Kilograms of feed consumed

A_o = Per cent nutrient content of feed

W_1 = Kilograms of feces excreted

A_1 = Per cent nutrient content of feces.

All data were expressed on dry matter basis.

(b) Chromic Oxide Method of Digestibility Determination:

The coefficient of digestibility of the feed nutrients was calculated by the formula:

$$\text{Coefficient of Digestibility (\%)} = 100 - \left(100 \frac{\text{\% indicator in feed}}{\text{\% indicator in feces}} \times \frac{\text{\% nutrient in feces}}{\text{\% nutrient in feed}}\right)$$

[Maynard and Loosli (124)].

2. Estimation of Digestible Energy Intake

The average daily digestible energy intake for each heifer by months of lactation was estimated by multiplying the average daily gross energy intake for each heifer by the per cent digestible energy.

3. Estimation of Methane Energy Production

Daily methane energy production by the animals was estimated using the following equation of Axelsson (1949) as modified by Blaxter and Clapperton (16):

CH_4 (kcal/100 kcal feed) = 14.3 - (49400/x) - 0.0001291x

where x is the number of kcal feed ingested.

4. Estimation of Urine Energy Excreted

Daily urine energy excreted by the animals was estimated using the following regression equation by Blaxter *et al.* (17):

U = 0.25P + 1.6 where

U = Urine energy (kcal/100 kcal of feed).

P = Per cent crude protein content of the diet.

5. Estimation of Heat Production

Daily heat production by the animals was estimated using the following regression equation by Flatt *et al.* (54).

Heat Production (HP) = $0.299\ DE_i + 11.52$ where

HP is in megacalories/24 hrs.

DE_i is digestible energy intake in megacalories/24 hrs.

6. Estimation of Metabolizable Energy Intake

Daily metabolizable energy (ME) intake was estimated as Digestible Energy-methane energy-urine energy. All values are expressed as megacalories/24 hrs.

7. Estimation of Total Energy Balance

Total energy balance was estimated as the difference between metabolizable energy and heat production.

EB = ME - HP where

EB = Total energy balance (Mcal/24 hrs.)

ME = Metabolizable energy (Mcal/24 hrs.)

HP = Heat Production (Mcal/24 hrs.)

8. Estimation of Milk Energy

Daily milk energy (Mcal/24 hours) produced was calculated from the average daily milk produced and its fat content using the following regression equation by Moe and Flatt (129):

Milk Energy (Mcal/kg) = 0.353 + 0.096% milk fat.

9. Estimation of Tissue Balance (Mcal)

Energy as tissue balance was estimated as the difference between total energy balance and milk energy.

10. Estimation of Estimated Net Energy (ENE)

ENE was calculated using the following equation by Moore *et al.* (138) as modified by Moe and Flatt (129):

ENE (Mcal/kg DM) = 0.0307 %TDN - 0.764

11. Statistical Analysis

Data were subjected to Analysis of Variance according to Snedecor and Cochran (165) and the means of the sources of variation found significant were tested by Duncan's new multiple range test (40).

The Null Hypothesis was used to test all correlation coefficients.

$H: \rho = 0.$

IV

RESULTS AND DISCUSSIONS

A. Feed Composition

The average nutrient composition of feeds used during the entire experiment is shown in Table IV. Details of dry matter, crude protein and gross energy contents of the feeds used during the entire period are shown in Appendix Table I. The per cent crude protein and crude fibre indicate that the hay fed the experimental animals was, in general, above average in quality.

B. Digestion Trials

1. Conventional and Chromic Oxide Methods of Digestibility Determination

The digestibility coefficients for the various nutrients as determined by the conventional and indicator methods in the first and second trials are shown in Table VA. The results of the digestibility trials indicate that digestion coefficients obtained by the conventional method in the two trials were essentially the same regardless of the length of time of fecal collection, whereas those obtained by the Cr_2O_3 method were consistently lower. The decrease in digestibility coefficients were 3.0 (4.3%) less for dry matter, 2.3 (3.4%) for gross energy, 1.8 (2.8%)

for crude protein, 5.2 (11.0%) for crude fibre, 0.5 (0.88%) for ether extract and 1.6 (0.74%) for NFE. This consistently lower digestibility coefficients obtained with the Cr_2O_3 method confirms the earlier observations by McGuire *et al.* (121) in 1966 and those of Phar *et al.* (145). Hoogendoorn *et al.* (81) in 1970.

The lower digestion coefficients resulting from Cr_2O_3 method reflected the failure to obtain 100% recovery of the indicator. The recovery of Cr_2O_3 in the feces was calculated as "absolute" recovery defined by Curran, Leaver and Weston (37) as the weight of marker recovered in total fecal collections expressed as a percentage of the weight of marker given. When calculated in this way the recoveries of Cr_2O_3 in the feces of the two animals used for this trial were 89.0% and 87.2% with an average of 88.1%. Obračevič *et al.* (144) by administering 40 g of Cr_2O_3 in two rations per day observed recoveries ranging from 73.1 to 99.43% with an average of 88.1%. Whereas workers like Kane *et al.* (107), Putnam *et al.* (148) and Corbett *et al.* (35) have reported near 100% recovery of ingested Cr_2O_3, Hardison *et al.* (76), Clanton (27), Lassiter *et al.* (114), McGuire *et al.* (121), Phar *et al.* (145), Hattan *et al.* (81) and Wilkinson *et al.* (184) reported incomplete recoveries varying from 78 to 97%.

The usual assumption in the use of indicator (Cr_2O_3) method for determining digestibility is that the recovery of the indicator is 100%. Experiences and observations from this work and from literature have indicated that 100% recovery of Cr_2O_3 is uncertain, consequently lower than conventional method digestibility coefficients often obtained with indicator methods would not be totally unexpected.

Table IV - Average Nutrient Composition of Feeds (D.M. Basis)

Feed		Dry Matter	Crude Protein	ADF[a]	Crude Fibre[b]	Ash	Ether Extract	Gross Energy kcal/g
		%						
Hay		89.42	16.33	35.50	30.19	8.5	1.77	4.374
	S.D.	±1.84	±2.85	±3.67	±2.75	±0.83	±0.29	±0.083
Beet Pulp		90.51	10.55	20.13	13.27	7.0	0.53	4.094
	S.D.	±1.31	±1.00	±1.12	±0.74	±0.50	±0.06	±0.056
Concentrate		87.17	16.95	9.61	6.35	7.1	3.63	4.393
	S.D.	±1.23	±1.15	±0.70	±0.46	±0.60	±0.50	±0.041

[a] ADF = Acid Detergent Fibre

[b] Crude Fibre was calculated from ligno—cellulose (ADF) content using the equations developed by Van Soest [cited by Flatt *et al.* (51)]

S.D. = Standard Deviation

Table VA - Coefficients of Apparent Digestibility Determined by Total Collection and Chromic Oxide Methods (%)

Nutrient	Trial I Conventional Method	Trial II[a] Conventional Method	Trial II[a] Chromic Oxide
Dry Matter	70.0	69.3	66.3
Gross Energy	68.1	68.3	66.0
Crude Protein	63.9	63.2	61.4
Crude Fibre	45.4	47.2	42.0
Ether Extract	59.5	56.8	56.3
Nitrogen Free Extract (NFE)	82.3	81.0	79.4

[a] Both conventional and chromic oxide methods were used on fecal samples obtained by total collection.

Lucas (119) has proposed an equation which can be used to obtain estimates of accurate digestibility when Cr_2O_3 recovery is not 100% and which would be equal to those obtained by conventional method thus:

$$d = 100 - \frac{r(100 - d^*)}{r^*} \quad \text{where}$$

d = % apparent digestibility of the nutrient determined by the conventional method.

d* = % apparent digestibility of the nutrient determined by the indicator method.

r = True recovery of indicator in %.

r* = Assumed recovery of indicator in %. Usually r* = 100%.

When this equation was used to estimate the true digestibility the various values obtained are shown in Table VB.

The various digestion coefficients obtained when Lucas' Formula was applied were only slightly higher than those actually determined by the conventional method. This indicates that Cr_2O_3 can give reasonably accurate estimates of digestibility of diets but can hardly be as accurate as the conventional method. Thus, in estimations of digestible energy done in this study the average of the gross energy digestion coefficients obtained by the conventional method for the two trials has been used.

2. Pattern of Chromic Oxide Excretion

(a) Daily Excretion of Chromic Oxide

The daily excretion of chromic oxide is presented in Figure 2. Contrary to the observation of many workers (76, 88) the gradual increase in fecal Cr_2O_3 concentration within the first few days after the administration of the initial dose and before a plateau is reached when Cr_2O_3

Table VB - Coefficients of Apparent Digestibility as Determined with the Conventional Method and Estimated with Lucas' Equation (119)

	Digestibility (%)		
Nutrient	Conventional Method	Estimated	Per Cent Increase
Dry Matter	69.3	70.3	1.4
Gross Energy	68.3	70.0	2.5
Crude Protein	63.2	66.0	4.4
Crude Fibre	47.2	48.9	3.6
Ether Extract	56.8	61.5	8.3
Nitrogen Free Extract (NFE)	81.0	81.9	1.1

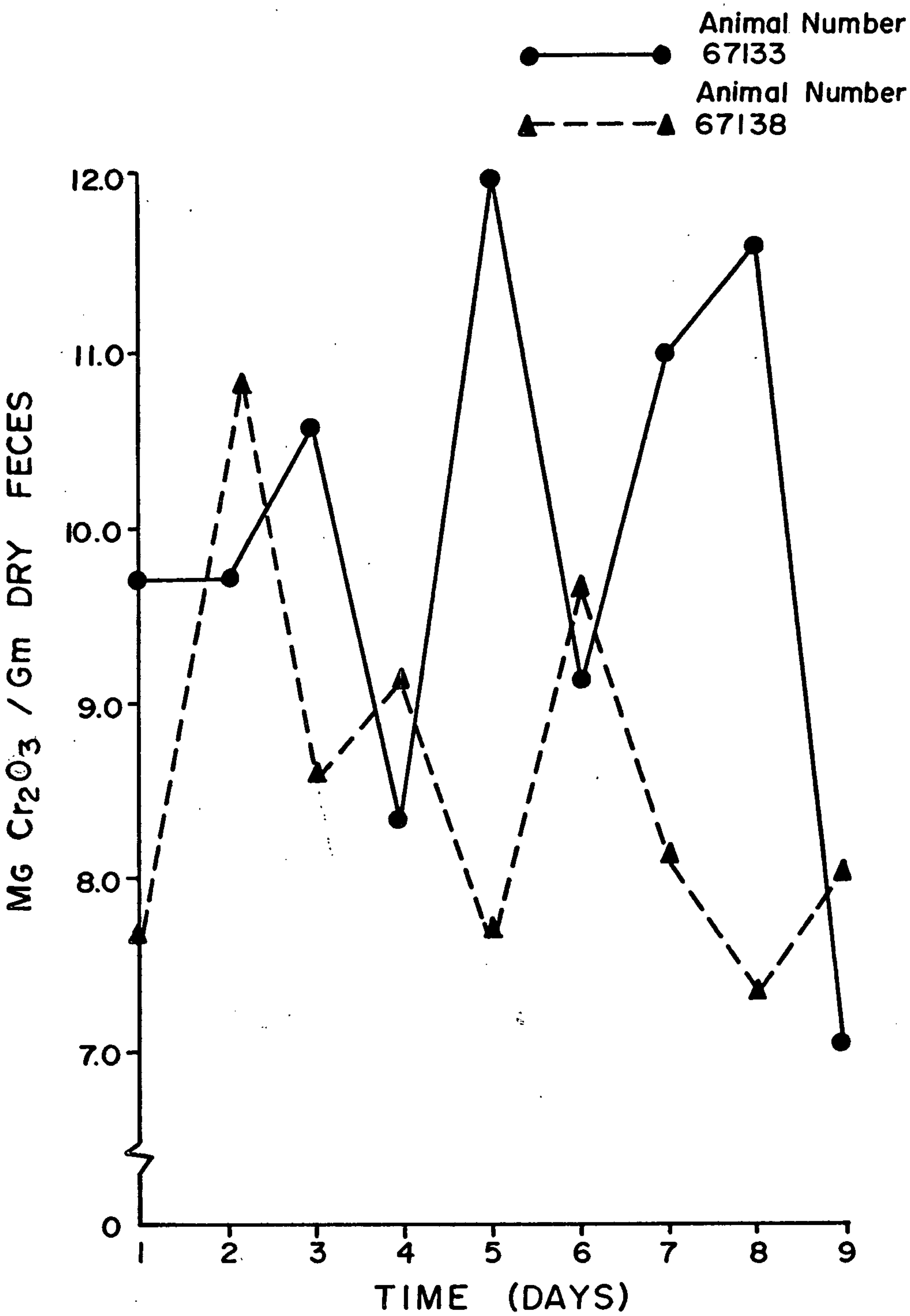

Figure 2. Daily Excretion of Chromic Oxide

excretion is relatively constant was not observed in this trial. This observation is in agreement with those of Elam *et al.* (42).

An analysis of variance of the concentration of chromic oxide in the feces revealed significant ($P < .01$) differences between animals and between days in the excretion of Cr_2O_3. The day to day variation is in agreement with those observed by Wilkinson *et al.* (184) using steers fed low barley diet and Kameoka *et al.* (105). The day to day coefficient of variation was 16% for animal No. 67133 and 13.2% for animal No. 67138. This coefficient of variation was higher than 9.9% and 6.2% reported by Wilkinson *et al.* (184) and 3% in a 7-day grab sampling period calculated by Corbett *et al.* (35). In animal No. 67133 the highest peak was observed on the 5th day while the lowest occurred on the 9th day. In animal No. 67138 the highest peak appeared on the second day and the lowest on the 8th day.

The day to day variation of concentration of Cr_2O_3 excretion had been reported to be a normal occurrence (105). In this trial, even though the feces were collected at the same time each day with the exception of the day when the intraday variation was measured, their amounts varied every day; the amount of this variation reaching up to 7.43% for animal No. 67133 and 10.5% for animal No. 67138. It is thus possible that a high level of Cr_2O_3 excretion might be associated with a large amount of feces voided while a low level might correspondingly be associated with small amount of feces. As Kameoka *et al.* (105) have suggested, it is possible that the Cr_2O_3 might accumulate in some parts of the digestive tract such as the omasum or abomasum, by unknown laws, and the accumulated Cr_2O_3 might be excreted on a certain day thereby resulting in high levels of Cr_2O_3 in the feces voided that day or that particular hour of the day.

The significant ($P < .01$) difference between animals in their Cr_2O_3 excretion observed in this trial lends support to the finding of Kameoka *et al.* (105) in their work with goats. This animal variation would suggest that the movement of Cr_2O_3 through the digestive tract was not at the same rate for all animals, and since these animals were consuming the same feed during the trial, the type of ration would not have caused such a variation. Variation could, therefore, be due to differences in individual physiology of the animal. Bloom *et al.* (20) have suggested that although digestion in ruminants is a continuous process, the absorption of nutrients may proceed at varying rates. Such differential rates in absorption of the gut contents could be reflected in varying quantities of Cr_2O_3 being excreted over a daily period in relation to the remaining residue in the tract. Thus, during days of high absorptive activity, the amount of Cr_2O_3 would increase in relation to the smaller amount of ingesta remaining in the tract; the reverse being the case during days of low absorptive activity. This suggestion might explain the differences observed in the animals used in this trial.

(b) Intraday Excretion of Chromic Oxide

The diurnal excretion pattern of Cr_2O_3 from the feces of the experimental animals taken at intervals during the fourth day of the total collection period is shown in Figure 3. The result obtained in this trial is in agreement with the observations of various workers

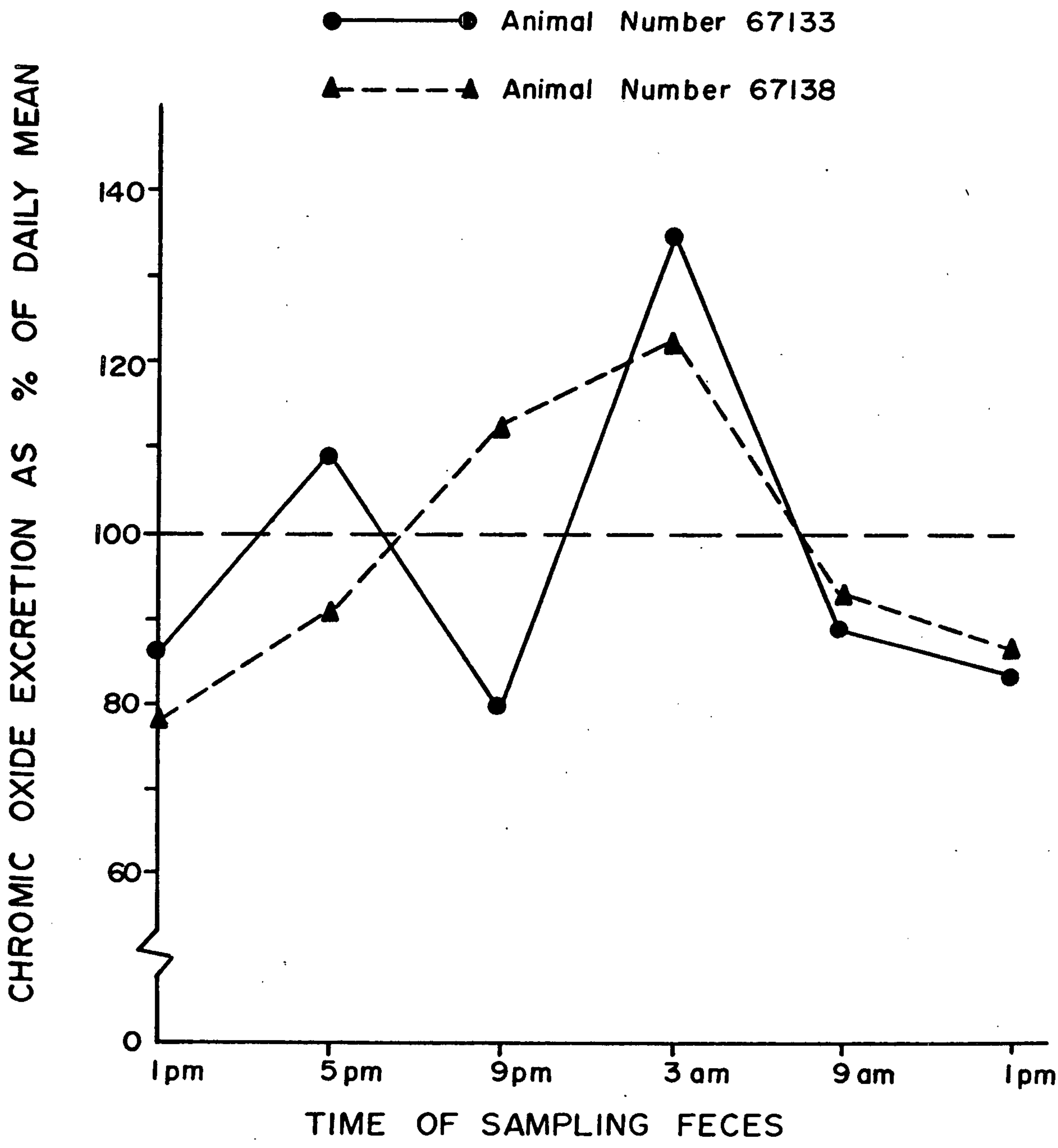

Figure 3. Chromic Oxide Excretion Curves over a 24-Hour Period

(162, 42, 38, 121, 120, 88, 145, 184) who, by using different experimental designs, reported diurnal variations in the excretion of Cr_2O_3. When Cr_2O_3 was administered twice daily to ruminants, two peaks might be expected to appear in the diurnal variation of Cr_2O_3 excretion. In this trial there was only one high peak for the day inspite of twice a day feeding at 12 hours interval. This is in agreement with those of Kane *et al.* (108), Hardison *et al.* (77), Smith and Reid (162) and Elam *et al.* (42). In work with goats Kameoka *et al.* (105) also observed one distinct peak in Cr_2O_3 excretion when the marker was fed at 9:00 A.M. and 4:00 P.M., whereas two distinct peaks were noted when feeding was always at excactly 12 hours interval. This is in contrast to the present observation.

The range in the rate of recovery of Cr_2O_3 was 79.9 to 135.2% with a mean of 97.0% and 78.1 to 123.4% with a mean of 97.6% for animal Nos. 67133 and 67138 respectively, while the range of recovery for both animals was 82.2 to 124.3% with a mean of 97.0% and a standard deviation of ±18.5%. These ranges are comparable to those reported by Davis *et al.* (38).

An analysis of variance of the concentration of chromic oxide in the feces sampled at different times of the day did not show any significant difference due to time of sampling. However, there was a significant ($P < .01$) difference between animals. A non-significant difference between time of sampling had been reported by McGuire *et al.* (121) and Phar *et al.* (145). This indicated that the Cr_2O_3 had been fed in a uniform manner, that it had been thoroughly distributed in the ingesta and that it had been excreted uniformly from time to time at least for the day when the measurements were taken. The animal variation is in agreement with reports by Linkous *et al.* (115), Hardison *et al.* (75), Clanton (28), McGuire *et al.* (121) and Phar *et al.* (145).

C. Feed Consumption

The average daily dry matter and energy consumed at different stages of lactation are shown in Table VI. The consumption of dry matter and energy by individual heifers is shown in Appendix Tables II to VII.

Although gross energy digestibility was determined with only two of the heifers, the result was used to estimate digestible energy (DE) intake of the other heifers for all stages of lactation. Workers like Andersen *et al.* (2), Moe *et al.* (130), Reid (152) and Wagner and Loosli (179) have reported decreases in digestibility when consumed feed quantity increased up to four or five times maintenance at which concentrates formed about 75% of the ration. However, with 40% concentrates in the ration and a level of feed intake of three times maintenance, Wagner and Loosli (179) found very little or no decrease in digestibility. The work of Brown *et al.* (25) showed an unchanged digestibility at high levels of feed consumption while the recent work by Wiktorsson (183) involving the use of hay, beet pulp and concentrate in a long-term input/output relationship experiment with dairy cows showed no decreases in digestibility when the feeds were consumed at high levels. Wiktorsson (183) concluded that there is no reason to assume a lower digestibility

Table VI - Average Daily Dry Matter and Energy Consumed at Different Stages of Lactation

Month of Lactation	Dry Matter (kg)	TDN (kg)	Gross Energy (Mcal)	DE (Mcal)	ME (Mcal)	ENE (Mcal)
1	11.20	7.42	47.85	32.63	26.80	14.22
2	13.34	8.83	56.97	38.86	32.54	16.93
3	13.83	9.15	59.01	40.24	33.83	17.50
4	13.32	8.82	56.90	38.81	32.37	16.90
5	13.62	9.03	58.27	39.74	33.25	17.33
6	12.98	8.62	55.62	37.93	31.56	16.53
7	12.62	8.34	53.83	36.71	30.43	15.97
8	12.47	8.25	53.22	36.29	30.03	15.79
9	12.32	8.16	52.65	35.91	29.68	15.63
10	12.35	8.18	52.76	35.98	29.73	15.67
Mean	12.81	8.48	54.71	37.31	31.02	16.25
S.D.	±0.78	±0.52	±3.33	±2.28	±2.11	±1.0

TDN is Total Digestible Nutrients
DE is Digestible Energy
ME is Metabolizable Energy
ENE is Estimated Net Energy
S.D. is Standard Deviation

at high feed consumption as long as the animals are adapted to a normal feeding ration with long hay and crushed concentrate. On the basis of these evidence and the fact that the heifers used in this experiment were on their feed throughout the experimental period (lactation period), and at no stage did they consume more than 2.5 times maintenance, it was considered appropriate to apply the gross energy digestibility obtained with two of the heifers in estimating the DE intake from the gross energy intake by the other heifers for all stages of lactation.

Table VI showed that dry matter and the various categories of energy intake were lowest at the first month of lactation, increased to the maximum at the 3rd month and thereafter declined steadily throughout lactation. The lactation average daily dry matter consumption was 12.81 kg. This is equivalent to 2.61 kg/100 kg body weight. The pattern of dry matter consumption observed in this study is in agreement with that observed by Swanson *et al.* (170). Since most of the heifers were not able to consume all of the feed offered at the first month of lactation, consumption at this stage of lactation could be considered *ad libitum* rather than controlled.

The changes in dry matter and hence energy consumption during lactation more or less paralleled changes in milk yield as shown in Figure 4. That is,milk production increased as dry matter intake increased and declined as dry matter intake declined. Since hay and beet pulp consumption were kept relatively constant, changes in dry matter consumption were primarily caused by changes in concentrates which were fed according to the milk produced. As lactation progressed, and lesser concentrate rations were fed, the dry matter intake declined.

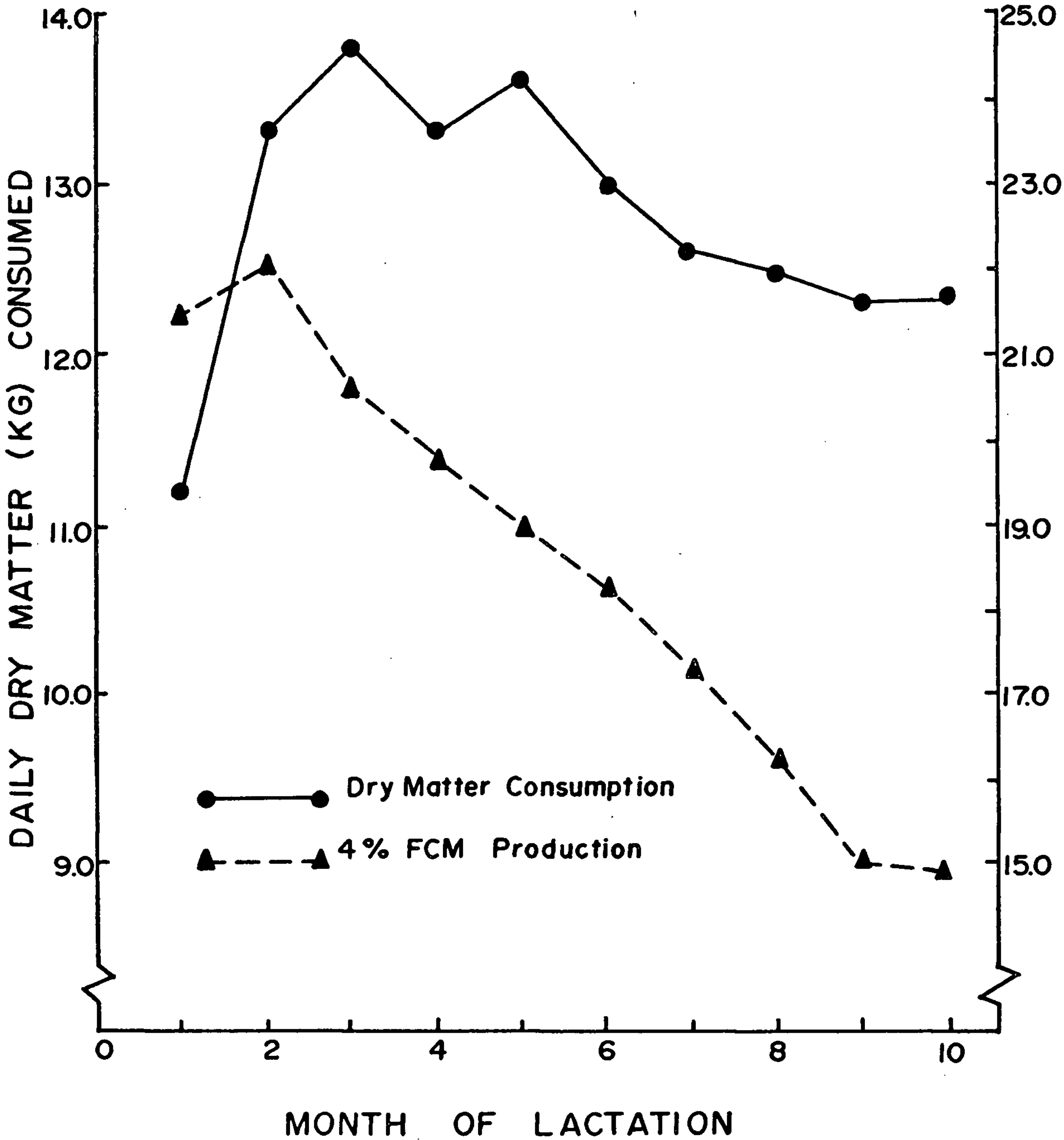

Figure 4. Daily Dry Matter Consumption in Relation to daily 4 % FCM Production during Lactation

D. Body Weight and 4% Fat-Corrected Milk Production

The average monthly body weights and 4% fat-corrected milk (FCM) production with their deviations from the mean are summarized in Table VII and shown graphically in Figure 5. The lactation 4% FCM production is shown in Table VIII. Details of monthly body weight and 4% FCM production are contained in Appendix Tables VIII and IX respectively. The average total change in weight for these heifers was 45.9 kg (-13.9 to + 32.0 kg). Figure 5 illustrates that there was a decrease in weight from the first to the second month of lactation and thereafter there was a steady increase throughout lactation. This pattern of weight change is in agreement with the observations of Swanson *et al.* (170). However, Miller *et al.* (126) did not observe this initial decrease in weight in their first-parity cows. The decrease in weight in the first to second month of lactation was probably due to fat mobilization to meet the high energy requirements for lactation at this early stage of lactation. Flatt *et al.* (51, 53) have showed that good cows are unable to consume enough feed for the first few weeks of lactation to prevent loss of body energy when energy intake is inadequate to meet the animal's requirements for lactation. The cessation of weight loss at the end of the second month of lactation and the continuous increase in body weight thereafter could be due to lower level of milk yield generally observed in heifers and continuous growth. In viewing this result tissue and fluid associated with foetus have been included in the weights for four of the heifers were pregnant during the experiment. These could form a substantial proportion of the total gain in weight as indicated by Mosely *et al.* (141).

Table VII - Summary of Body Weight and 4% Fat-Corrected Milk Production During Lactation

Month of Lactation	Body Weight (kg) Monthly Average	Body Weight (kg) Deviation from Mean	4% FCM (kg) Monthly Average	4% FCM (kg) Deviation from Mean
At Calving	491.7	0.0		
1	477.8	-13.9	644.4	90.2
2	461.2	-30.5	664.0	109.8
3	469.5	-22.2	619.1	64.9
4	473.3	-18.4	594.0	39.8
5	486.7	- 5.0	570.5	16.3
6	490.4	- 1.3	548.2	- 6.0
7	502.0	10.3	520.2	-34.0
8	510.8	19.1	485.4	-68.8
9	521.9	30.2	448.9	-105.3
10	523.7	32.0	447.4	-106.8
Mean	491.7		554.2	

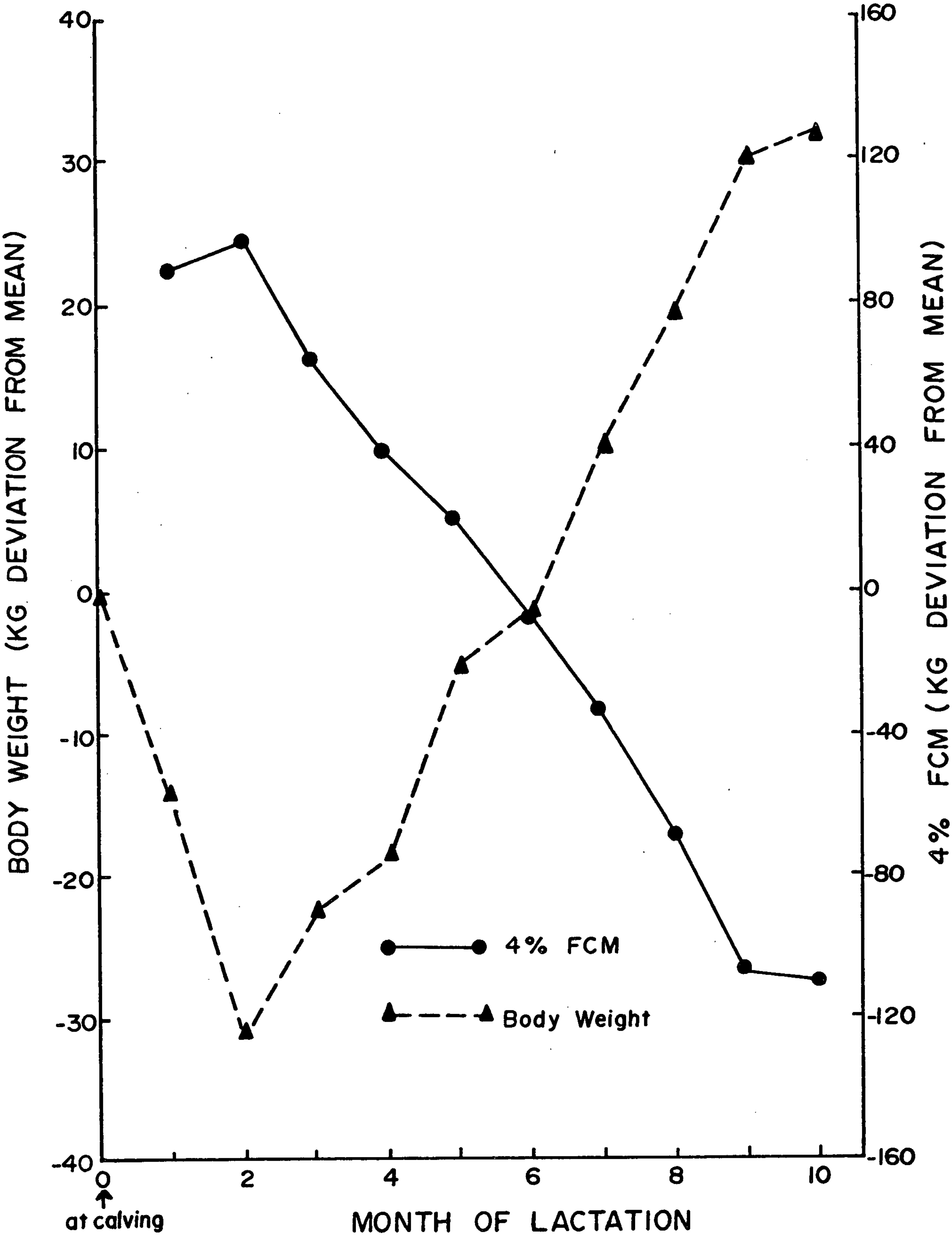

Figure 5. Changes in Body Weight and average 4% FCM During Lactation

These workers, by studying weights of 53 Holstein cows of various ages from date of service to calving found that of the 129 kg average weight gain, 70 kg was estimated due to foetus, placental membranes and amniotic fluids and the remainder attributed to a combination of growth and fat deposition.

Headley (83) showed that for mature cows weight loss ceases after 8-9 weeks of lactation while Reid (152) indicated that the loss of body weight (presumably body tissue) after calving usually reaches a maximum within 30 to 75 days post-partum. For most cows the minimum weight was recorded within 60 days post-partum. Figure 5 showed that weight loss by these heifers ceased after their second month of lactation. This suggests that perhaps as a result of continuous mobilization of body fat to meet lactational demand, these heifers could not start gaining weight earlier than the end of their second month of lactation. Reid (152) indicated that the extent of body tissue losses depends greatly upon the amount of feed ingested during lactation and the amount of tissue available. The minimum dry matter intake (Figure 4) and hence gross energy consumption by these heifers occurred during the first month of lactation. This relatively low level of gross energy consumption would then explain in part the loss in weight suffered by these heifers in their early stage of lactation.

Table VII showed that the heifers reached their mean lactation weight somewhere between the sixth and seventh month of lactation. Morgan and Davis (139) by studying monthly weights of 656 lactations including 299 Holstein cows found that the mean monthly weight of the lactation was reached between the fifth and sixth month of pregnancy. Assuming Morgan and Davis' experimental animals had an average of 60 days open, this would mean that the animals used by these workers would reach their mean lactation weight somewhere between the seventh and eighth month of lactation. Miller *et al.* (126) observed that heifers reached their mean lactation weight between 150 and 180 days (5 to 6 months) after calving while mature cows did not attain their mean lactation weight until 180 days (6 months) after calving. These observations indicate that heifers tend to gain weight at a faster rate than mature cows during lactation. This suggestion is supported by the result of Miller *et al.* (126) in which heifers gained 84 kg while mature cows gained only 34 kg during lactation.

There was a highly significant ($P < .01$) negative correlation ($r = -0.98$) between weight change and 4% FCM yield. Similarly there was a highly significant ($P < .01$) negative correlation ($r = -0.79$) between weight change and gross efficiency (See Gross Efficiency, Page 95). These observations are in agreement with the findings of Hooven *et al.*(90) who showed that the net change in weight from calving to the end of lactation has a moderately high negative correlation with both milk yield and gross efficiency of milk production.

Table VIII and Appendix Table IX show the total 4% FCM production by individual heifers during the entire lactation. There was a significant ($P < .01$) difference between the heifers in their 4% FCM production during lactation. Figure 5 shows that there was an increase in 4% FCM production from the first to the second month of lactation and thereafter

Table VIII - 4% Fat-Corrected Milk Production by Individual Heifers During Lactation

Heifer No.	Months in Lactation ≠	Total Production (kg)	Monthly Mean Production (kg)	Daily Mean Production (kg)
68002	10	4672.20	467.2	15.6[c]
67007	9	4354.00	483.8	16.1[c]
67130	9	4690.10	521.1	17.4[bc]
67133	8	4262.80*	532.9	17.8[bc]
68004	10	6110.70	611.1	20.4[ab]
67138	10	6959.00	695.9	23.2[a]
Mean		5174.8	554.2	18.4

≠ Each month of lactation is of 30 days duration.

* Production for the last 8 months of lactation.

a, b, c. Means with different superscript letters are significantly different ($P < .05$) (40).

consistently declined throughout lactation. This is in agreement with the reports by Miller *et al.* (126). The lactation curve tends to complement the weight curve. That is, as body weight decreases due probably to fat mobilization, 4% FCM production increases and as body weight increases due to more energy being used for growth and fat synthesis 4% FCM production declines as a result of less energy being available for milk synthesis.

E. Energetic Efficiency of Milk Production

1. Gross Energetic Efficiency

Gross energetic efficiency was determined for all the heifers during the experiment and was calculated according to the definition by Armsby *et al.* (168) and as employed by Brody (23)(reviewed on page 32)

$$\text{Gross Energetic Efficiency (\%)} = \frac{\text{Milk calories produced}}{\text{Digestible feed calories consumed}} \times 100$$

The mean monthly gross energetic efficiency of milk production for the heifers is shown in Table IX. Details of the gross energetic efficiency for individual heifers througout lactation are shown in Appendix Table X.

Table IX shows that the gross energetic efficiency ranged between 29.93% in the last month of lactation to 47.58% at the first month of lactation. The overall mean gross energetic efficiency was 36.42 ±5.55%. This average gross energetic efficiency obtained with these heifers is in the range (34.7 to 46.8%) reported by Jumah *et al.* (104). The high gross efficiency values obtained by these workers have been reported to be due to losses in body weight due to fat catabolism by

Table IX - Summary of the Gross Energetic Efficiency of Milk Production During Lactation

Month of Lactation	Average Daily Milk Energy Produced (Mcal)	Gross Energetic Efficiency (%)
1	15.55	47.58[a]
2	16.56	42.62[a]
3	15.43	38.43
4	14.70	38.14
5	14.09	35.65
6	13.42	35.30
7	12.63	34.22
8	11.76	32.29
9	10.87	30.03[b]
10	10.80	29.93[b]
Mean	13.58	36.42
S. D.	±2.03	±5.55

S. D. = Standard Deviation

a = Mean for five heifers

b = Mean for four heifers

the animals. The highest gross efficiency in this study was obtained in the first month of lactation. This was the period when the heifers consumed the least dry matter and lost body weight (Figure 5), consequently the high gross efficiency obtained at the beginning of lactation could be due to the same reason given by Jumah *et al.* (104). Brody (23) indicated that the average dairy cow has a gross energetic efficiency in the range of 28 to 34%. His data showed a trend toward an increased gross efficiency with higher milk yield. The highest gross energetic efficiency obtained by Brody (23) was 47.5% with Jersey cow. The present-day dairy cows produce much more milk than those available at the time of Brody. It is, therefore, not surprising why the gross energetic efficiency of milk production obtained in this study and those reported by Jumah *et al.* (104) should be higher than the suggested average values of Brody.

Table IX showed a decrease in gross energetic efficiency throughout lactation. This is probably due to more and more digestible feed energy consumed being diverted to growth and body tissue deposition with advancing lactation in these heifers and a smaller proportion being available for milk synthesis with a consequent decrease in gross energetic efficiency. This suggestion is supported by the observation of a highly significant ($P < .01$) negative correlation ($r = -0.79$) between weight change in the heifers and the gross energetic efficiency of their milk production. There was a highly significant ($P < .01$) positive correlation ($r = 0.91$) between gross energetic efficiency and 4% FCM production.

2. Net Energetic Efficiency

Net energetic efficiency was determined for all heifers during the experiment and calculated by the method of Brody (23).

$$\text{Net Energetic Efficiency (\%)} = \frac{\text{Milk Calories Produced}}{\text{Digestible feed Calories consumed} - \text{Calories DE for Maintenance}} \times 100$$

Maintenance requirements were computed by conversion of Morrison's standard of 7.9 lb TDN/1000 lb body weight (140) using the factor 4400 kcal DE/kg TDN (143). By this conversion maintenance requirement was found to be 160.5 kcal DE/$W_{kg}^{.75}$ where $W_{kg}^{.75}$ is metabolic body weight in kilograms (110). This maintenance requirement was assumed to be constant at all stages of lactation. Body weight used was the monthly average weight obtained during the experiment. Values of net energetic efficiency calculated for the first month of lactation were unusually high due probably to excessive mobilization of body fat for milk synthesis and a relatively low level of gross energy intake. Also the net energetic efficiency calculated for animal No. 67133 was rather inconsistent. Therefore, data for the first month of lactation and for animal No. 67133 were eliminated from the analysis.

The net energetic efficiency and the net energetic requirements of DE and TDN corresponding to various levels of 4% FCM produced are shown in Table X. Details of net energetic efficiency and requirements of DE and TDN for individual heifers are shown in Appendix Tables XI, XII and XIII respectively. Table X shows that net energetic efficiency was highest in early lactation when milk production was highest and gradually decreased as milk production declined. The decrease in net

Table X - Summary of Net Energetic Efficiency and Daily Requirements of Total Digestible Nutrients and Digestible Energy above Maintenance during Lactation

Month of Lactation	Average Daily 4% FCM Yield (kg)	Net Energetic Efficiency (%)	Net Energetic Requirements Digestible Energy/FCM (Mcal/kg)	Net Energetic Requirements TDN/FCM (g/kg)
1	Data Eliminated			
2	22.13	72.68	1.057	240.4
3	20.57	67.06	1.191	270.6
4	20.12	69.71	1.062	241.6
5	19.44	65.15	1.167	265.4
6	18.22	64.99	1.176	267.0
7	16.85	63.13	1.178	267.6
8	15.91	59.62	1.249	284.2
9	14.72	58.04	1.294	294.0
10	15.20	57.57	1.309	297.3
Mean		64.22	1.187	270.0
S. D.		±5.20	±0.089	±20.0

S. D. = Standard Deviation

energetic efficiency from the second month to 10th month of lactation was 15.11%. Corresponding to net energetic efficiency, both DE and TDN requirements per kilogram of 4% FCM were lowest in early lactation and increased as production declined during lactation. Similar observations have been reported by Brody (23) and Jumah *et al.* (104). The relatively high net energetic efficiency observed in the fourth month of lactation as compared to the third month could be due to the fact that some of the animals were off-feed for short periods due to bloat and other minor disorders during the month consequently there was a reduction in their gross energy intake as compared to the 3rd and 5th months of lactation. However, the animals did not decline appreciably in milk production nor lose weight excessively during the period. This high net energetic efficiency is probably due to mobilization of body reserves for milk synthesis without being reflected in body weight changes as indicated by Flatt (49). This is illustrated in the amount of tissue loss (Table XIV) which was observed higher in the 4th month than either the 3rd or 5th month. Higher net energetic efficiency and, hence, lower net energetic requirement per kilogram of 4% FCM at early stages of lactation may be due to the contribution of energy for milk production by the metabolism of body fat in early lactation. The declining net energetic efficiency as lactation progressed might be due to an increasing acetate/propionate ratio resulting from declining concentrate consumption with advancing lactation. Elliot and Loosli (44) in comparative feeding trials coupled with digestibility trials, found that the efficiency of milk secretion, defined as the ratio of milk yield to the digested energy consumed above maintenance, that is, net energetic efficiency, increased as the molar proportion of propionic acid in the rumen liquor increased from about 18% to 22% and the molar proportion of acetic acid decreased from about 68% to 59%. The differences in molar proportions of acids in the rumen were obtained by varying the proportion of concentrate in the ration. Thus as roughage substitutes for concentrate net energetic efficiency declines.

There was a highly significant ($P < .01$) positive correlation ($r = 0.88$) between net energetic efficiency and 4% FCM produced.

Analysis of variance (165) revealed that there was a highly significant ($P < .01$) difference between heifers in their net energetic efficiency of milk production. This animal variation is in agreement with reports by Blaxter (13), Forbes and Voris (63), Edwards (41), Hooven and Matthews (89), Stone *et al.* (168) and Smith and Rice (164). Heifers producing the greatest quantity of milk during lactation had the highest mean lactation net energetic efficiency; while those producing the least quantity of milk had the lowest mean lactation net energetic efficiency as Table XI shows.

The over-all net energetic efficiency of milk production was 64.22 ±5.20%. This net energetic efficiency was slightly higher than Brody's (23) suggested average value of 60%. This higher value may be due to the fact that while Brody's cows were consuming 9.5 kg TDN/day and producing 15.9 kg 4% FCM/day, the heifers used in this experiment consumed on an average 8.5 kg TDN/day and produced 18.1 kg 4% FCM/day thus indicating that these heifers were more energetically efficient than Brody's cows.

Table XI - 4% Fat-Corrected Milk Production and Net Energetic Efficiency During Lactation

Heifer No.	Total 4% FCM Production (kg)	Daily Mean Production (kg)	Average Net Energetic Efficiency (%)
67138	6959.00	23.2^{a}	73.18^{d}
68004	6110.70	20.4^{ab}	71.14^{d}
67130	4690.10	17.4^{bc}	64.33^{de}
67007	4354.00	16.1^{c}	57.64^{e}
68002	4672.20	15.6^{c}	55.56^{e}

a, b, c, d, e - Any two means with different superscript letters within the same column are significantly different ($P < .05$) (40).

Individual regressions of net energetic efficiency on 4% FCM production were calculated for each heifer within lactation. Simple linear regression equation relating 4% FCM to per cent net energetic efficiency was fitted for each heifer as shown in Table XII.

Table XII shows that all the regressions were statistically significant at 1% level ($P < .01$) except for animal No. 67007 which was significant at 5% level ($P < .05$). The regressions were tested as outlined by Snedecor and Cochran (165). There was a significant ($P < .01$) difference among the individual regressions, indicating that net energetic efficiency did not decline at similar rates with declining 4% FCM production among the individual heifers. Because of this, it was not considered appropriate to pool all data to calculate a common regression for all heifers.

The over-all digestible energy required above maintenance for the production of a kilogram of 4% FCM was 1.187 ±0.089 Mcal. This is equivalent to 270 ±20 grams TDN. Armsby (4) calculated a TDN requirement of 0.285 lb/lb FCM. This is equivalent to 0.285 kg/kg FCM (285g/kg FCM). Reid (152) recommended allowances of 0.31 lb TDN/lb FCM and 0.32 lb TDN/lb FCM when daily production of 4% FCM are 11 to 20 lb and 21 to 30 lb respectively. These requirements are equivalent to 310 g TDN/kg FCM and 320 g TDN/kg FCM for production of 11 to 20 kg and 21 to 30 kg FCM respectively. All these literature values are higher than the requirements observed with heifers in this experiment perhaps due to the fact that the experiments from which these cited requirements were obtained were conducted with dairy cows and not heifers.

Table XII - Regression of Net Energetic Efficiency on 4% FCM Production Calculated for Each Heifer Within Lactation

Heifer	Regression Coefficient 'b'	Regression Equation	Level of Significance ≠
67007	1.46	Y = 34.66 + 1.46X	*
67130	3.76	Y = -1.43 + 3.76X	**
67138	0.48	Y = 62.20 + 0.48X	**
68002	4.00	Y = -3.68 + 4.0X	**
68004	2.41	Y = 22.87 + 2.41X	**

Y = % Net Energetic Efficiency
X = 4% FCM (kg/day)
* = Significant at 5% Level ($P < .05$)
** = Significant at 1% Level ($P < .01$)
≠ = The sums of squares accounted for by the regression of Y on X in this case was significant as shown.

The daily requirements of TDN determined for these heifers were compared with the recommended standards of National Research Council (143) and those proposed by Moe *et al.* (133) in Table XIII. This table shows that in all cases except one all the heifers consumed less than the recommended standards of NRC (143) and Moe *et al.* (133) indicating that in most cases heifers have not got the capacity to consume enough feeds to satisfy their requirements for growth, maintenance and milk production, nor the capacity to consume feeds as mature cows. This is more marked with heavier producers, animal Nos. 67138 and 68004, which consumed 37.8 and 36.8% respectively less TDN than NRC requirement (143) and 30.3 and 29.1% respectively less TDN than the proposed standards of Moe *et al.* (133)

Statistical analysis revealed a significant ($P < .01$) difference between the heifers in their daily requirement of TDN or DE for 4% FCM production with the less energetically efficient heifers requiring more TDN or DE per kilogram of 4% FCM produced. Similarly, there was a significant ($P < .01$) difference between the observed requirement and the NRC standards (143) and that proposed by Moe *et al.* (133) indicating that these standards do not gain practical significance with heavy producing lactating dairy heifers until perhaps such animals have attained their mature size. Since energy intake is a major factor limiting milk production and since the capacity to consume is limited in dairy heifers, it is, therefore, not unexpected why dairy heifers should produce less milk than mature cows of equivalent genetic ability.

Table XIII - Daily Requirements of TDN for Milk Production by the Experimental Heifers Compared with NRC (143) and Moe *et al.* (133) Standards

Animal No.	4% FCM Produced per day (kg)	Observed TDN Reqt. (g/kg FCM)	NRC Reqt. (g/kg FCM)	Moe *et al.* Reqt. g/kg FCM	Difference between observed and NRC	Difference between observed and Moe *et al.*	Difference as % of NRC	Difference as % of Moe *et al*
67007	16.4	291	330	320	39	29	11.8	9.1
67130	17.4	269	330	320	61	51	18.5	15.9
67138	23.2	230	370	330	140	100	37.8	30.3
68002	15.6	320	330	320	10	0.0	3.0	0.0
68004	20.4	234	370	330	136	96	36.8	29.1

F. Energy Balance Studies

The distribution of the gross energy (GE) consumed per day in feces, urine, methane, milk, heat production, energy balance and tissue loss from the body expressed as per cent of GE consumed is shown in Table XIV and illustrated in Figure 6. Details of the daily energy distributed in feces, urine, methane, heat, milk, energy balance and tissue gained or lost for individual heifers are shown in Appendix Tables XIV to XX.

1. Gross Energy Intake

GE consumed ranged from 47.85 to 59.01 megacalories (Mcal) per day with the lowest consumption occurring in the first month of lactation and the highest in the third month of lactation. After the third month GE intake more or less declined throughout lactation due to decreases in GE intake as concentrates. The mean GE intake during lactation was 54.71 ±3.33 Mcal/24 hours.

2. Urine and Methane Energy

The estimates of the per cent gross energy lost as urine and methane were relatively constant even though varying quantities of gross energy were consumed at different stages of lactation. Flatt (49) showed that at higher levels of feed intake a depression in apparent digestibility of gross energy was compensated for by a concomitant decrease in energy losses as urine and methane. Since no depressions in apparent digestibility of gross energy were assumed in this study, a relatively constant loss of energy as urine and methane would be expected as indicated in Table XIV.

Table XIV - Daily Distribution of Gross Energy Consumed at Different Stages of Lactation

Month of Lactation	Gross Energy Consumed (Mcal)	Per Cent of Gross Energy Distributed as: Feces (%)	Urine (%)	Methane (%)	Heat (%)	Milk (%)	Energy Balance (%)	Tissue Loss (%)
1	47.85	31.8	5.2	7.0	44.5	32.5	11.6	-21.4
2	56.97	31.8	5.1	6.0	40.6	29.1	16.5	-12.6
3	59.01	31.8	5.2	5.6	39.9	26.2	17.4	- 8.7
4	56.90	31.8	5.3	6.0	40.6	25.8	16.2	- 9.6
5	58.27	31.8	5.3	5.9	40.2	24.2	16.9	- 7.3
6	55.62	31.8	5.3	6.2	41.1	24.1	15.7	- 8.5
7	53.83	31.8	5.2	6.4	41.8	23.5	14.7	- 8.7
8	53.22	31.8	5.3	6.5	42.0	22.1	14.4	- 7.7
9	52.65	31.8	5.3	6.5	42.3	20.6	14.1	- 6.5
10	52.76	31.8	5.3	6.5	42.2	20.5	14.1	- 6.3
Mean	54.71	31.8	5.30	6.30	41.5	24.9	15.2	- 9.7
S. D.	±3.33	±0.0	±0.07	±0.55	±1.35	±3.75	±1.73	

S. D. = Standard Deviation

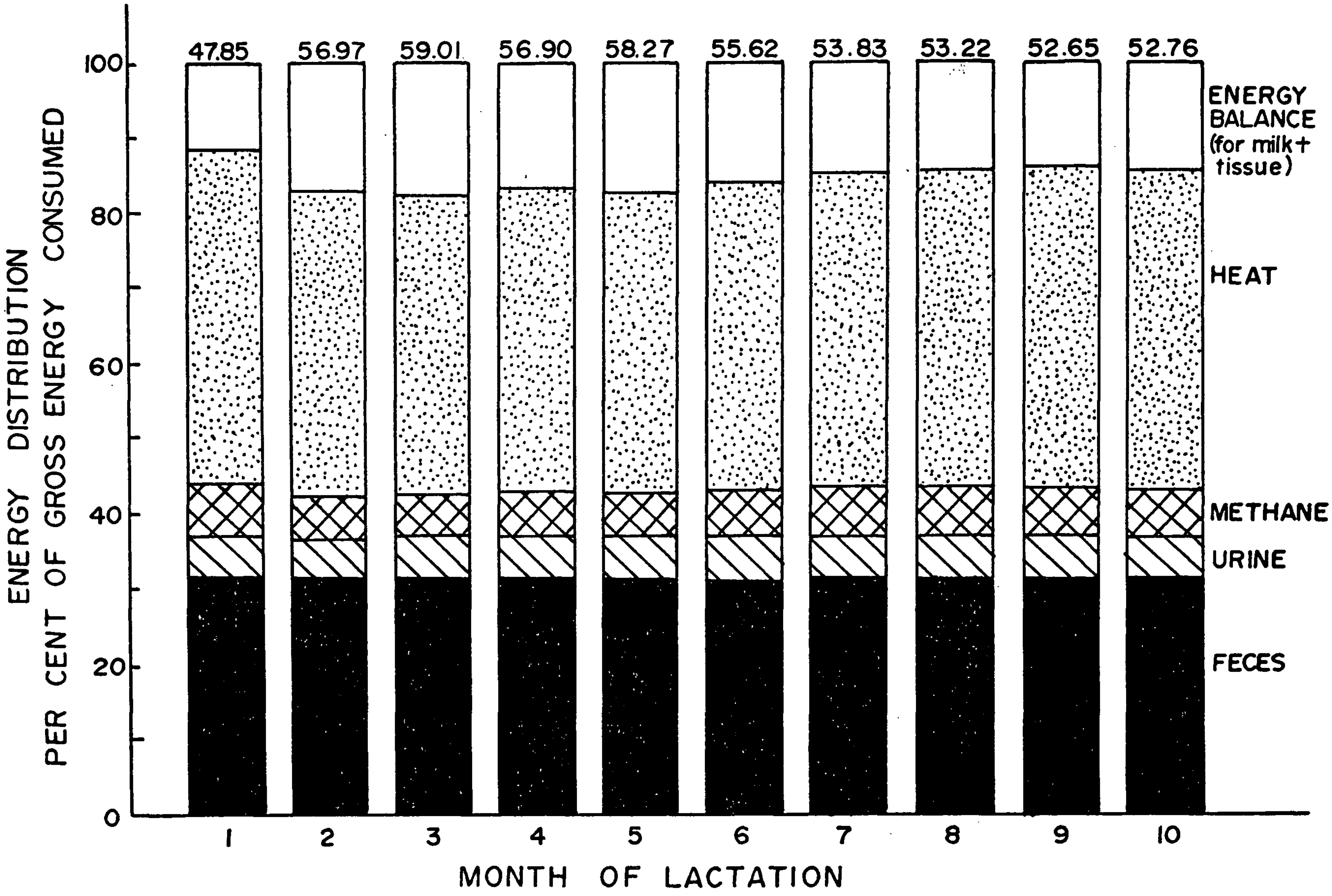

Figure 6. Distribution of Gross Energy Consumed at different Stages of Lactation (Figures above each bar represent the average megacalories of gross energy consumed by the experimental animals)

The average daily losses of energy as urine and methane were 2.86 and 3.42 Mcal/24 hrs. respectively. These losses were equivalent to 5.30 ±0.07% and 6.30 ±0.55% of the gross energy intake respectively and were within the ranges of 4 to 6% and 5 to 12% of the gross energy respectively suggested by Reid (150) and Hardison (74).

3. Heat Production

Heat production accounted for the largest single source of energy loss regardless of the stage of lactation. Heat loss ranged from 39.9 to 44.5% with an average of 41.5 ±1.35% of the GE consumed. The average heat loss was 22.68 Mcal/24 hours.

Heat production was highest in the first month of lactation when feed intake was lowest (Table VI, page 84). As feed intake increased up to the third month of lactation heat production declined. However, as feed intake decreased from the fourth month of lactation due to decreases in concentrate consumption heat production increased to the end of lactation. This suggests that ME is utilized with less heat loss when concentrate is present in a ration. The period of increases in heat production was also the period when most of the heifers were pregnant. These observations are in agreemwnt with those of Flatt *et al.* (52, 54). These Beltsville workers observed that when cows were fed *ad libitum* 43% of the GE intake was lost as heat, as compared to 45% when feed was limited. They also observed a great increase in heat production by pregnant cows as compared to non-pregnant ones.

4. Milk Energy

Milk energy expressed as per cent of GE intake declined progressively throughout lactation with the highest (32.5%) production occurring in the first month of lactation and the lowest (20.5%) in the last month of lactation. The mean was 24.9 ±3.75%. A higher milk energy production in the first month than in the second month in the face of a higher milk production in the second month (Figure 4) may be explained on the basis of higher fat and protein contents in the milk produced in the first month than in the second month of lactation. Energy secreted as milk ranged from 10.80 to 15.55 Mcal/24 hours with an average of 13.58 Mcal/24 hours.

5. Body Tissue Energy

Body tissue energy loss was observed throughout lactation, a phenomenon that is rather unusual. The greatest body tissue loss occurred in early lactation with 21.4% and 12.6% of GE consumed being lost in the first and second month respectively. In early lactation, tissue loss has been reported inevitable (48, 49, 51, 52, 54) since lactating cows are often unable to consume enough energy to meet their requirements for lactation. They, therefore, draw upon their body reserves for milk synthesis. As milk energy secreted decreased with advancing lactation, tissue loss also decreased. This is probably because as lactation advanced and feed intake became gradually reduced, instead of mobilizing more tissue to meet energy demands, the heifers compensated by producing less milk.

Tissue deposition in late stages of lactation have been noted with non-pregnant lactating cows (48, 54). Tissue deposition would have been expected after the early stages of lactation were passed, but soon after this stage the heifers became pregnant which meant more energy demand for them. Since the rations were not increased with advancing stages of pregnancy and no allowance was added for pregnancy, the animals drew upon their body tissue to meet the additional energy requirements due to pregnancy, consequently they lost body tissue as it was expected. The increase in body weight observed in the heifers even when they were continuously mobilizing body fat, although at a decreasing rate, might probably be due to gains in body water as suggested by Jumah *et al.* (104) and increase in the foetus and the associated placental membranes and amniotic fluids (141). Flatt *et al.* (52) have showed that pregnant cows could lose body tissue even at late stages of lactation or pregnancy, while non-pregnant cows often gained body tissue at this stage thus indicating that pregnancy is an energy demanding physiological process and failure to provide adequately for this may push the animal into body tissue loss.

The Utilization of Metabolizable Energy (ME) for Milk Production

Method 1. Metabolizable energy has been defined in the review (page 14) as the gross energy of the feed consumed minus the energy of the feces, urine and methane and was estimated as such. The total ME consumed by individual heifers per day at different stages of lactation is shown in Appendix Table VI.

The ratio of ME to DE calculated for each month of lactation was not constant but varies very little from the average value of 82% observed by Blaxter *et al.* (17). The ratio of ME to DE obtained in this experiment varies between 82.13% to 84.07% with a mean of 83.12%.

ME is often "corrected" to nitrogen balance because all of the energy from protein origin is not potentially useful to an animal. The procedure involves multiplying the balance of nitrogen by 7.45 to give the energy associated with that nitrogen if excreted in the urine; and in the case of negative nitrogen balance the value is deducted from the urine energy thus giving a larger ME value for the feed. Harris (78) indicated that the conversion factor was obtained in experiments with dogs and doubted its applicability to other animals. Since nitrogen balance was not carried out in this study and since there is no certainty of the applicability of the conversion factor to dairy heifers, the metabolizable energy consumed by the experimental animals was an uncorrected metabolizable energy.

The arithmetic procedure for calculating the efficiency with which ME is converted to milk energy is the same as outlined in Table I, page 44 of the review. Total heat production was estimated with the equation of Flatt *et al.* (54). The difference between the ME consumed and heat production (HP) represents the total energy balance or that amount of energy secreted as milk and deposited as tissue. If milk energy is a larger value than the total energy balance, then the difference represents the amount of energy derived from tissue. The factors 1.61 and 1.43 of Van Es (45) were used to adjust the ME consumed for tissue gained or tissue lost respectively. These factors imply an efficiency of conversion of ME to tissue deposited of 62% (1/1.61) and tissue mobilized for milk production of 70% (1/1.43). The maintenance value of 131 kcal ME/kg$^{.75}$/24 hours by Kleiber *et al.* (111) was used as the maintenance requirement of these heifers. Calculations were carried out for each heifer and for each month of lactation. Table XV shows the efficiency of utilization of ME for milk production as calculated for each heifer.

Table XV shows that the efficiency values obtained ranged from 52.11% towards the end of lactation to 55.37% at the early stages of lactation with a mean of 53.76 ±1.14%. This is within the range obtained by Jordan *et al.* (103) and Haecker (73). This table also shows that as lactation progressed there was a tendency toward a declining efficiency with which ME was converted to milk by individual heifers. This is illustrated in the plot of means for the months of lactation in Figure 7. This observation did not agree with those of Forbes *et al.* (61). These workers observed an increase in ME utilization for milk production in the later stages of lactation. The declining efficiency observed in this study may be due to the declining concentrate consumption as lactation progressed. Coppock *et al.* (33) and Flatt (48) observed a higher efficiency of utilization of ME for milk production with rations containing higher proportions of concentrates than with rations containing low proportions as concentrates or all-forage rations. This indicates that ME is used more efficiently for milk production when concentrates form a good proportion of the ration than when the ration is low in concentrate or when the ration is 100% forage.

Table XV - Efficiency of Utilization of ME for Milk Production (%) (Assuming 131 kcal ME/kg$^{.75}$/24 hrs. for Maintenance [Kleiber *et al.* (111)] and adjusting for Tissue Gain or Loss [Van Es (45)])

Month of Lactation \ Animal	67138	68004	67130	67007	68002	Mean
	(%)	(%)	(%)	(%)	(%)	(%)
1	57.44	58.03	54.32	55.38	51.08	55.25
2	57.58	57.80	53.75	53.83	53.87	55.37
3	57.42	57.28	51.43	54.52	51.59	54.45
4	55.74	57.51	53.26	53.93	51.60	54.41
5	57.62	56.17	56.04	52.70	48.16	54.14
6	57.55	55.29	55.95	52.00	46.61	53.48
7	56.96	55.05	55.49	50.86	47.06	53.08
8	56.55	54.79	55.24	50.38	46.99	52.79
9	56.46	54.64	55.71	46.91	46.85	52.11
10	55.81	54.18	-	-	47.51	52.50
Mean	56.91[a]	56.07[ab]	54.58[b]	52.28	49.13	53.76
S. D.	±0.73	±1.46	±1.54	± 2.61	±2.63	±1.14
C. V. (%)	1.28	2.61	2.82	5.0	5.36	2.12

S. D. - Standard Deviation
C. V. - Coefficient of Variation
a, b. - Means with the same superscript letters are not significantly different at 5% level of probability (40).

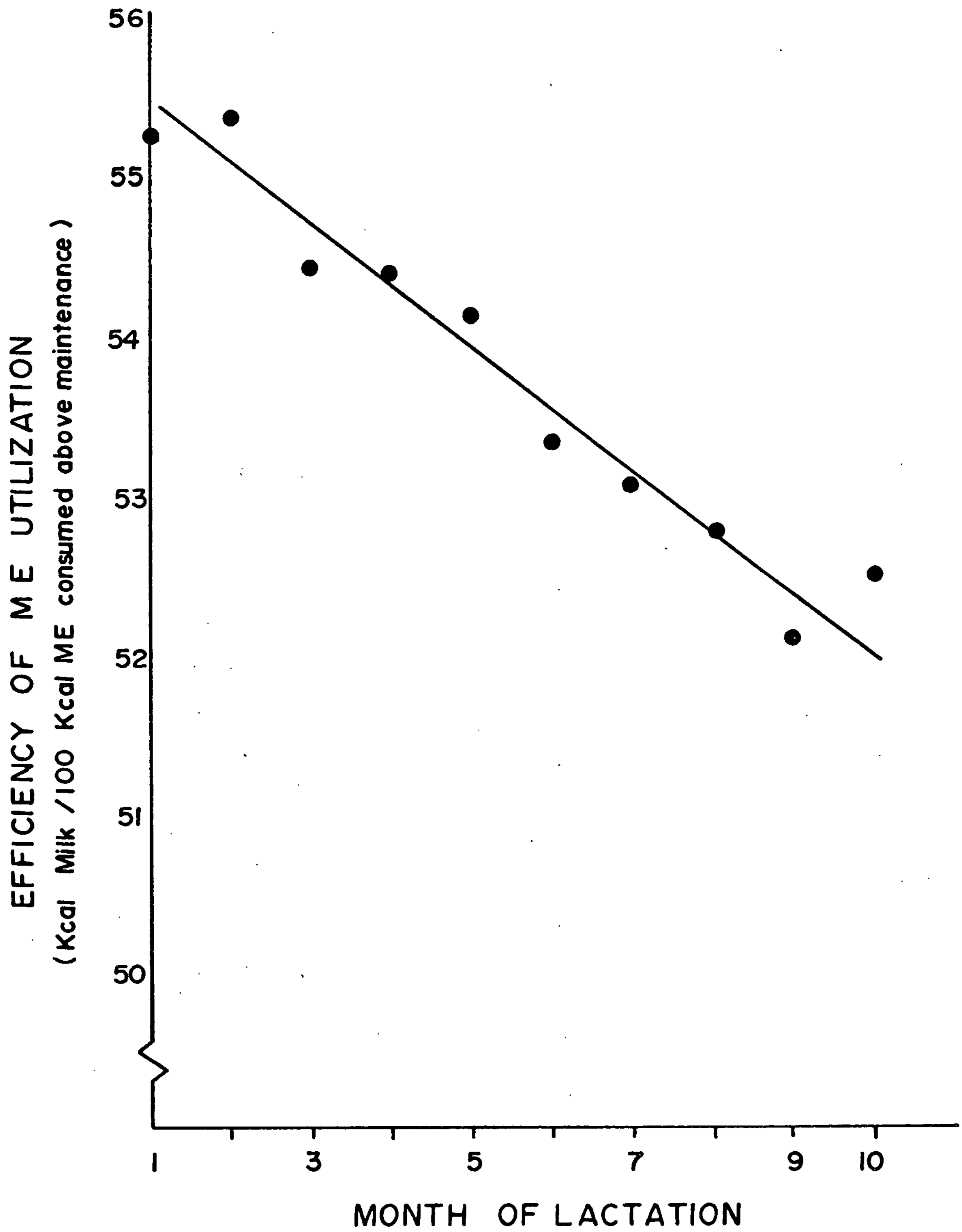

Figure 7. Efficiency of Utilization of ME for Milk Production during Lactation

Blaxter (14) has hypothesized that the efficiency of utilization of ME for lactation varies depending upon the relative proportions of volatile fatty acids in the rumen. When roughages were substituted for concentrates, acetic acid formed the greater proportion of the total volatile acids in the rumen (9, 169). Blaxter (14) proposed that ME given above maintenance needs would be maximally utilized for milk production when rations resulting in 50 to 60% molar per cent acetic acid in the rumen were fed, and would decline outside this range. Coppock *et al.* (34) in an experiment in which the molar per cent of acetic acid was 71.4, 68.2 and 65.3 with rations containing 0%, 25% and 50% ENE as concentrates respectively observed a negative correlation (r = -0.73) between efficiency of ME utilization for milk production and the molar per cent of acetic acid present in the rumen. This implies that with increasing molar per cent of acetic acid, probably beyond 60% proposed by Blaxter (14), as a result of decreasing proportions of concentrate in the ration, the efficiency of ME utilization for milk production declines. Since the roughage intake was held at a constant level in this experiment, then a decreasing concentrate proportion of the ration with advancing lactation would result into a narrowing of the roughage: concentrate ratio and consequently an increase in the molar per cent of acetic acid present in the rumen. It is, therefore, possible that the molar per cent of acetic acid resulting from a ration of narrow roughage: concentrate ratio may exceed the 50 to 60% for maximum ME utilization proposed by Blaxter (14) and therefore an increasing acetate:propionate ratio would result. If this is the case, the efficiency of ME utilization for milk production would decline with advancing lactation as noted in this experiment. This suggestion is supported by the work of Elliot and Loosli (44). These workers noted an increasing efficiency when grain was substituted for roughage resulting in an increasing proportion of propionic acid and a decreasing acetic acid in the rumen liquor.

The relatively low efficiency values obtained with individual heifers as compared to literature values (14, 32, 48, 54, 61, 62, 64, 80, 153) may be due to the maintenance requirement used in the computation since the magnitude of the maintenance requirement determines the magnitude of the efficiency value. Evidence are now available which indicate that the maintenance requirements of young animals are higher than those of older animals (14, 47). Therefore, if a maintenance requirement such as that obtained by Kleiber *et al.* (111) with mature cows is used to compute efficiency with lactating heifers, a relatively lower value as obtained in this study would be expected since the maintenance requirements would probably be higher than those of mature cows. A regression procedure for estimating the maintenance requirement of milking heifers is discussed in the next section and this may throw some light on the problem. In the calculation of efficiency, the assumed fixed maintenance requirement based on metabolic weight was at best a constant approximation. There is the possibility that the maintenance requirement is not constant but varies throughout lactation as Wallace's work (181) suggests. In fact, Van Es (45) has showed that the within animal variation in the requirement of ME for maintenance was about 7% and the among animal variation within breeds was about 8 - 10%.

Analysis of variance (165) showed that there was a highly significant ($P < .01$) difference between the heifers in their efficiency of ME utilization for milk production. The between-animal variation observed in this experiment lends support to the work of Blaxter (13) and Stone *et al.* (168) which showed that there are differences in the efficiency with which dairy cows utilize feed nutrients for milk production.

Although there was a tendency toward a decreasing efficiency with advancing lactation, analysis of variance revealed that periods were non-significant. This is in agreement with the observation of Coppock *et al.* (33). This observation as well as the small coefficients of variation for individual heifers within lactation lend support to the opinion of Reid (154) that ME available for milk production is used with nearly constant efficiency, independent of the level of intake. The non-significant period does not lend support to the assumption that the stage of lactation influences greatly the transformation of ME into milk. So far, there is paucity of information available in literature to show any relationship between stage of lactation and the utilization of ME for milk production.

Method II. Regression Method of Calculating the Efficiency of Utilization of ME for Milk Production

In order to obtain an estimate of the overall efficiency with which ME was converted to milk and the maintenance requirements of the heifers a regression analysis was performed with megacalories of ME available for milk plus maintenance, after adjusting for tissue gained or lost, as the dependent variable, Y, and the megacalories milk energy produced as the independent variable, X. Unlike the arithmetic procedure discussed previously, the method does not involve an assumption of the maintenance requirement. Regression equations were calculated for individual heifers within lactation and a pooled regression calculated for all heifers. The Y intercept or "a" value of the regression equation gives an estimate of the maintenance requirement of the heifers. Since literature values are often expressed in kcal ME/kg$^{.75}$, the "a" value was divided by the mean lactation metabolic weight in order to give the estimated maintenance requirement in kilocalories per kilogram of metabolic weight (kcal ME/kg$^{.75}$) for comparative purposes. The regression coefficient "b" gives an estimate of the megacalories of ME required to produce one megacalorie of milk energy, and its reciprocal multiplied by 100 gives an estimate of the efficiency with which ME is converted to milk. The various regression equations and estimates of efficiency of ME utilization and maintenance requirements for individual heifers are shown in Table XVI. The pooled regression equation is plotted in Figure 8. The linearity of the regression line confirms the observation of Flatt (48, 49) that the utilization of ME above maintenance is linear up to levels of intake equal to five times maintenance.

Although the small number of animals involved in this study precludes any definite conclusions, the amount of milk produced by individual heifers during lactation which ranged from 4354 to 6959 kg FCM and the mean lactation metabolic weight which ranged from 95.4 to 106.4 kg$^{.75}$ make comparisons of relatively low and high producers and small and large heifers possible, a situation that is very probable in a large herd. It can be seen from the computations in Tabe XVI that

Table XVI - Regression of ME available for Milk and Maintenance on Milk Energy (after adjusting for Tissue Loss or Gain) for Individual Animals within Lactation

Animal No.	Regression Equation Y = ME for Milk and Maintenance (Mcal) X = Milk Energy (Mcal)	Regression Coefficient "b"	Sy.x	Estimate of ME Utilization (%)	r	Mean Lactation Weight ($kg^{.75}$)	Estimate of Maintenance Reqt. (kcal ME/$kg^{.75}$)
67007	Y = 1.460X + 18.72	1.460	±0.1314	68.49	0.999**	103.3	181.2
67130	Y = 1.441X + 18.92	1.441	±0.1389	69.40	0.997**	105.9	178.7
67138	Y = 1.435X + 19.06	1.435	±0.0837	69.69	0.999**	104.1	183.1
68002	Y = 1.487X + 18.52	1.487	±0.4459	67.25	0.996**	95.4	194.1
68004	Y = 1.430X + 19.09	1.430	±0.0866	69.93	0.999**	106.4	179.4
Pooled	Y = 1.445X + 18.90	1.445	±0.2019	69.20	0.999**	103.0	183.5

Sy.x is the Standard Deviation from Regression or Standard error of estimate.
r is the simple linear correlation.
** Significant at 1% level of probability.

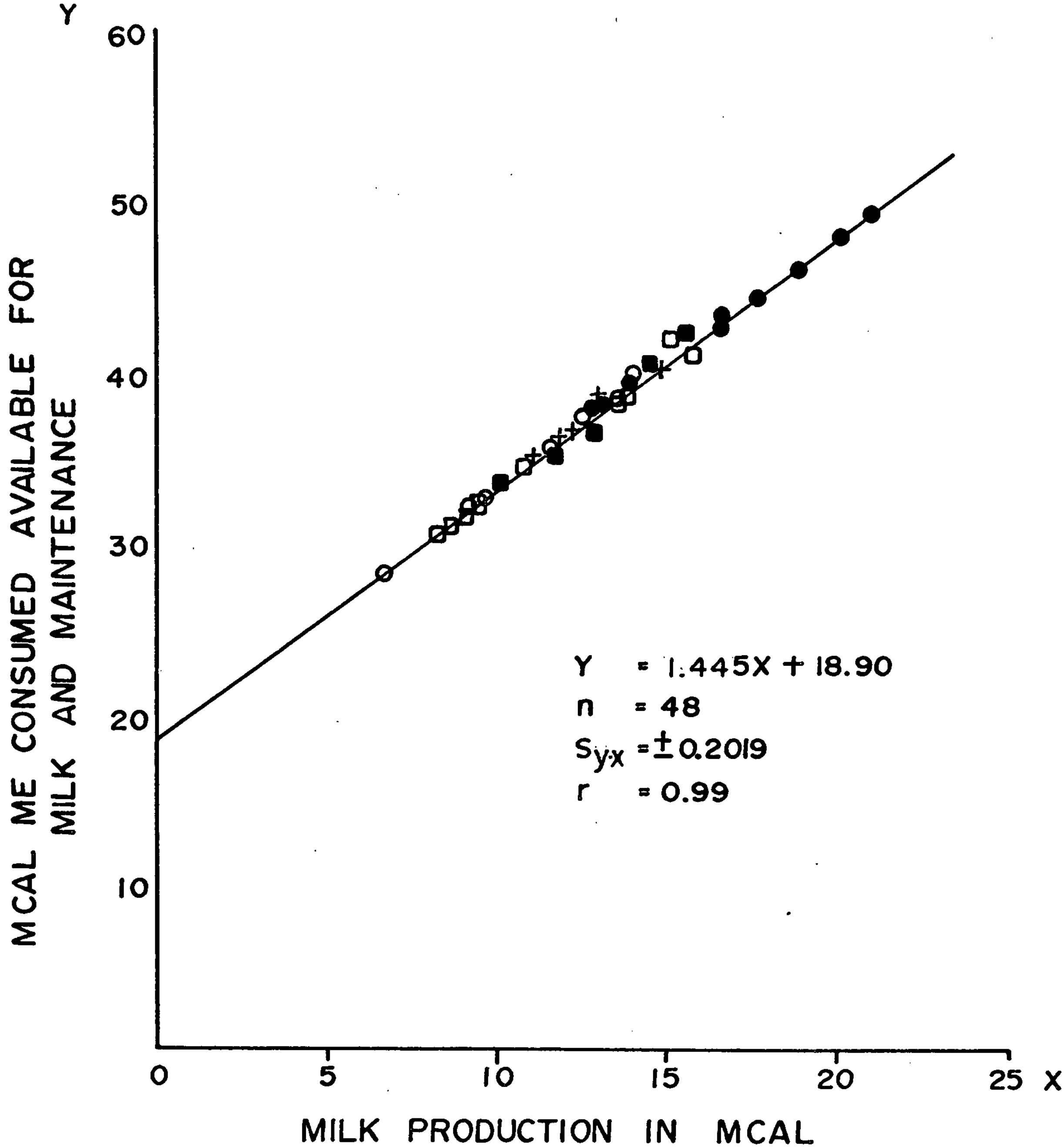

Figure 8. Regression of ME consumed for Milk and Maintenance on Milk Energy

the estimates of ME utilization for milk production were almost identical for all heifers regardless of whether the heifer was a low producer or a high producer and whether a small heifer or a large heifer. The pooled regression equation indicates that 1.445 Mcal ME are required for the production of 1 Mcal of milk energy or 1.069 Mcal ME/kg 4% FCM, a requirement equivalent to an efficiency of ME utilization of 69.2% (1/1.445 x 100), and that the overall estimate of maintenance requirement was 183.5 kcal ME/kg$^{.75}$.

The ME intake by the heifers was partitioned into utilization for milk production, tissue energy loss and maintenance by multiple regression analysis. The following model represented the relationship between the dietary metabolizable energy intake and the use of energy by the lactating heifers.

$$Y = b_1X_1 + b_2X_2 + b_3X_3 + a$$

where Y is metabolizable energy intake in megacalories

X_1 is milk energy produced in megacalories

X_2 is tissue energy loss in megacalories

X_3 is metabolic body size (kg$^{.75}$)

The partial regression coefficients

b_1 represents the amount of ME required for milk production,

b_2 represents the amount of dietary energy which is spared per unit of body tissue energy loss,

b_3 represents ME required for maintenance,

a is a constant.

The reciprocal $1/b_1$ represents the efficiency of milk production and the ratio b_2: b_1 is the efficiency with which body tissue is used for milk production. The constant "a" represents the amount of ME intake which was not assigned to any specific variable in the model. As recently suggested by Moe *et al.* (132) it appears most logical to assign such constants to the maintenance cost. Therefore, the constant was divided by the average lactation metabolic body size and added to the partial maintenance coefficient, b_3, to arrive at an estimate of the maintenance requirement per kilogram of metabolic body size ($kg^{.75}$). The results of these computations are shown in Table XVII. The overall multiple regression equation obtained from these computations was:

$$Y = 1.429X_1 - 1.407X_2 - 0.0037X_3 + 19.38$$

where the terms are the same as described above with standard errors of ±0.017, ±0.020 and ±0.006 for the partial regression coefficients 1.429, 1.407 and 0.0037 respectively.

$$N = 48,\ R^2 = 0.994.$$

This equation indicates that 1.429 Mcal ME are required for the production of 1 megacalorie of milk energy or 1.058 Mcal ME/kg 4% FCM. Thus the efficiency of utilization of ME for milk production was $\frac{1}{1.429} = 70\%$ and the efficiency of conversion of body tissue energy into milk was 1.407/1.429 = 98.5%. The overall maintenance requirement was calculated as indicated earlier on and found to be 184.5 kcal ME/$kg^{.75}$. Thus, by either the multiple regression analysis shown in Table XVII or the linear regression analysis of ME available for milk plus maintenance on milk energy shown in Table XVI, the overall estimates of ME utilization for milk production and maintenance were found to be approximately the same in both cases.

Table XVII - Multiple Regression Analysis of Metabolizable Energy Intake on Milk Energy, Body Tissue Energy Loss and Metabolic Body Size for Lactating Heifers

Heifer No.	Multiple Regression Equation	Regression Coefficients b_1	b_2	b_3	R^2	Mean Lactation Weight ($kg^{.75}$)	Milk from ME (%)	Milk from Tissue (%)	Maintenance Reqt. (kcal ME/$kg^{.75}$)
67007	$Y = 1.531X_1 - 1.515X_2 + 0.0426X_3 + 13.84$	1.531	1.515	0.0426	0.999	103.3	65.3	99.0	176.6
	Sy.x	±0.010	±0.010	±0.008					
67130	$Y = 1.488X_1 - 1.489X_2 - 0.0083X_3 + 17.73$	1.488	1.489	0.0083	0.999	105.9	67.2	100.0	175.7
	Sy.x	±0.019	±0.010	±0.0052					
67138	$Y = 1.462X_1 - 1.413X_2 + 0.0194X_3 + 16.46$	1.462	1.413	0.0194	0.999	104.1	68.4	96.6	177.5
	Sy.x	±0.026	±0.039	±0.011					
68002	$Y = 0.966X_1 - 1.049X_2 - 0.0243X_3 + 24.93$	0.966	1.049	0.0243	0.992	95.4	103.5	108.6	237.0
	Sy.x	±0.100	±0.064	±0.026					
68004	$Y = 1.484X_1 - 1.486X_2 + 0.0066X_3 + 17.97$	1.484	1.486	0.0066	0.999	106.4	67.4	100.0	175.5
	Sy.x	±0.030	±0.022	±0.029					
Pooled	$Y = 1.429X_1 - 1.407X_2 - 0.0037X_3 + 19.38$	1.429	1.407	0.0037	0.994	103.0	70.0	98.5	184.5
	Sy.x	±0.017	±0.020	±0.0061					

Table XVII - Continued

Y = Metabolizable Energy Intake (Mcal)

X_1 = Milk Energy (Mcal)

X_2 = Tissue Energy Loss (Mcal)

X_3 = Metabolic Body Size ($kg^{.75}$)

b_1, b_2, b_3 = Partial Regression Coefficients

R^2 = Multiple Coefficient of Determination

Sy.x = Standard error of estimate

The estimates of ME utilization for milk production were found to be very close or the same as 70% suggested by Blaxter (14) and Reid (153). This high efficiency might be due to the tremendous ability of these heifers to utilize body tissue energy efficiently for milk production. The efficiency of body tissue energy utilization was found to be almost 100% (actual 98.5%), a value much higher than 84% to 85% reported by Moe *et al.* (128, 132) with lactating cows in negative tissue balance. The high constant ("a" value = 24.93) obtained with Heifer No. 68002 and which was assigned to the maintenance cost might suggest that the greater proportion (87.3%) of the ME consumed by this heifer was used for maintenance purposes while only 12.7% was used for milk production. The high efficiency of ME utilization for milk production might therefore suggest that most of the milk produced by this heifer was derived from body tissue energy and this is perhaps the reason why the total lactation 4% FCM production was low.

The estimates of efficiency of ME utilization for milk production and maintenance requirements obtained by the regression procedures indicate that there is perhaps a difference in the maintenance requirements of the heifers as well as a difference in the efficiency with which ME is converted to milk. If the estimates were the same for all heifers as Table XVI tends to indicate, then the significant differences observed in the 4% FCM production by the heifers might probably be due to differences in the inherent ability of each heifer to produce milk. This suggestion is in agreement with the observations of Bloom *et al.* (19). These workers, in their investigation, concluded that regardless of the type of ration fed, the inherent ability of cows to produce milk was more significant than the intensity of feeding. The over-all estimate of efficiency obtained by the two regression procedures was higher than the values similarly obtained by Coppock *et al.* (33) and Flatt *et al.* (54) with cows. This might suggest that perhaps heifers have higher efficiency of ME utilization for lactation than cows. More work would be required to actually compare heifers with cows under identical conditions in order to ascertain any differences that may exist in the efficiency with which they utilize ME for lactation. Such trials should not be complicated by the growth requirements of heifers.

The various maintenance requirements obtained by different workers have been reviewed (page 45). The estimated maintenance requirements obtained in this study were much higher than most literature values. This might be due to the fact that the animals were still growing so that they were using energy to synthesize new body tissue in addition to such other physiological functions as pregnancy, lactation and tissue mobilization demanding energy. Thus, growth and these other physiological functions would mean an increasing demand for energy consequently the maintenance requirement was high and would not be constant as Kleiber *et al.* (111) suggested and assumed in the arithmetic procedure for efficiency calculation but increasing as Wallace (181) suggested perhaps until the mature size of the animal is attained.

V

ECONOMIC CONSIDERATIONS

In a commercial dairy herd one of the primary objectives is the economic returns in terms of revenue from milk over and above the costs of feed consumed by the animals. It is, therefore, the purpose of this part of this thesis to determine the revenue from milk over and above the feed costs basing all calculations on the current price of feeds and milk.

(A) Cost of Feeds

The cost of the feeds consumed by individual heifers was calculated using the following prices:

Hay: $42/ton (4.62 cents/kg)

Beet Pulp: $64.80/ton (7.13 cents/kg)

Grain: $65.40/ton (7.19 cents/kg)

The costs of the feeds consumed at successive stages of lactation by individual heifers are shown in Appendix Table XXI.

(B) Revenue from Milk

Since milk is paid for by the dairy plant on the basis of 3.5% butterfat, the milk produced by the individual heifers was converted to 3.5% FCM on the basis of energy using the equation of Moe and Flatt (129). This is to avoid such corrections in payment that would be necessary for such milks that contain more than 3.5% butterfat. The following prices were used in the calculation:

Quota milk: \$6.71/100 lb 3.5% FCM or \$6.71/45.45 kg 3.5% FCM,

Surplus milk (milk supplied in excess of Quota milk): \$3.46/100 lb 3.5% FCM or \$3.46/45.45 kg 3.5% FCM.

Calculations were carried out for the milk when it was supplied to the dairy plant partly as Quota and partly as surplus milk. In the computations it was assumed that the ratio of milk supplied as Quota: milk supplied as surplus for each month and for the whole herd was the same ratio by which milk from individual heifers was supplied as Quota and as surplus milk to the dairy plant. On the basis of this assumption the total 3.5% FCM produced by individual heifers was divided into Quota milk and surplus milk. The revenue for each category of milk was calculated using the above prices and the total revenue for each month of lactation obtained by the addition of the revenue from the two categories of milk sold.

Calculations were also carried out assuming that all the milk were sold either as Quota or as Surplus. The results of these computations are shown in Appendix Tables XXII, XXIII and XXIV.

(C) Revenue from Milk over and above Feed Costs

The revenue from milk over and above feed costs was calculated as the difference between the revenue from milk and the cost of feeds. The summary of the average daily returns from milk when supplied as partly Quota and partly surplus milk, as all-Quota and as all-surplus milk over and above feed costs is shown in Table XVIII. Details of the daily returns at successive stages of lactation are contained in Appendix Tables XXV, XXVI and XXVII.

Table XVIII - Average Daily Milk Revenue ($) over and above Feed Costs during Lactation

Heifer No.	Quota and Surplus Milk Basis ($) *	Quota Milk Basis ($)	Surplus Milk Basis ($)
67138	2.21[a]	2.66[d]	0.90[g]
68004	1.83[ab]	2.28[de]	0.74[gh]
67133	1.60[bc]	1.81[ef]	0.43[i]
67130	1.57[bc]	1.89[ef]	0.54[hi]
67007	1.42[bc]	1.64[f]	0.42[i]
68002	1.28[c]	1.63[f]	0.44[i]
Daily Revenue from all Heifers	1.67	2.00	0.59

* System of Milk Sales actually used.

a,b,c,d,e,f,g,h,i. Any two means with different superscript letters within the same column are significantly different ($P < .05$) (40).

Results and Discussion

Of the total cost of feeds consumed by the heifers, grain accounted for 38.3%, beet pulp 36.2% and hay 25.5%. If beet pulp and grain were grouped together as concentrate (140) then these two items combined would account for 74.5% of the total cost of feeds. Thus, the economics of dairy cattle feeding is one limited mainly to concentrate feeding. This does not imply that the kind and quality of forage have an unimportant influence on the economics of feeding. Forage quality has been known to affect the economic optimum for levels of grain feeding (86, 161) and net income from milk production (87).

Table XVIII shows that when milk was sold partly as Quota milk and partly as surplus milk, the average daily returns over and above feed costs during lactation ranged from $1.28 to $2.21 per day with an overall average of $1.67 per day. The least return was observed with Heifer No. 67007 which returned 49 cents per day in the ninth month of her lactation; while the highest return was from Heifer No. 67138 which returned $3.20 per day over and above feed costs in her second month of lactation.

Statistical analysis revealed a highly significant ($P < .01$) difference between animals in their daily milk revenue over feed costs. When Table XVIII was compared with Table XI a definite trend was observed. Heifers that have significantly higher net energetic efficiency produce significantly greater quantity of 4% FCM and have significantly greater returns per day during lactation than those heifers that have significantly lower net energetic efficiency. Heifers that do not differ significantly in their net energetic efficiency similarly do not differ significantly in their 4% FCM production and in their daily returns over feed costs. This trend was the same regardless of whether calculations were based on milk sold as partly Quota and partly surplus, all-Quota or all-surplus. This observation suggests that under the conditions of this experiment the net energetic efficiency determines the level of milk output and the returns from milk. Since net energetic efficiency is influenced by the concentrate proportion in the ration, the net income would probably be influenced by the concentrate proportion in the ration. Merrill *et al.* (125) have indicated that the profitability of feeding more grain depends on 1) the ability of the cow to produce more milk, and 2) the ratio of grain cost to milk price. Undoubtedly, net energetic efficiency and milk production increase with increasing proportions of concentrate in the ration (44). This increase may lead to the production of more surplus milk. In the face of this, if the grain cost to milk price ratio is very wide, the margin of profit becomes narrow and the high net energetic efficiency attained becomes meaningless.

Analysis of variance (165) showed that the milk revenue over and above feed costs when calculated on all-surplus milk basis were significantly ($P < .01$) lower than when calculated either as Quota and surplus or as all-Quota. There was no significant difference in milk revenue based on Quota and surplus and all-Quota. Although differences were not significant the higher milk revenue per day from all-Quota milk would suggest that all milk could be sold as Quota in order to realise higher revenue per animal. This suggestion is not feasible for practical reasons. The British Columbia Milk Marketing Board regulation which controls the acquisition of Quota by a producer would not permit him to sell all of his milk as quota milk. Moreover, if a producer wanted to sell all of his milk as quota, it is practically difficult for him to meet the conditions for quota milk all the year round due to seasonal variations in milk production. This means that short of all-quota milk system, the partly quota and partly surplus will be the most economically sound system of sales of milk. Thus to maximise his profit, the producer has to aim at high energetic efficiency and increased milk production from his herd but should avoid the production of more surplus milk.

VI

SUMMARY

The work reported in this thesis investigated mainly the utilization of energy and energy requirements by lactating dairy heifers for milk production at different stages of lactation and at different levels of production. Other investigations include 1) conventional versus chromic oxide method of determining digestibilities of nutrients and the pattern of chromic oxide excretion; 2) body weight changes and 4% FCM production and 3) returns from milk over and above feed costs.

Digestibilities determined with the Cr_2O_3 indicator were found to be only slightly lower than those determined by the conventional total collection method. This result confirms the result obtained by other workers. Daily excretion of Cr_2O_3 did not exhibit the gradual increase in concentration in the first few days after the initial dose as was observed by many workers. However, result agreed with observations of some other workers. There was a significant ($P < .01$) difference between animals in the concentration of Cr_2O_3 in their daily output of feces. The intraday excretion pattern of Cr_2O_3 exhibited only one high peak inspite of twice a day feeding. There was no significant difference in the concentration of Cr_2O_3 in the feces due to time of sampling during the day, but a significant ($P < .01$) difference between animals was observed.

Body weight (kg) declined in the first two months of lactation and thereafter increased steadily throughout lactation. The initial decrease in weight was attributed to tissue mobilization. The mean lactation weight was 491.7 kg. 4% FCM production increased from the first to the second month of lactation and thereafter declined throughout the lactation period. The mean lactation 4% FCM production was 5175 kg. A significant ($P < .01$) difference between animals in their 4% FCM production was observed. There was a highly significant ($P < .01$) negative correlation ($r = -0.98$) between body weight and 4% FCM and between body weight and gross efficiency ($r = -0.79$).

Gross energetic efficiency of milk production declined from 47.58% at the beginning of lactation to 29.93% at the end of lactation. The over-all average gross efficiency was 36.42 ±5.55%. There was a highly significant ($P < .01$) positive correlation ($r = 0.91$) between gross energetic efficiency and 4% FCM production.

Net energetic efficiencies were higher at early stages than at late stages of lactation. Corresponding DE and TDN requirements for milk production increased from early lactation to late lactation. The over-all average net energetic efficiency was 64.22 ±5.20%. This was equivalent to a requirement 1.187 ±0.089 Mcal DE/kg 4% FCM or 270 ±20 g TDN/kg 4% FCM. These requirements were found to be significantly ($P < .01$) lower than the recommendations of NRC or Moe *et al.* There was a highly significant ($P < .01$) difference between heifers in their daily net energetic requirements. A highly significant ($P < .01$) positive correlation ($r = 0.88$) was found between net energetic efficiency and level of production.

In the total energy balance trials, an assumed maintenance requirement of 131 kcal $ME/W_{kg}^{.75}$ was used to calculate ME utilization for milk production. It was found that the efficiency with which ME was converted to milk declined gradually from 55.37% in early lactation to 52.11% in late lactation. Higher ME utilization in early lactation was attributed to tissue energy mobilization for milk production. A significant ($P < .01$) difference between animals in their ME utilization for milk production was observed but period effect was non-significant. Both linear regression analysis of ME available for milk plus maintenance on milk energy and multiple regression analysis of dietary ME intake on milk energy, tissue energy loss and metabolic body weight gave estimates of ME utilization for milk production to be 69.2 to 70.0% and maintenance requirement of 183.5 to 184.5 kcal $ME/kg^{.75}$. Higher maintenance requirements than most literature values were attributed to growth, pregnancy, lactation and tissue mobilization. Multiple regression analysis showed that tissue energy was used for milk production with an efficiency of 98.5%.

The average daily returns from milk over and above feed costs were \$1.67, \$2.00 and \$0.59 when calculations were based on Quota and surplus milk, all-quota milk and all-surplus milk respectively. A significant ($P < .01$) difference between animals in their daily returns over feed costs was observed in the three systems of payment for milk considered. The net returns from all-surplus milk was significantly ($P < .01$) lower than returns from either all-Quota milk or Quota and surplus milk. Although the daily net returns from all-Quota milk was higher than those from Quota and surplus milk, no significant difference was observed between the two systems. However, practical considerations would prevent payment on all-quota milk basis and hence the quota and surplus milk system would appear to be the most profitable system of milk payment at the moment. Energetic efficiency seems to influence the level of milk production and the daily net returns. Thus, to maximize profit, a producer should aim at high energetic efficiency but should avoid the production of more surplus milk.

VII

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VIII

APPENDICES

Appendix Table I - Dry Matter, Crude Protein and Gross Energy Contents of the Feeds Fed During the Experiment.

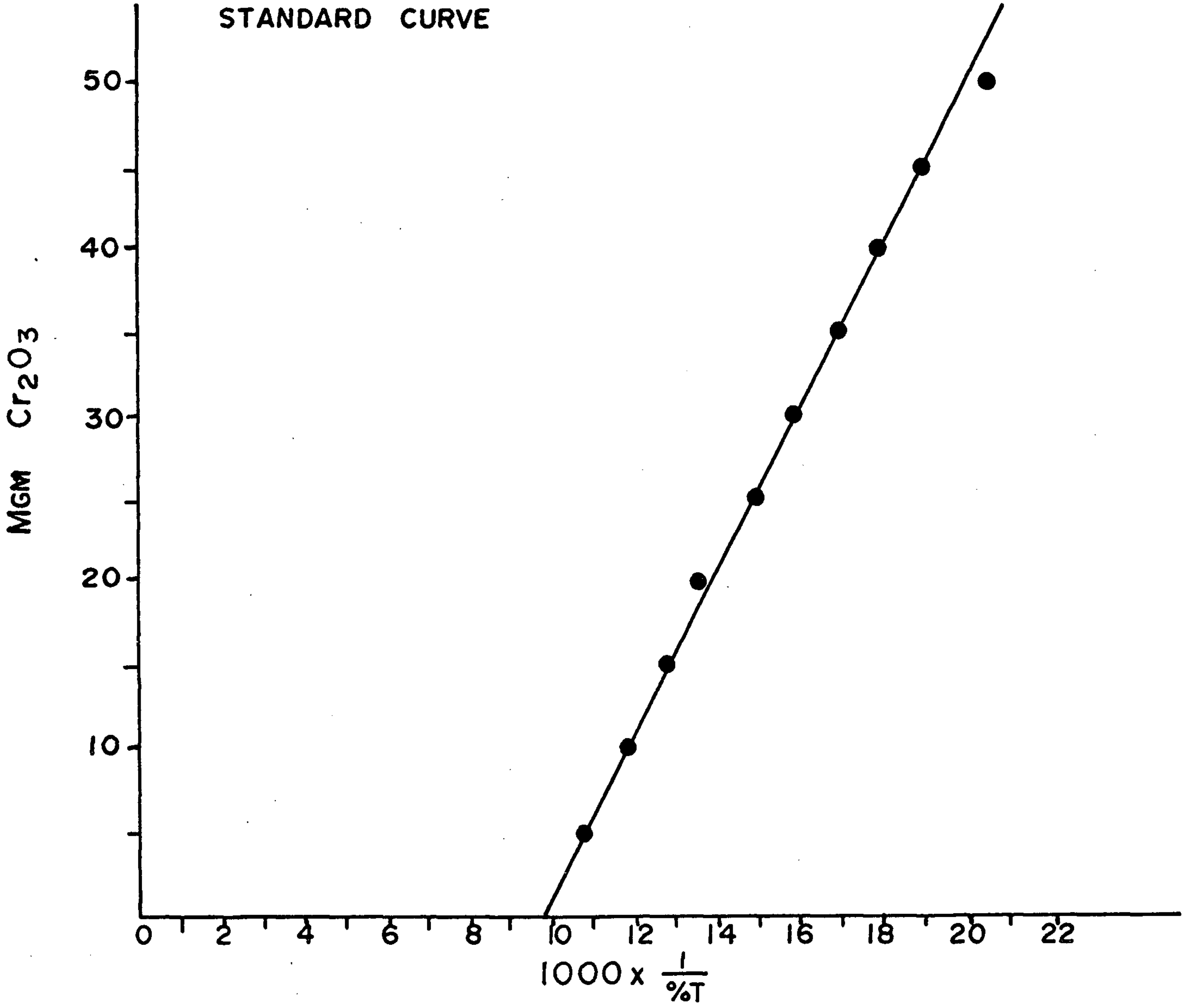
Month of Sampling	HAY D.M. (%)	HAY Crude Protein (%)	HAY Gross Energy (kcal/g)	BEET PULP D.M. (%)	BEET PULP Crude Protein (%)	BEET PULP Gross Energy (kcal/g)	CONCENTRATE D.M. (%)	CONCENTRATE Crude Protein (%)	CONCENTRATE Gross Energy (kcal/g)
Feb. 1970	89.50	19.44	4.45	87.50	10.68	4.05	88.10	17.15	4.39
Mar. 1970	89.00	19.25	4.20	88.90	9.67	4.10	85.80	18.58	4.42
Apr. 1970	87.02	14.04	4.41	91.10	8.42	4.05	88.10	16.39	4.41
May 1970	89.42	17.29	4.55	90.47	10.71	4.25	88.15	16.24	4.39
June 1970	89.72	14.34	4.35	91.27	9.45	4.11	89.53	15.90	4.40
July 1970	86.47	14.08	4.28	90.51	12.07	4.01	84.65	16.54	4.32
Aug. 1970	89.90	13.63	4.35	90.98	11.10	4.07	87.14	14.55	4.43
Sept. 1970	88.87	17.64	4.41	89.75	11.52	4.10	86.58	16.80	4.43
Oct. 1970	90.90	18.57	4.36	91.70	10.77	4.08	87.80	18.62	4.44
Nov. 1970	92.20	16.86	4.38	92.30	11.30	4.11	86.50	16.61	4.40
Dec. 1970	91.80	11.46	4.35	89.40	11.73	4.10	85.80	18.15	4.32
Jan. 1971	90.70	13.78	4.35	91.40	10.40	4.10	87.20	18.34	4.32

Appendix Table I - Continued

Month of Sampling	HAY D.M. (%)	HAY Crude Protein (%)	HAY Gross Energy (kcal/g)	BEET PULP D.M. (%)	BEET PULP Crude Protein (%)	BEET PULP Gross Energy (kcal/g)	CONCENTRATE D.M. (%)	CONCENTRATE Crude Protein (%)	CONCENTRATE Gross Energy (kcal/g)
Feb. 1971	86.10	21.60	4.37	90.70	9.80	4.08	87.40	17.00	4.41
Mar. 1971	90.21	16.60	4.42	91.22	10.10	4.11	87.61	16.40	4.43
Mean	89.42	16.33	4.374	90.51	10.55	4.094	87.17	16.95	4.393
S. D.	±1.84	±2.85	±0.083	±1.31	±1.00	±0.056	±1.23	±1.15	±0.041

S. D. = Standard Deviation

D. M. = Dry Matter



Appendix Figure 1. Regression of Chromic Oxide Concentration on 1000 Times the Reciprocal of the per cent Transmittance

Appendix Table II - Daily Dry Matter (kg) Intake at Successive Stages of Lactation

Month of Lactation \ Heifer No.	67007	67130	67133	67138	68002	68004	Mean
1	11.7	9.7	-	13.2	10.3	11.1	11.20
2	14.1	12.7	-	14.8	11.8	13.3	13.34
3	13.1	13.9	16.1	14.7	11.6	13.6	13.83
4	13.0	12.5	15.8	13.3	12.1	13.2	13.32
5	13.5	13.5	16.0	14.0	12.3	12.4	13.62
6	12.2	12.5	14.5	13.7	12.3	12.7	12.98
7	11.7	12.3	13.6	13.3	12.2	12.6	12.62
8	11.7	12.7	12.7	12.7	12.3	12.7	12.47
9	11.1	12.7	13.1	12.6	12.0	12.4	12.32
10	-	-	12.1	12.5	12.2	12.6	12.35
Mean	12.5	12.5	14.2	13.5	11.9	12.7	12.81

Appendix Table III - Daily TDN (kg) Intake at Successive Stages of Lactation

Month of Lactation \ Heifer No.	67007	67130	67133	67138	68002	68004	Mean (kg)
1	7.76	6.45	-	8.78	6.74	7.35	7.42
2	9.39	8.37	-	9.79	7.76	8.85	8.83
3	8.64	9.18	10.69	9.78	7.62	8.97	9.15
4	8.57	8.23	10.54	8.85	7.96	8.77	8.82
5	8.98	8.91	10.60	9.32	8.15	8.22	9.03
6	8.03	8.30	9.66	9.13	8.18	8.43	8.62
7	7.69	8.09	8.98	8.84	8.09	8.36	8.34
8	7.69	8.49	8.23	8.49	8.15	8.43	8.25
9	7.28	8.49	8.64	8.36	7.96	8.23	8.16
10	-	-	7.96	8.30	8.09	8.36	8.18
Mean	8.23	8.28	9.41	8.96	7.87	8.40	8.48

TDN was calculated from DE assuming
1 kg TDN = 4.4 Mcal DE (143)

Appendix Table IV - Daily Gross Energy (Mcal) Intake at Successive Stages of Lactation

Month of Lactation \ Heifer No.	67007	67130	67133	67138	68002	68004	Mean
1	50.05	41.64	-	56.61	43.51	47.45	47.85
2	60.55	53.99	-	63.17	50.08	57.08	56.97
3	55.74	59.23	68.96	63.09	49.14	57.89	59.01
4	55.30	53.11	67.99	57.08	51.33	56.58	56.90
5	57.92	57.48	68.42	60.11	52.61	53.05	58.27
6	51.80	53.55	62.30	58.91	52.79	54.36	55.62
7	49.61	52.23	57.92	57.05	52.20	53.95	53.83
8	49.61	54.80	53.11	54.80	52.61	54.36	53.22
9	46.98	54.80	55.73	53.96	51.33	53.08	52.65
10	–	–	51.36	53.52	53.20	53.95	52.76
Mean	53.06	53.43	60.72	57.83	50.88	54.18	54.71

Appendix Table V - Daily Digestible Energy (DE) (Mcal) Consumption at Successive Stages of Lactation

Month of Lactation \ Heifer No.	67007	67130	67133	67138	68002	68004	Mean
1	34.13	28.40	-	38.61	29.67	32.36	32.63
2	41.30	36.82	-	43.08	34.15	38.93	38.86
3	38.01	40.39	47.03	43.03	33.51	39.48	40.24
4	37.71	36.22	46.37	38.93	35.01	38.59	38.81
5	39.50	39.20	46.66	41.00	35.88	36.18	39.74
6	35.33	36.52	42.49	40.18	36.00	37.07	37.93
7	33.83	35.61	39.50	38.91	35.60	36.79	36.71
8	33.83	37.37	36.22	37.37	35.88	37.07	36.29
9	32.04	37.37	38.01	36.80	35.01	36.20	35.91
10	-	-	35.03	36.50	35.60	36.79	35.98
Mean	36.19	36.43	41.41	39.44	34.63	36.95	37.31

Appendix Table VI - Daily Metabolizable Energy (ME) (Mcal) Intake at Successive Stages of Lactation

Month of Lactation \ Heifer No.	67007	67130	67133	67138	68002	68004	Mean
1	27.93	22.98	-	32.25	24.25	26.61	26.80
2	34.84	30.61	-	36.43	28.23	32.58	32.54
3	31.61	33.90	40.01	36.85	27.59	33.03	33.83
4	31.51	30.09	39.22	32.54	28.80	32.03	32.37
5	33.03	32.85	39.96	34.43	29.48	29.76	33.25
6	29.37	30.29	35.75	33.52	29.74	30.71	31.56
7	27.73	29.29	33.15	32.22	29.56	30.63	30.43
8	27.66	30.88	30.02	31.05	29.74	30.82	30.03
9	26.20	31.05	31.83	30.61	28.67	29.74	29.68
10	-	-	28.80	30.15	29.44	30.52	29.73
Mean	30.00	30.22	34.84	33.01	28.55	30.64	31.02

Appendix Table VII - Daily Estimated Net Energy (ENE) (Mcal) Intake at Successive Stages of Lactation

Month of Lactation \ Heifer No	67007	67130	67133	67138	68002	68004	Mean
1	14.88	12.39	-	16.86	12.84	14.11	14.22
2	18.06	15.99	-	18.77	14.82	17.00	16.93
3	16.49	17.54	20.52	18.78	14.53	17.16	17.50
4	16.37	15.74	20.28	16.99	15.20	16.82	16.90
5	17.25	17.04	20.34	17.93	15.64	15.76	17.33
6	15.32	15.93	18.57	17.59	15.64	16.14	16.53
7	14.66	15.45	17.17	16.99	15.51	16.05	15.97
8	14.66	16.38	15.56	16.38	15.64	16.14	15.79
9	13.87	16.38	16.49	16.05	15.25	15.76	15.63
10	-	-	15.20	15.93	15.51	16.05	15.67
Mean	15.73	15.87	18.02	17.23	15.06	16.10	16.25

Appendix Table VIII - Monthly Body Weight (kg) During Lactation

Heifer No. \ Month of Lactation	1	2	3	4	5	6	7	8	9	10
67007	493.8	479.5	474.0	468.9	469.5	467.1	495.5	505.0	509.8	-
67130	493.1	469.2	476.4	481.1	500.2	505.0	516.5	524.1	544.1	-
67133	-	-	514.5	519.3	539.1	540.1	545.4	549.1	564.1	570.1
67138	468.9	446.5	444.1	457.7	495.0	510.8	512.2	514.5	524.1	524.1
68002	434.1	421.6	412.7	412.7	419.2	421.4	439.5	455.5	469.3	476.4
68004	499.3	489.1	495.5	500.2	497.4	497.8	503.1	516.8	520.0	524.1
Mean	477.8	461.2	469.5	473.3	486.7	490.4	502.0	510.8	521.9	523.7

Appendix Table IX - Monthly 4% FCM Production (kg) During Lactation

Month of Lactation \ Heifer No.	67007	67130	67133	67138	68002	68004	Mean
1	581.2	496.8	-	771.2	670.6	702.0	644.4
2	541.7	535.8	-	863.0	637.3	742.1	664.0
3	577.1	428.5	628.3	834.1	549.7	696.8	619.1
4	565.6	484.8	546.0	689.1	562.4	716.3	594.0
5	521.2	599.7	506.4	732.7	432.5	630.5	570.5
6	484.6	585.7	556.1	691.6	389.6	581.8	548.2
7	406.9	542.7	592.8	654.4	377.8	546.3	520.2
8	387.9	521.1	526.1	603.8	363.9	509.5	485.4
9	287.8	495.0	485.0	572.3	345.9	507.1	448.9
10	-	-	422.1	546.8	342.5	478.3	447.4
Total	4354.0	4690.1	4262.8	6959.0	4672.2	6110.7	

Appendix Table X - Gross Energetic Efficiency (%) for Individual Heifers During Lactation

Month of Lactation \ Heifer No.	67007	67130	67133	67138	68002	68004	Mean
1	41.61	42.96	-	49.26	50.93	53.15	47.58
2	33.66	36.94	-	49.21	46.27	47.01	42.62
3	37.88	27.98	33.49	47.41	40.73	43.06	38.43
4	36.60	34.24	30.04	43.41	39.70	44.83	38.14
5	32.15	37.76	28.08	43.41	30.21	42.29	35.65
6	33.12	39.16	33.18	41.81	26.75	37.77	35.30
7	28.97	37.07	36.96	40.60	25.84	35.88	34.22
8	27.20	33.98	35.89	39.07	24.39	33.18	32.29
9	21.54	32.11	31.31	37.50	24.00	37.70	30.03
10	-	-	28.98	36.16	23.60	30.99	29.93
Mean	32.53	35.80	32.24	42.78	33.24	40.19	36.42 S.D. ±5.55

S.D. = Standard Deviation

Appendix Table XI - Net Energetic Efficiency (%) for Individual Heifers during Lactation

Month of Lactation \ Heifer No.	67007	67130	67138	68002	68004	Mean
1	Data Eliminated					
2	55.91	65.89	77.09	82.25	82.28	72.68
3	66.36	47.04	74.16	72.57	75.19	67.06
4	64.10	62.88	73.05	68.44	80.06	69.71
5	54.48	66.61	73.71	51.57	79.36	65.15
6	60.94	73.60	73.22	47.70	69.48	64.99
7	57.78	72.41	73.01	45.57	66.90	63.13
8	54.96	64.14	72.85	43.64	62.53	59.62
9	46.56	62.08	71.76	44.61	65.17	58.04
10	-	-	69.73	43.68	59.31	57.57
Mean	57.64	64.33	73.18	55.56	71.14	64.22 S.D.±5.20

S. D. = Standard Deviation

Appendix Table XII - Daily Requirement of Digestible Energy (Mcal/kg FCM) above Maintenance during Lactation

Month of Lactation \ Heifer No.	67007	67130	67138	68002	68004	Mean
1	Data Eliminated					
2	1.373	1.153	0.955	0.906	0.900	1.057
3	1.130	1.680	1.142	1.028	0.975	1.191
4	1.139	1.217	0.970	1.080	0.094	1.062
5	1.340	1.111	1.007	1.460	0.918	1.167
6	1.185	0.996	1.040	1.621	1.039	1.176
7	1.247	1.007	0.951	1.602	1.084	1.178
8	1.298	1.138	0.997	1.657	1.157	1.249
9	1.544	1.172	1.007	1.637	1.108	1.294
10	-	-	1.040	1.687	1.201	1.309
Mean	1.282	1.184	1.012	1.409	1.032	1.187 S.D. ±0.089

S. D. = Standard Deviation

Appendix Table XIII - Daily Requirements of TDN (g/kg FCM) above Maintenance during Lactation

Month of Lactation \ Heifer No.	67007	67130	67138	68002	68004	Mean
1	Data Eliminated					
2	312	262	217	206	205	240.4
3	257	382	259	234	221	270.6
4	259	277	221	246	205	241.6
5	304	253	229	332	209	265.4
6	269	226	236	368	236	267.0
7	283	229	216	364	246	267.6
8	295	259	227	377	263	284.2
9	351	266	229	372	252	294.0
10	-	-	236	383	273	297.3
Mean	291	269	230	320	234	270.0
					S.D.	±20.0

S. D. = Standard Deviation

Appendix XIV - Daily Energy Losses (Mcal) in Feces at Successive Stages of Lactation

Month of Lactation \ Heifer No.	67007	67130	67133	67138	68002	68004	Mean	Mean as % of Gross Energy
1	15.92	13.24	-	18.00	13.84	15.09	15.22	31.8
2	19.25	17.17	-	20.09	15.93	18.15	18.12	31.8
3	17.73	18.84	21.93	20.06	15.63	18.41	18.77	31.8
4	17.59	16.89	21.62	18.15	16.32	17.99	18.09	31.8
5	18.42	18.28	21.76	19.11	16.74	16.87	18.53	31.8
6	16.41	17.03	19.81	18.73	16.79	17.29	17.69	31.8
7	15.78	16.61	18.42	18.14	16.60	17.16	17.12	31.8
8	15.78	17.43	16.89	17.43	16.73	17.29	16.92	31.8
9	14.94	17.43	17.72	17.16	16.32	16.88	16.74	31.8
10	-	-	16.33	17.02	16.92	17.15	16.78	31.8
Mean	16.87	16.99	19.31	18.39	16.18	17.23	17.40	31.8

Appendix Table XV - Daily Urine Energy (Mcal) Excreted at Successive Stages of Lactation

Month of Lactation \ Heifer No.	67007	67130	67133	67138	68002	68004	Mean	Mean as % of GE
1	2.77	2.20	-	2.90	2.14	2.37	2.476	5.2
2	3.03	2.74		3.26	2.49	2.89	2.882	5.1
3	2.94	3.04	3.79	3.25	2.50	2.99	3.085	5.2
4	2.72	2.67	3.89	2.87	2.77	3.09	3.002	5.3
5	3.01	2.89	3.45	3.13	2.94	2.96	3.063	5.3
6	2.51	2.77	3.33	3.29	2.81	2.90	2.935	5.3
7	2.68	2.87	2.89	3.14	2.59	2.70	2.812	5.2
8	2.75	3.02	2.74	2.85	2.68	2.79	2.805	5.3
9	2.47	2.85	2.71	2.73	2.90	3.00	2.777	5.3
10	-	-	2.78	2.89	2.71	2.81	2.800	5.3
Mean	2.76	2.78	3.19	3.03	2.65	2.85	2.864	5.30 S.D. ±0.07

S. D. = Standard Deviation

Appendix Table XVI - Daily Methane Energy (Mcal) Production at Successive Stages of Lactation

Month of Lactation \ Heifer No.	67007	67130	67133	67138	68002	68004	Mean	Mean as % of GE
1	3.43	3.22	-	3.46	3.28	3.38	3.354	7.0
2	3.43	3.47	-	3.39	3.43	3.46	3.436	6.0
3	3.46	3.45	3.23	2.93	3.42	3.46	3.325	5.6
4	3.48	3.46	3.26	3.52	3.44	3.47	3.438	6.0
5	3.46	3.46	3.25	3.44	3.46	3.46	3.422	5.9
6	3.45	3.46	3.41	3.37	3.45	3.46	3.433	6.2
7	3.42	3.45	3.46	3.55	3.45	3.46	3.465	6.4
8	3.42	3.47	3.46	3.47	3.46	3.46	3.457	6.5
9	3.37	3.47	3.47	3.46	3.44	3.46	3.445	6.5
10	-	-	3.45	3.46	3.45	3.46	3.455	6.5
Mean	3.44	3.43	3.37	3.41	3.43	3.45	3.423	6.3
							S.D.	±0.55

S. D. = Standard Deviation

Appendix XVII - Daily Heat Production (Mcal) at Successive Stages of Lactation

Month of Lactation \ Heifer No.	67007	67130	67133	67138	68002	68004	Mean	Mean as % of GE
1	21.72	20.01	-	23.06	20.39	21.20	21.276	44.5
2	23.87	22.53	-	24.40	21.73	23.16	23.138	40.6
3	22.88	23.60	25.58	24.39	21.54	23.32	23.552	39.9
4	22.80	22.35	25.38	23.16	21.99	23.06	23.123	40.6
5	23.33	23.24	25.47	23.78	22.25	22.34	23.402	40.2
6	22.08	22.44	24.22	23.53	22.28	22.60	22.858	41.1
7	21.64	22.17	23.33	23.15	22.16	22.52	22.495	41.8
8	21.64	22.69	22.35	22.69	22.25	22.60	22.370	42.0
9	21.10	22.69	22.88	22.52	21.99	22.34	22.253	42.3
10	-	-	22.00	22.43	22.16	22.52	22.278	42.2
Mean	22.34	22.41	23.90	23.31	21.87	22.57	22.675	41.5 S.D. ± 1.35

S. D. = Standard Deviation

Appendix Table XVIII - Daily Energy Yields in Milk (Mcal) at Successive Stages of Lactation

Month of Lactation \ Heifer No.	67007	67130	67133	67138	68002	68004	Mean (Mcal)	Mean as % of GE
1	14.20	12.2	-	19.02	15.1	17.2	15.55	32.5
2	13.9	13.6	-	21.2	15.8	18.3	16.56	29.1
3	14.4	11.3	15.8	20.4	13.7	17.0	15.43	26.2
4	13.8	12.4	13.9	16.9	13.9	17.3	14.70	25.8
5	12.7	14.8	13.1	17.8	10.8	15.3	14.09	24.2
6	11.7	14.3	14.1	16.8	9.6	14.0	13.42	24.1
7	9.8	13.2	14.6	15.8	9.2	13.2	12.63	23.5
8	9.2	12.7	13.0	14.6	8.8	12.3	11.76	22.1
9	6.9	12.0	11.9	13.8	8.4	12.2	10.87	20.6
10	-	-	10.2	13.2	8.4	11.4	10.80	20.5
Mean	11.8	12.9	13.3	17.0	11.4	14.8	13.58 S.D.	24.9 ±3.75

S. D. = Standard Deviation

Appendix Table XIX - Daily Energy Balance (Mcal) at Successive Stages of Lactation

Month of Lactation \ Heifer No.	67007	67130	67133	67138	68002	68004	Mean	Mean as % of GE
1	6.21	2.97	-	9.19	3.86	5.41	5.528	11.6
2	10.97	8.08	-	12.03	6.50	9.42	9.400	16.5
3	8.73	10.30	14.43	12.46	6.05	9.71	10.280	17.4
4	8.71	7.74	13.84	9.38	6.81	8.97	9.242	16.2
5	9.70	9.61	14.49	10.65	7.23	7.42	9.850	16.9
6	7.29	7.85	11.53	9.99	7.46	8.11	8.705	15.7
7	6.09	7.12	9.82	9.07	7.40	8.11	7.935	14.7
8	6.02	8.19	7.67	8.36	7.49	8.22	7.658	14.4
9	5.10	8.36	8.95	8.09	6.68	7.40	7.430	14.1
10	-	-	6.80	7.72	7.28	8.00	7.450	14.1
Mean	7.65	7.80	10.94	9.69	6.68	8.08	8.348 S.D.	15.2 ±1.73

S. D. = Standard Deviation

Appendix Table XX - Daily Tissue Gained or Lost (Mcal) at Successive Stages of Lactation

Month of Lactation \ Heifer No.	67007	67130	67133	67138	68002	68004	Mean	Mean as % of GE
1	-7.99	-9.23	-	-9.83	-12.44	-11.79	-10.256	-21.4
2	-3.07	-5.52	-	-9.17	- 9.30	- 8.88	- 7.188	-12.6
3	-5.67	-1.00	-1.32	-7.94	- 7.60	- 7.29	- 5.137	- 8.7
4	-5.09	-4.66	-0.09	-7.52	- 7.09	- 8.33	- 5.463	- 9.6
5	-3.00	-5.19	+1.39	-7.15	- 3.61	- 7.88	- 4.240	- 7.3
6	-4.41	-6.45	-2.57	-6.81	- 2.17	- 5.89	- 4.717	- 8.5
7	-3.71	-6.08	-4.78	-6.73	- 1.80	- 5.09	- 4.698	- 8.7
8	-3.18	-4.51	-5.33	-6.24	- 1.26	- 4.08	- 4.100	- 7.7
9	-1.80	-3.64	-2.95	-5.71	- 1.72	- 4.80	- 3.437	- 6.5
10	-	-	-3.35	-5.48	- 1.12	- 3.40	- 3.338	- 6.3
Mean	-4.21	-5.14	-2.38	-7.26	- 4.81	- 6.74	- 5.257	- 9.7

Appendix Table XXI - Cost ($) of Feeds Consumed at Successive Stages of Lactation

Heifer No.	Month of Lactation	1	2	3	4	5	6	7	8	9	10	Lactation Total ($)	Daily ($)
67007	Total	25.33	31.50	28.67	27.76	29.15	25.85	24.52	24.52	23.03	-	240.33	
	Daily	0.84	1.05	0.96	0.93	0.97	0.86	0.82	0.82	0.77	-		0.89
67130	Total	20.71	27.82	30.09	26.88	29.06	26.70	26.14	26.47	26.47	-	240.34	
	Daily	0.69	0.93	1.00	0.90	0.97	0.89	0.87	0.88	0.88	-		0.89
67133	Total	-	-	36.22	35.58	36.08	32.04	29.60	27.15	28.07	25.62	250.36	
	Daily	-	-	1.21	1.19	1.20	1.07	0.99	0.91	0.94	0.85		1.05
67138	Total	29.04	32.28	35.62	28.24	30.39	30.39	27.13	26.47	26.47	26.47	292.50	
	Daily	0.97	1.08	1.19	0.94	1.01	1.01	0.90	0.88	0.88	0.88		0.98
68002	Total	22.00	25.45	23.97	25.49	25.49	25.49	25.49	25.49	25.49	25.49	249.85	
	Daily	0.73	0.85	0.80	0.85	0.85	0.85	0.85	0.85	0.85	0.85		0.83
68004	Total	24.05	29.21	28.88	28.27	25.69	26.47	26.47	26.47	26.47	26.47	268.45	
	Daily	0.80	0.97	0.96	0.94	0.86	0.88	0.88	0.88	0.88	0.88		0.89
All Heifers	Total	121.13	146.26	183.45	172.22	175.86	166.94	159.35	156.57	156.00	104.00	1541.83	
	Daily	4.03	4.88	6.12	5.75	5.86	5.56	5.31	5.22	5.20	3.46		

Appendix Table XXII - Revenue ($) from Milk at Successive Stages of Lactation (Calculated on Quota and Surplus Milk Basis)

Heifer No.	Month of Lactation	1	2	3	4	5	6	7	8	9	10	Lactation Total ($)	Daily ($)
67007	Total	90.79	85.73	88.32	82.60	71.85	63.62	52.77	50.42	37.60	-	623.70	
	Daily	3.03	2.86	2.94	2.75	2.40	2.12	1.76	1.68	1.25	-		2.31
67130	Total	76.20	83.43	68.36	71.67	81.35	77.34	71.68	69.77	65.78	-	665.58	
	Daily	2.54	2.78	2.28	2.39	2.71	2.58	2.39	2.33	2.19	-		2.47
67133	Total	-	-	101.18	88.47	80.10	86.29	86.48	71.85	64.26	54.58	633.21	
	Daily	-	-	3.37	2.95	2.67	2.88	2.88	2.40	2.14	1.82		2.64
67138	Total	116.64	128.24	117.05	92.57	96.15	91.07	86.89	80.13	75.79	72.73	957.26	
	Daily	3.89	4.27	3.90	3.09	3.21	3.04	2.90	2.67	2.53	2.42		3.19
68002	Total	94.23	86.58	73.66	75.20	59.57	52.69	50.46	48.27	45.97	47.17	633.80	
	Daily	3.14	2.89	2.46	2.51	1.99	1.76	1.68	1.61	1.53	1.57		2.14
68004	Total	99.60	100.61	91.81	93.87	84.17	76.84	72.21	67.73	66.62	64.18	817.64	
	Daily	3.32	3.35	3.06	3.13	2.81	2.56	2.41	2.26	2.22	2.14		2.73

Appendix Table XXIII - Revenue ($) from Milk at Successive Stages of Lactation (Calculated on Quota Milk Basis)

Heifer No.	Month of Lactation	1	2	3	4	5	6	7	8	9	10	Lactation Total ($)	Daily ($)
67007	Total	91.47	89.13	92.54	88.46	81.52	75.00	62.97	59.38	44.07	-	684.54	
	Daily	3.05	2.97	3.08	2.95	2.72	2.50	2.10	1.98	1.47	-		2.54
67130	Total	78.48	87.50	72.65	80.02	95.31	92.17	84.89	81.66	77.30	-	749.98	
	Daily	2.62	2.92	2.42	2.67	3.18	3.07	2.83	2.72	2.58			2.78
67133	Total	-	-	101.23	89.45	84.17	90.31	93.54	83.27	76.33	65.24	683.54	
	Daily	-	-	3.37	2.98	2.81	3.01	3.12	2.78	2.54	2.17		2.85
67138	Total	122.30	136.59	131.28	108.64	114.61	107.67	101.72	94.15	88.58	85.01	1090.55	
	Daily	4.08	4.55	4.38	3.62	3.82	3.59	3.39	3.14	2.95	2.83		3.64
68002	Total	104.72	101.28	87.74	89.20	69.68	61.92	59.08	56.26	54.02	53.86	737.76	
	Daily	3.49	3.38	2.92	2.97	2.32	2.06	1.97	1.88	1.80	1.80		2.46
68004	Total	110.68	117.68	109.37	111.35	98.46	90.29	84.55	78.96	78.28	73.29	952.91	
	Daily	3.69	3.92	3.65	3.71	3.28	3.01	2.82	2.63	2.61	2.44		3.18

Appendix Table XXIV - Revenue ($) from Milk at Successive Stages of Lactation (Calculated on Surplus Milk Basis)

Heifer No.	Month of Lactation	1	2	3	4	5	6	7	8	9	10	Lactation Total ($)	Daily ($)
67007	Total	47.17	45.96	47.72	45.62	42.04	38.67	32.47	30.62	22.72	-	352.98	
	Daily	1.57	1.53	1.59	1.52	1.40	1.29	1.08	1.02	0.76	-		1.31
67130	Total	40.47	45.12	37.46	41.26	49.15	47.53	43.77	42.11	39.86	-	386.73	
	Daily	1.35	1.50	1.25	1.38	1.64	1.58	1.46	1.40	1.33	-		1.43
67133	Total	-	-	52.20	46.13	43.40	46.57	48.23	42.94	39.36	33.64	352.46	
	Daily	-	-	1.74	1.54	1.45	1.55	1.61	1.43	1.31	1.12		1.47
67138	Total	63.06	70.43	67.69	56.02	59.10	55.52	52.45	48.55	45.68	43.83	562.34	
	Daily	2.10	2.35	2.26	1.87	1.97	1.85	1.75	1.62	1.52	1.46		1.87
68002	Total	54.00	52.22	45.24	46.00	35.93	31.93	30.47	29.01	27.86	27.77	380.42	
	Daily	1.80	1.74	1.51	1.53	1.20	1.06	1.02	0.97	0.93	0.93		1.27
68004	Total	57.07	60.68	56.40	57.42	50.77	46.56	43.60	40.71	40.36	37.79	491.36	
	Daily	1.90	2.02	1.88	1.91	1.69	1.55	1.45	1.36	1.35	1.26		1.64

Appendix Table XXV - Daily Milk Revenue ($) over and above Feed Costs from Individual Heifers at Successive Stages of Lactation (Calculated on Quota and Surplus Milk Basis)

Month of Lactation \ Heifer No.	67007	67130	67133	67138	68002	68004	Mean
1	2.18	1.85	-	2.92	2.41	2.52	2.38
2	1.81	1.85	-	3.20	2.04	2.38	2.26
3	1.99	1.28	2.17	2.71	1.66	2.10	1.99
4	1.83	1.49	1.76	2.14	1.66	2.19	1.85
5	1.42	1.74	1.47	2.19	1.14	1.95	1.65
6	1.26	1.69	1.81	2.02	0.91	1.68	1.56
7	0.94	1.52	1.90	1.99	0.83	1.52	1.45
8	0.86	1.44	1.49	1.79	0.76	1.38	1.29
9	0.49	1.31	1.21	1.64	0.68	1.34	1.11
10	-	-	0.97	1.54	0.72	1.26	1.12
Mean	1.42	1.57	1.60	2.21	1.28	1.83	1.67

Appendix Table XXVI - Daily Milk Revenue ($) over and above Feed Costs from Individual Heifers at Successive Stages of Lactation (Calculated on Quota Milk Basis)

Month of Lactation \ Heifer No.	67007	67130	67133	67138	68002	68004	Mean
1	2.20	1.93	-	3.11	2.76	2.89	2.58
2	1.92	1.99	-	3.48	2.53	2.95	2.57
3	2.13	1.42	2.17	3.19	2.13	2.68	2.29
4	2.02	1.77	1.80	2.68	2.12	2.77	2.19
5	1.75	2.21	1.60	2.81	1.47	2.43	2.05
6	1.64	2.18	1.94	2.58	1.21	2.13	1.95
7	1.28	1.96	2.13	2.49	1.12	1.94	1.82
8	1.16	1.84	1.87	2.26	1.03	1.75	1.65
9	0.70	1.69	1.61	2.07	0.95	1.73	1.46
10	-	-	1.32	1.95	0.95	1.56	1.45
Mean	1.64	1.89	1.80	2.66	1.63	2.28	2.00

Appendix Table XXVII - Daily Milk Revenue ($) over and above Feed Costs from Individual Heifers at Successive Stages of Lactation (Calculated on Surplus Milk Basis)

Month of Lactation \ Heifer No.	67007	67130	67133	67138	68002	68004	Mean
1	0.73	0.66	-	1.13	1.07	1.10	0.94
2	0.48	0.58	-	1.27	0.89	1.05	0.85
3	0.64	0.25	0.53	1.07	0.71	0.92	0.69
4	0.60	0.48	0.35	0.93	0.68	0.97	0.67
5	0.43	0.67	0.24	0.96	0.35	0.84	0.58
6	0.43	0.69	0.48	0.84	0.22	0.67	0.56
7	0.27	0.59	0.62	0.84	0.17	0.57	0.51
8	0.20	0.52	0.53	0.74	0.12	0.47	0.43
9	- 0.01	0.45	0.38	0.64	0.08	0.46	0.33
10	-	-	0.27	0.58	0.08	0.38	0.33
Mean	0.42	0.54	0.43	0.90	0.44	0.74	0.59