AN ECONOMIC EVALUATION AND REPLACEMENT MODEL FOR THE LACTATING DAIRY COW INCLUDING BIOLOGICAL COMPONENTS

By

Joseph G. Hlubik

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Dairy Science

1979

ABSTRACT

AN ECONOMIC EVALUATION AND REPLACEMENT MODEL
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A computer model was developed to estimate the annualized net present value of a dairy cow, enabling comparisons among cows as an aid in determining optimum voluntary replacement patterns. Expected values (probabilistic sense) were used to account for the uncertainty underlying involuntary culling. Milk production, hence income, is estimated based upon DHIA estimated mature equivalent milk yield, standardized for age and season of calving. Similarly, a credit is made for the sale of cull animals. Costs include both feed and nonfeed variable costs. The feed cost component characterizes dry matter intake and nutrient requirements over the life cycle, and within a lactation, based on expected production performance. Feed disappearance is estimated using a linear programming subsystem which balances a diet and, in turn, projects feed disappearance. The model is flexible; additional subsystems can easily be entered that deal with significant biological and economic factors.

DEDICATION

This thesis is dedicated to
the Sacred Heart of Jesus Christ.

ACKNOWLEDGMENTS

I would like to express my appreciation to John and Sarah Dumschat for encouraging me to enter a Master's program at Michigan State and for their hospitality and friendship. Sincere thanks to Winston Ingalls for his much appreciated advice and friendship. Special thanks are due to Drs. Russel Erickson and Roy Black for invaluable assistance and also to members of the committee: Dr. Roy Emery, Dr. Glenn Johnson, and Dr. Donald Hillman.

I am indebted to the Department of Dairy Science for financial assistance during the course of my studies.

I would also like to thank Mrs. Mary Hillman and Susan MacMahon for helping prepare and type the manuscript.

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INTRODUCTION

The objective of this research is to develop a dynamic macro-level bio-economic model of the dairy cow, integrating the following subsystem: 1) milk production; 2) dry matter intake; 3) nutrient requirements; 4) growth; and 5) odds of involuntary individual animal removal from the herd. The model's economic focus is to estimate the expected net present value of a cow at any point in her lifetime. Thus, the model can be used or a decision-aid by dairymen when making cow replacement decisions. Questions such as: "Should I replace a four-year old cow whose mature equivalent is 15,000 lbs of milk with a heifer whose mature equivalent is 16,500 lbs?" can be asked.

The model has potential for other uses also, including projection of feed budgets, estimation of variable costs, projection of cash-flow statements, estimation of herd turnover rate, and forecasting herd milk output.

Other studies have dealt with the replacement problem, but none have focused on the characteristics of the particular replacement animal or the animal being replaced. Production level is usually assumed at an average herd value, and if genetic improvement is considered it is usually expressed as a yearly rate of herd improvement. Dry matter intake and diet characteristics have been typically considered as fixed factors or modeled in a relatively naive manner. Therefore, the focus of this study was on accurately forecasting feed disappearance for cows of alternative mature equivalents.

This study is only a beginning point in the development of a "dairy cow model." As parameters become more refined, corrections can be incorporated. The program is composed of various subsystems which can be easily added to or deleted.

With the age of electronic identification and computer analysis upon us it is not difficult to imagine such programs becoming important in dairy management.

LITERATURE REVIEW OF REPLACEMENT MODELS

Development of replacement decision theory, computer simulation modeling and refinement in biological conceptual framework and parameters have been concurrent with the evolution of models dealing with the question of optimal replacement of dairy cows. Jenkins and Halter, (1962), Redman and Kuo, (1969), and Giaver, (1966), presented the problem as one involving maximization of present value using a multi-stage decision analysis. Whereas a single-stage decision policy is obtained by looking at each decision independent of other decisions in time, a multi-stage policy can be obtained by looking at all possible decision points for the entire time period being considered (Ahmed, 1974). The policy which yields the maximum net returns will be the optimal sequence of decisions. For example, each year a farmer must decide whether to keep or replace an animal based upon the expected returns of the cow versus her replacement candidate. The series of decisions which maximizes expected returns over the years considered is referred to as an optimal policy.

Solutions obtained by Giaver (1966), Redman and Kuo (1969) involve a Markovian programming approach. A Markovian process is a stochastic process where the probability distribution of outcomes at any given stage depends only on the outcome at the last preceding stage (i.e. if we use a Markovian process and know the outcome of the last observation, we can neglect any information we have about previous observations in predicting the future) (Buffa and Dyer, 1977). Hutton (1966) developed a simulated replacement model which was intended for use at the farm level. Interested dairymen filled out a 50-item questionnaire specifying conditions present at each particular farm. The complexity of the questions made the model impractical.

Rundell (1967) examined replacement strategies among 6 operationally practical systems of culling cows. The strategies employed were: (1) mature equivalent (M.E.) milk production, (2) M.E. gross milk income, (3) actual milk production, (4) actual gross income, (5) income over feed cost, and (6) present value of expected gross income of a cow and her subsequent replacement candidate. The objective criterion was maximization of income over feed costs. Results of his study showed no significant differences among the strategies examined. Smith (1971) and Stewart et al. (1977) formulated generalized production prediction models. As the models evolved, levels of variability of the factors advance from discrete to more continuous variation.

Table 1 shows a comparison among the various replacement studies. The following observations help illustrate some of the strengths and weaknesses of the models examined and the various factors taken into consideration.

(1) The probability of success or failure of any given lactation was handled as a stochastic factor across the various studies. Smith and Stewart *et al*. separated the probability of death from the probability of failure in order to more accurately account for salvage value.

(2) Production prediction of milk was handled in a variety of ways across the studies. Genetic improvement of replacement candidates was taken into account by Smith, Rundell and Stewart *et al*. by assuming an increase in production per year of replacements over the herd average production level. Stewart *et al*. compared cows to an "average" producing replacement candidate to determine whether or not to cull.

(3) Except for Stewart *et al*. differences in body weight among cows within any age group were ignored.

(4) The calving interval was handled as a stochastic factor only by Giaver and Smith.

(5) Season of calving effects on production were not accounted for in any of the studies to date.

(6) Feed disappearance was not accurately accounted for in any of the studies. Stewart *et al*. at-

tempted to deal with the problem in a more advanced manner but did not include enough flexibility in their approach. Since feed costs comprise over 60% of the variable costs of milk production this is a serious weakness of previous replacement models.

Keeping the above observation in mind it is believed that the proper approach is to focus attention upon a more flexible biological model which could be used to predict inputs and outputs for any given cow at any stage of her lifetime. Once the biological model was defined, an economic analysis could then be incorporated and the replacement problem considered. Thus the objectives of this study are two-fold: 1) to begin the process of developing a biological dairy cow model and 2) to use the model to address the question of the proper time to replace a dairy cow and who she should be replaced with. The analysis can be used in answering questions such as: "Should I replace a 4-year old cow whose mature equivalent is 15,000 lbs with a heifer whose mature equivalent is 16,500 lbs?"

The first part of the thesis examines the important biological parameters needed to be taken into consideration. Background research findings are presented to make the reader aware of the sources of information used to define the parameters and the controversy that still envelopes some of them such as the area of protein requirements.

The second part of the thesis explains the economic analysis employed to solve the replacement problem and illustrates how the model operates. The quantitative and qualitative restrictions and parameters used in this particular model are defined there.

The last section presents the results and conclusions of this study pointing out the strengths and weaknesses of the model to date.

Table I. Review of Replacement Models

	Jenkins & Halter 1962 OREGON	Kuo & Redman 1967 KENTUCKY	Giaver 1966 CALIFORNIA Jerseys	Smith 1971 FLORIDA Jerseys	Stewart *et al.* 1977 ONTARIO	Hutton 1966 USDA	Rundell 1967 MICHIGAN
Kind of model	Dynamic program Multistage analysis	Dynamic program Markovian	Dynamic program Markovian	Dynamic program Markovian	Dynamic program Simulation	Simulation	Simulation
Maximum number of lactations considered	12+	7	6	6	7	User input	Based on Pearl's life expectancy formula
Strategy resulting from the study	Keep a cow for the first seven lactations, then replace with a heifer	Keep a cow for the first six lactations, then replace with a heifer	Depends upon the calving interval and prices	Depends upon the calving interval and prices	Depends upon the calving interval and prices	Depends upon user inputs	Depends upon price information
Size of animals	Used mature weighting index	Used mature weighting index	Used mature weighting index	Used mature weighting index	Used prediction equation, five levels, 100 kg apart, ranging from 450 kg to 850 kg	User input	Used a prediction equation
Production level of cows	3 levels considered: <350 lbs fat 350-450 lbs >450 lbs	3 levels considered: <12,000 lbs milk 12,000-15,000 lbs >15,000 lbs	Considers variation among cows in the herd and among lactations of the same cow	Predicted on the basis of previous records, 250 lb intervals from 5,000 to 12,000 lbs	Estimated 305 day milk production at 500 kg increments	305 day ME	Considers variation in production among cows and among lactation of the same cow
Production level of replacement candidates	3 levels considered	3 levels considered	Assumed to be equal to the average herd level	Genetic improvement over herd average of 1% per year	45 kg improvement of heifers per year over the herd average	User input	Genetic improvement over herd average of 2% per year

Table I. (cont'd)

	Jenkins & Halter 1962 OREGON	Kuo & Redman 1967 KENTUCKY	Giaver 1966 CALIFORNIA Jerseys	Smith 1971 FLORIDA Jerseys	Stewart et al. 1977 ONTARIO	Hutton 1966 USDA	Rundell 1967 MICHIGAN
Calving interval	Fixed	Fixed	Stochastic	Stochastic, 3 levels	Fixed at 12 months	User input	Fixed at 12 months
Feed disappearance	Feed consumption was modified by a body weight index	Feed consumption was modified by a body weight index; used DHIA feed consumption data from 1956-65	Gain consumption varies with monthly milk level; hay consumption is independent of production	Assumed relationship between size of animal and intake	Fixed level of corn silage; grain was assumed fed at 1 lb/3 lbs of milk; hay was used to fill remaining TDN requirements	User input	Fixed level of corn silage; grain was assumed fed at 1 lb/3 lbs of milk; hay was used to fill remaining TDN requirements
Success or failure of subsequent lactation	Stochastic	Stochastic	Stochastic	Stochastic; death was separated from failure	Stochastic; death was separated from failure	Derived from user input	Stochastic
Salvage value	Included as the price of beef	Included	Included as the function of age	Included as a function of beef prices and heifer prices	Included	User input	Fixed at average Michigan market prices over the years 1958-65
Value of calves	Not included	Not included	Not included	Stochastic, depending upon the probability of a heifer bull, the value of veal and the production of the dam	Not included	User input	Stochastic
Price of feed	3 levels of prices: 80% 100% of 1961 prices 120%	1956-1965 prices in various combinations	Included	Variation of a base price	Included at 3 levels	User input	2 prices each for hay, grain and silage

Table I. (cont'd)

	Jenkins & Halter 1962 OREGON	Kuo & Redman 1967 KENTUCKY	Giaver 1966 CALIFORNIA Jerseys	Smith 1971 FLORIDA Jerseys	Stewart *et al.* 1977 ONTARIO	Hutton 1966 USDA	Rundell 1967 MICHIGAN
Price of milk	3 levels of prices: 80%, 100%, 120% of the average price between years 1950-61	Expressed as a percent of 1965 prices	3 prices considered	Variation of a base price	Included at 3 levels	User input	2 base prices plus 2 fat differential prices
Interest rate on capital	Not included	Included	Set of 6%	Included	3 levels	User input	Included
Depreciation of a cow	Not included	Not included	Not included	Expressed as the difference in salvage value at the beginning and end of lactation	Expressed as the difference in present salvage value and value at the 60 days post-calving period	Not included	Not included
Transaction cost (transport, transfer fees)	Included	Included	Not included	Included	Included	Not included	Included

REVIEW OF IMPORTANT BIOLOGICAL AND ENVIRONMENTAL FACTORS THAT DEFINE THE INPUT-OUTPUT RELATIONSHIPS OF THE DAIRY COW

Milk Production

Estimating the Lactation Curve

The output of milk over the lactation cycle is characterized by a rapid rise during the first few weeks after calving until peak production per day is reached. Output then begins to decline in a linear fashion. Rate of rise in output, peak production and rate of decline in output vary with individual cows. Ridler and Broster (1969) examined the milk yields of 218 Friesian and Shorthorn first and second-half cows which had been individually rationed and subjected to constant managerial conditions. These records were analyzed to find the major characteristics of variability in the milk production cycle, with a view to prediction of performance. The values for the coefficients of variation were: (1) slope of curve from calving to peak yield, 15%; (2) days from calving to peak yield, 45%; (3) peak yield, 15%; (4) rate of decline per week in the three months after peak yield, 50%; (5) rate of yield decline per week in the period from peak yield to ½ peak yield, 25%; and (6) lactation yield, 20%. Peak yield was found to be the dominant feature of the curve for individual animals within groups. It markedly influenced the total output of milk in the lactation and the rate of decline in milk yield in mid-lactation. First lactation heifers were more persistent than cows, and cows calving in the autumn were more persistent than those calving in the spring.

Effects of Nutrition on the Lactation Curve

Line and Westgarth (1969) showed that the percentage decline in yield was linearly related to percentage reduction in feed consumed. Hillman *et al*. (1973) also found that feed intake was linearly related to milk yield.

Trimberger *et al*. (1972), in an experiment involving levels of concentrate fed, found that the weeks of peak production for both actual milk and 4 percent FCM were uniform among the different concentrate feeding groups and fairly uniform for individual cows for the three years, but variations from cow to cow were large. They concluded that peak production was higher in all groups on liberal grain during the three years when compared to the controls with one exception. (The slope of the milk curve with respect to days into lactation is an indication of persistency. Animals on liberal grain dropped in production slower than those fed limited grain.)

Van Ostergaard (1978) studied the effects of feeding different concentrate levels throughout the lactation independent of daily milk yield. The rate of decrease in milk yield was very dependent upon the manner in which the grain mix was fed. The decrease in milk yield is markedly lower when the grain mix was fed constantly from day to day instead of according to yield. Also, Thomas and Brown (1974) found that switching from a liberal grain feeding ratio of 1:1 to 1:3.5 pounds of grain per pound of milk caused a decrease in persistency from 92 percent to 79 percent of the previous month's milk yield.

Broster (1974) states that persistency is dominated by the individuality of the cows, but is also influenced by the system of feeding. The ability of the cow to "escape" at least temporarily, the effect of underfeeding, utilizing body reserves to support milk yield, adds to the problem of variation in persistency.

The potentially dangerous situation of low feed intake at the critically important stage of early lactation is met by a withdrawal of reserves to meet deficiencies. Broster (1974) determined that the cow's peak milk yield is critical in that her propensity to direct feed to milk in mid-lactation is favored by a high peak yield and reduced by a low one. The total milk yield output in the lactation is dominated by that peak yield. Broster further stated that once the peak yield is established, an optimal rate of decline in feed intake exists for an optimal level of milk production, fertility and refurbishing the bodyweight losses incurred earlier.

Equations for Estimating the Lactation Curve

Wood (1969, 1970, 1976) has studied the environmental factors which affect the shape of the lactation curve and how it varies between parities of cows and among herds. Also, he assessed the importance of variation in seasonality from year to year with particular reference to herd production forecasts. He found that in general cows calving in the same parity at the same time of year showed similar curves, modified only by total yield and abnormal season of production.

He proposed using the following equation to explain the shape of the lactation curve:

$$Y_n = an^b e^{cn}$$

where: Y_n = yield of milk being measured at time period n of the lactation

n = week into lactation

e = the base of natural logarithms

a,b,c = coefficients defining the lactation curve in question.

The curve reaches a turning point at $n_p = -(b/c)$. The turning point is independent of "a" which is the scaling factor. Thus, "b" and "c" define the shape of the curve. It is therefore possible to construct a curve for any given cow in any lactation by choosing the appropriate value for "a" provided it possesses the shape defined by "b" and "c" which have low coefficients of variation.

Wood (1969) ran a goodness of fit test using a sample of 859 Friesian lactation records drawn from 1964 to 1965. The data consisted of sets of weekly milk weights from calving to week 44 of lactation, or earlier if the cow went dry. Lactations were classified by parity number (1, 2, 3, 4+) as well as season of calving. The parameters "a," "b" and "c" were evaluated for each curve. At best, the model accounted for 91.2 percent of the variation in the logarithm of weekly yield and, at worst, 78.8 percent, with an average of 82.3 percent. The model fit best for those lactations beginning during the March-July period and showed the poorest fit during the September-December period.

Environmental Factors Affecting the Shape of the Curve

Shultz (1974) applied Wood's equation to Holstein Friesian cattle using Wisconsin DHIA records and attempted to determine which environmental factors had an effect on the lactation curve. Lactation number, season of calving, days open, days dry previous to lactation and an indication of the management level of the herd as measured by the folling herd average were investigated. Of the factors tested, lactation number, season of calving and days open exerted the greatest affect on the shape of the curve.

Lactation Number and Persistency

Shultz (1974), in agreement with Wood (1969), Ridler and Broster (1969), Sikka (1950) and Ripley *et al.* (1970), showed that persistency of yield decreases with lactation number.

Season of Calving

Season of calving was found by Shultz (1974) to influence the shape of the curve in the following ways: (1) Cows calving during the January-April period tend to be more persistent than cows calving during other seasons; (2) Cows calving during the May-June period show evidence of both a smaller increase in output at the beginning and the end of lactation; (3) Cows calving during the July-October period show a decrease in the relative height of the peak, resulting in a greater persistency than the population average in agreement with Appleven (1969) and Sikka (1950); (4) Cows calving during the November-December period produce a larger than normal percentage during mid-lactation with smaller proportions at the beginning and end, consistent with the findings of Wood (1969).

There was a definite seasonal stimulation to milk production, regardless of the stage of lactation, exerted during the March-June period. The shape of the curve was significantly determined by the relative position of these calendar months in the lactation.

Days Open and the Calving Interval

The calving interval is the sum of the days in milk and the days dry and depends upon how soon cows are re-bred after parturition. Days open refers to the period of time between parturition and subsequent conception. Ideally, to achieve maximum production a cow should calve every twelve months. However, this is usually not the case. Some high producers do not return to estrus soon enough after parturition to achieve a yearly calving interval.

Breeding Problems

Heritability and repeatability of factors relating to breeding problems are very low. Johansson and Hansson (1940) found a slight tendency of repeatability, .036, of the calving interval. They assumed heritability of the length of the calving interval to be in the range of 0 to 5%. Trimberger *et al*. (1972) found it impossible to predict the breeding efficiency (the number of inseminations required per conception) of a cow by her previous record.

Sonderegger *et al*. (1977) propose that excess digestible protein, particularly at levels 250-300 gram per cow per day lengthened the interval between parturition and first service. They also found that an abundant energy supply, particularly during the first 60 days after parturition, decreased the interval from first service to conception and from parturition to conception.

Persistency and the Calving Interval

Sanders (1923, 1930), Gains (1927) and Johansson *et al*. (1940) have shown that persistency of milk yield decreases for cows with shorter calving intervals. Shultz (1974) found that cows open more than 139 days produced a significantly greater proportion of their total during months 9 and 10 of lactation than cows open less than 70 days. Actually, it is not the length of the calving interval that affects milk production as much as the stage of pregnancy. Pregnancy begins to exert an effect upon lactation approximately 140 days after conception (Foley *et al*. 1972). At this time mammary cell numbers and milk yield begin to decrease, as compared with non-pregnant lactating cows.

If the calving interval is 350 days, this means that the cow has become pregnant approximately 350 - 280 = 70 days after parturition since the average gestation length is 280 days. The effects of pregnancy would begin to be noticeable about 70 + 140 = 210 days into lactation. For a longer calving interval of 420 days, the effects of pregnancy would not become evident until (420 - 280) + 140 = 280 days. This is approaching the time at which she would be dried off to prepare her for the next lactation.

Smith (1973) examined lactation persistency and derived factors for extending milk production beyond the standard 305-day lactation, accounting for variability in calving intervals. These factors were derived from 61,973 New York DHIA records and were split into 2 categories, lactation 1 and lactations   1. These factors can be applied to the lactation curve across calving intervals beginning 4 months after conception.

The Dry Period

Cows should be given a rest period of 6-8 weeks between lactations to allow refurbishment of the mammary gland (Foley et al. 1972). Shorter or longer periods of time will reduce subsequent milk production. Cows not given a normal dry period produced only 62 to 75 percent as much milk as their twins which were given a rest of 60 days between lactations (Foley et al. 1972).

Factors Influencing Dry Matter Intake

The stimulus initiating feed intake arises from an interaction of environmental and biological conditions mediated through the hypothalamus (Bailey, 1970; Baumgardt, 1970). These conditions define the physiological and physical status of the animal at any time. Body size, sex, age, species, previous nutritional history and production state (pregnancy, lactation, growth and fattening, environment and genetics) "set" the energy demands of the animal. Animals attempt to eat to satisfy this demand and achieve energy balance. Animals change voluntary intake in response to a change in energy demands and thus intake cannot be considered a constant attribute of any particular feed (Butler and Bailey, 1973).

In ruminants, the rate of energy expenditure, environmental temperature, qualitative characteristics of the diet and the physical effects of food in the gut are significant factors influencing the level and day to day changes in food consumption and therefore the amount of energy. Over a rather wide range of energy concentrations in the ration, animals are able to adjust the amount of feed voluntarily consumed so as to maintain equal caloric intakes (Baumgardt, 1970).

Ruminants appear to be exceptions to the energy homeostasis mechanism. Feed intake appears to operate in reverse on many roughage feeding programs. For example, ruminants consume more early-cut immature forage than late-cut mature forage. Since the digestible energy content of the early-cut forage is higher, the animal consumes more energy from the early-cut forage (the energy intake differs between these two forages). This is an example of a breakdown in a homeostatic system due to a secondary but potent force. The very low energy concentration in the late-cut forage coupled with its bulky nature results in a filling of the digestive tract capacity at a level of intake below that which is called for by the homeostatic mechanism (Baumgardt, 1970). This phenomenon can be demonstrated in nonruminant species as well as in ruminants if the ration is diluted to a very large extent with indigestible, bulky material. Such a response was demonstrated by Cowgill with dogs as early as 1928 (Balch and Compling, 1962) and has since been shown in many species including chickens, rats, swine, sheep and cattle (Baumgardt, 1970).

Feed intake is proportional to body size when eating capacity is restricted by intestinal fill and undigested residue (Conrad, 1964). Mather and Rimm (1958) found the ratio of feed intake to $W^{0.73}$ was equal to the least-squares regression for adjusting intake for differences in body size of lactating cows. Blaxter et al. (1961) concluded that voluntary intake in sheep varies with metabolic size ($W^{0.74}$).

Energy Content of Feeds

When the nutritive value is high, fill does not limit feed intake and rats, dairy heifers, lactating dairy cows and sheep adjust the amount of feed eaten to regulate energy intake. This explains why it was possible for Blaxter (1950) and Crampton (1957) to claim that the amount of feed consumed in terms of dry matter increases with increasing concentrations of net energy in the rations, whereas, Greenhalgh and Runcie (1962) found no causative relationship between feed intake and digestibility. Figure 1 demonstrates the relationship of nutritive value of rations and feed dry matter and erengy intake.

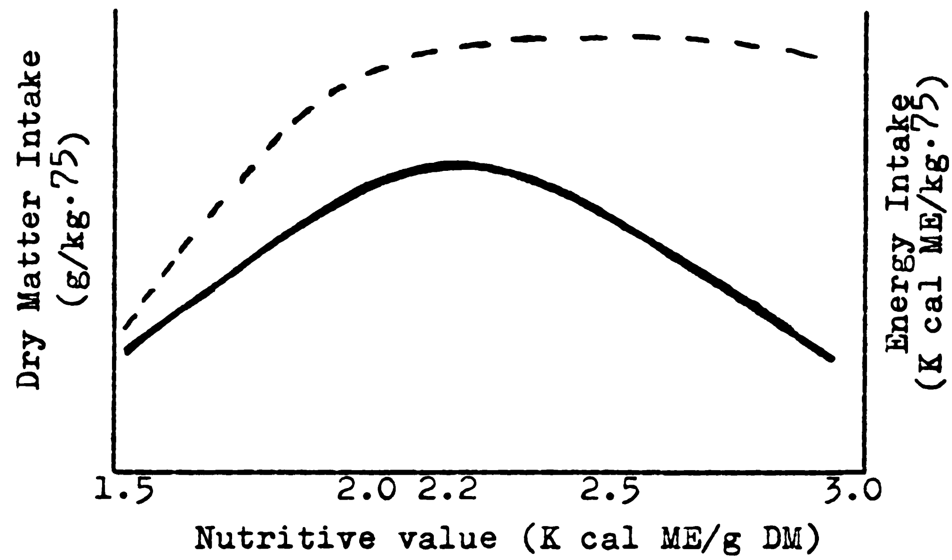

Figure 1. The Relationship Between Nutritive Value, Dry Matter Intake (———) and Energy Intake (- - -).

Source: Butler, G. and R. W. Bailey. 1973. Chemistry and Biochemistry of Herbage. (Academic Press: New York) Vol. 3, p. 141.

Dry matter intake increases with nutritive value until a value of 2.2 Kcal of metabolizable energy per gram of dry matter (65 to 70 percent apparent digestibility) is achieved. Above this value dry matter intake frequently decreases (Butler and Bailey, 1973). Energy intake (Kcal of metabolizable energy per gram of dry matter) also increases with nutritive value until a concentration of approximately 2.2 Kcal, after which it is relatively constant (Butler and Bailey, 1973).

Digestion of low nutritive value herbage within the gastrointestinal tract seems to form the basis for the control of intake, while changes caused within the animal's tissues by the absorbed end-products of digestion form the basis of the control of high nutritive value herbages (Baumgardt, 1969).

Physical characteristics of the diet such as volume displacement, surface area of particles, length of cut of forages, pelleting, grinding and heat processing, energy content of the ration, the rate of passage of digesta out of the rumen and the rate of absorption of nutrients, all affect the amount of energy derived from the feed.

In order to partially account for these factors, Montgomery et al. (1965) proposed the concept of multiplying a measure of digestibility and nutrient density and arriving at a caloric density measurement (Kcal of digestible energy/ml of diet). This provides a basis for estimating total dry matter intake. Baumgardt et al. (1976) showed that DE/ml (caloric density) accounted for 88 percent of the variation in body weight gains, whereas DE/gm accounted for only 67 percent. Bull et al. (1976) studied the relationship between caloric density and energy intake in 24 lactating cows fed five mixed diets of alfalfa hay and concentrate. For the most dilute rations, A and B, physical fill was limiting intake. DE intake of diets of increasing energy density, C, D and E, was similar indicating that gut fill was not limiting intake and that physiological regulation was occurring. In a similar study by DePeters (1975) with lactating cows, physical fill limited the intake of all four rations of grass and hay. These two data sets were combined by Baumgardt (1977) who found neutral detergent fiber (NDF) and bulk density (gm/ml) highly correlated with dry matter intake ($r = 0.91$ and 0.93, respectively). Dry matter digestibility was not correlated with intake. Mertens et al. (1973) and Thornton et al. (1972) found that density, the digestion coefficient for NDF and the rate of NDF digestion are parameters that are related to rumen retention time and rate of passage.

The maintenance of relatively constant energy intake may be related to some end product of digestion. In ruminants this may be acetate, the major VFA produced in the rumen. Rate of utilization of acetate may limit voluntary intake. Thus, in early lactation there is generally an increase in energy intake which may be linked to an increase in acetate utilization for milk synthesis.

Impact of Fermented Feeds

Investigations have shown that the voluntary intake of silage is lower than that of hay made from the same crop, harvested at the same time. Work by Thomas et al. (1973) showed that the lower dry matter content of the silage was not a causal factor per se in limiting intake. This work is supported by Baumgardt and Clancy (1975) who studied intake of alfalfa forage in five forms and found that voluntary intake was not significantly correlated with dry matter content of the forage per se. However, there was an indication that some chemical compound in the silage juice may have depressed intake. Data of Clark (1972), Thomas et al. (1970) and Brown (1965) were analyzed by Hillman et al. (1973) to elucidate the effect of moisture content of the ration on intake and are graphically illustrated in Figure 2. The data show that DMI expressed as a percent of body weight changed approximately -.016 to -.023 per 1% increase in the moisture content of the ration above 20%.

Table 2 estimates the percentage decline in intake with increasing moisture additions to the ration (Hillman et al., 1973).

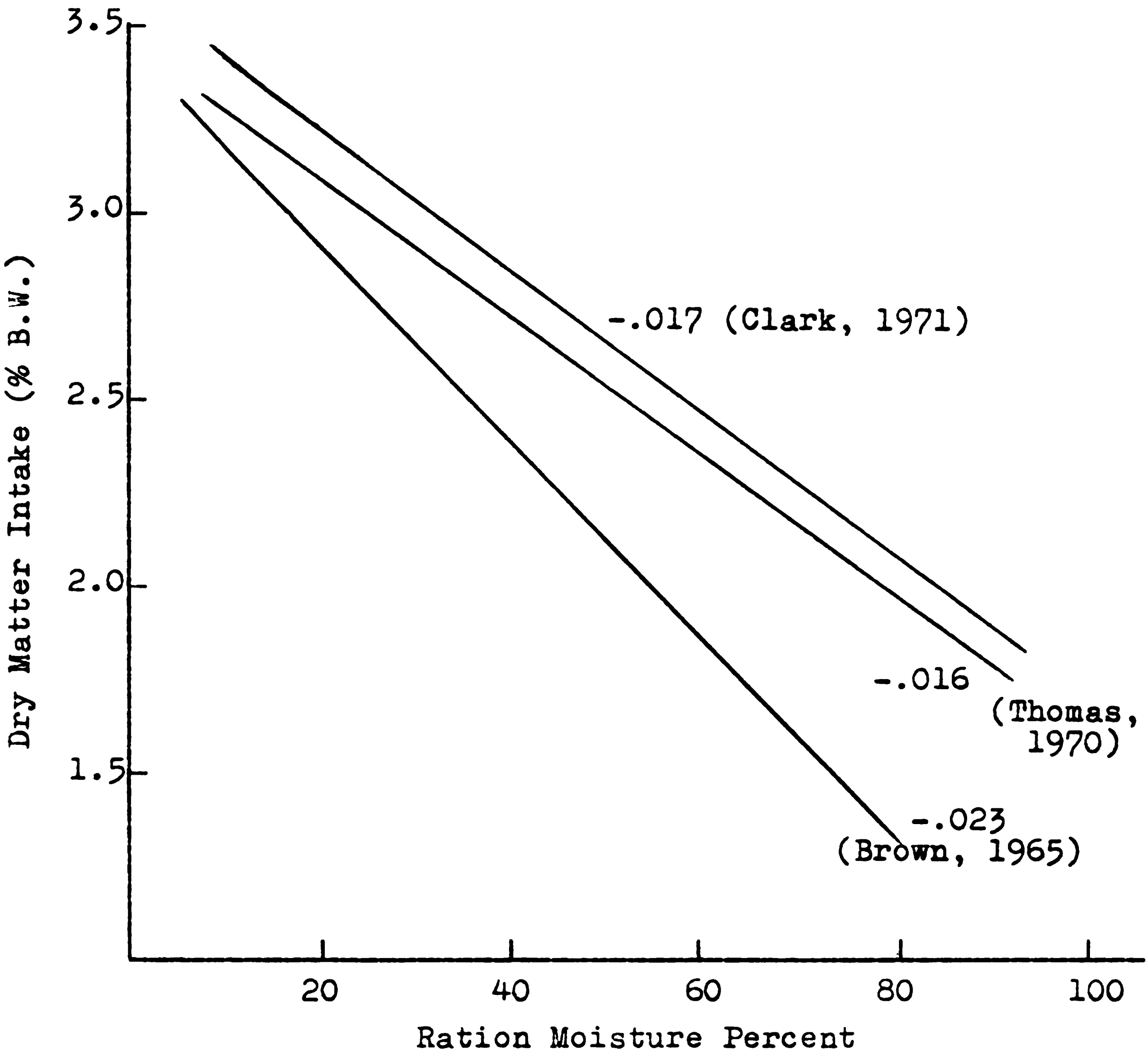

Figure 2. Effect of Moisture Content on Dry Matter Intake of Lactating Cows.

Source: Hillman, D. et al. 1973. Least Cost Rations: A Look at the Michigan System. Unpublished. Michigan State Univ., East Lansing.

Table 2. Expected Impact of Alternative Quantities of Fermented Feeds on Daily Dry Matter Intake of Lactating Dairy Cows*

Percent Moisture in the Ration	Expected Intake as a % of Potential Intake	Expected Daily Dry Matter Intake for a 1400 lb Cow Producing 60 lbs Milk
20 or less	100.0	45.8
25	96.4	44.2
30	93.0	42.6
35	89.9	41.2
40	86.9	39.8
45	84.2	38.6
50	81.6	37.4

*The percent moisture in the ration is a proxy for the impact of fermented feeds. It does not depict the impact of wetting dry feeds.

Source: Hillman, D. *et al*. 1973. Least Cost Rations: A Look at the Michigan System. Unpublished. Michigan State Univ., East Lansing.

Impact of Crude Fiber

The level of fiber in the diet affects the energy density of the ration, the pH of the rumen and the rate of passage of material through the digestive system; thus the percent fiber has an influence on the level of intake. The data in Figure 3 show the impact of varying the roughage:

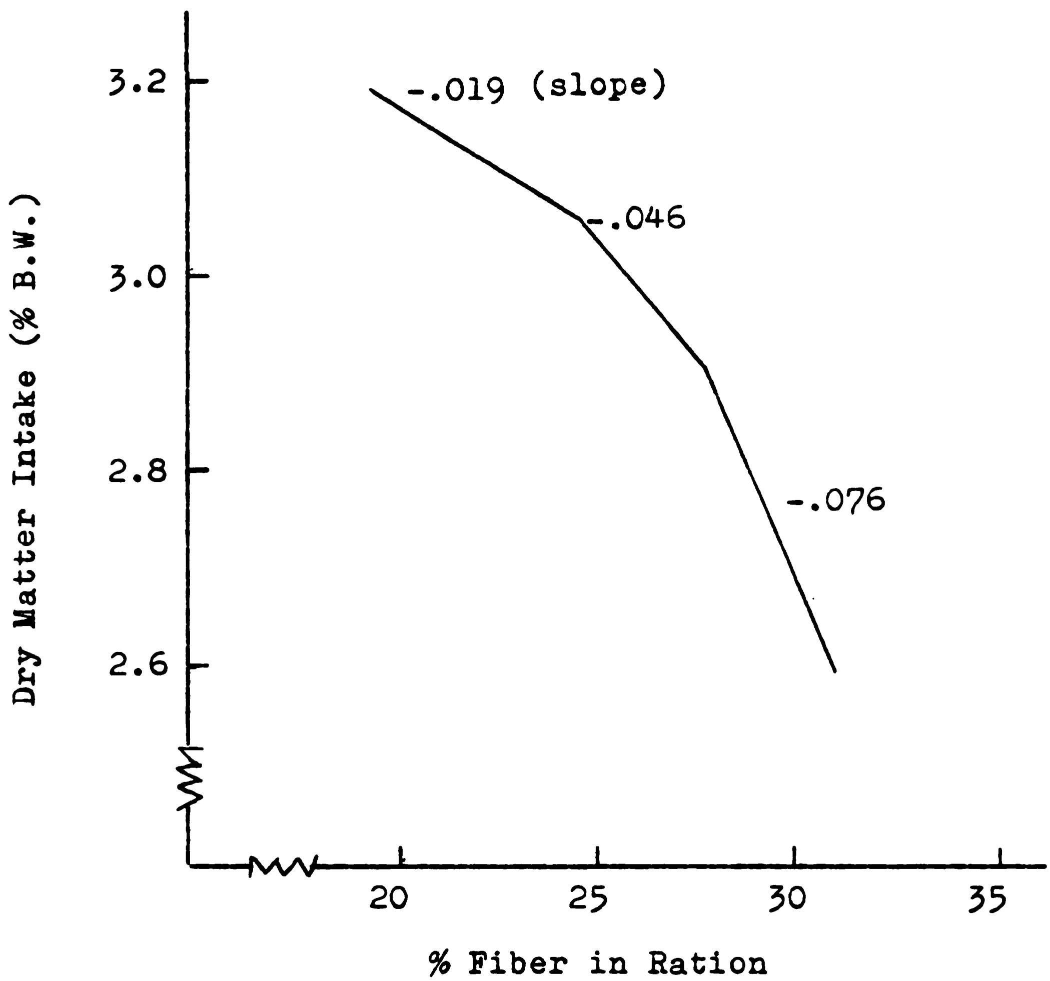

Figure 3. Impact of Ration Fiber Content on Dry Matter Intake of Lactating Cows Fed Four Levels of Grain and Two Qualities of Hay.

Source: Hillman, D. et al. 1973. Least Cost Ration: A Look at the Michigan System. Unpublished. Michigan State Univ., East Lansing, as adapted from: Stoddard and Anderson, J. Dairy Sci. 48:798, 1965.

concentrate ratios on daily feed intake based on a study by Stoddard and Anderson (1965). At low levels of concentrate consumption, dry matter consumed as a percent of body weight increased by .076 lbs per percent decrease in fiber. From .25 lbs of grain fed above 20 lbs of milk to .5 lbs, the increase in intake as per percent decrease in fiber is .046. The change for the next increment is .019.

Relative Intake of Forages

Intake of legumes tends to be higher than that of grasses when they are harvested at the same digestibility (Wilkinson, 1976). Since legumes generally contain more protein and minerals than do grasses, they contain more cell contents and a lower proportion of digestible cell walls than grasses when harvested at the same digestibility. Cell contents are believed to be digested at a faster rate than cell walls. Also, the buffering effect of protein and minerals in legumes which alters rumen pH should give a faster rate of digestion of the digestible cell wall portions. Stage of maturity at harvest influences the digestibility of forages and therefore can influence intake. Its effect on the rate of decline in digestibility differs between forage species, and is greater after seed-head emergence than prior to it (Wilkinson, 1976).

Influence of Protein on Feed Intake

Rogers _et_ _al_. (1973) have shown in rats that intake is depressed when diets are: (1) low or devoid of a single AA, (2) contain an excess of a single AA, or (3) contain a high level of protein. According to Baumgardt (1969), extremes in protein level have marked effects on intake by ruminants. The low feed intake on a low protein diet is related to the inability of rumen microbiota to function properly and failure of such a diet to support normal growth and milk production. Depressed intake on very high protein rations is due in part to the high specific dynamic activity (SDA) associated with protein metabolism and in part due to a deficiency of enzymes involved in amino acid catabolism (Baumgardt, 1969).

Dry Matter Intake and High-Producing Cows

For a limited period of time, high-producing cows regulate energy intake in a very acceptable manner. However, some cows with a lower genetic ability for milk production and also high-ability cows late in lactation, will deposit body fat at an increasing rate rather than convert the extra energy into milk. Body fat deposition becomes uneconomical, but it does not necessarily mean that the cow lacks the ability to regulate energy intake. At least two other possible explanations are presented by Baumgardt

(1969). First, the set point on the cow's energy has been raised to an unusually high level. This can be explained on the basis of selection for high production. Such selection may have resulted in animals that would be considered "pathological." Since lactation has a higher biological priority than fattening, obesity is not observed as often in dairy cattle where limited feeding is practiced. The second explanation involves no change in the set point of the regulator. The main difference is that energy status is monitored on the basis of a circulating metabolite pool or undissipated heat load rather than on the basis of energy balance per se. Thus, increasing enzymatic potential (the level of which is under genetic control) can be visualized as removing metabolites from the circulating pool at an accelerated rate in the fattening animal. Intake is related to energy output, but all functions using energy, including fattening, are considered as drains on the energy metabolite pool, which is the parameter being monitored (Baumgardt, 1969).

Eckles and Reed (1910) state, "The cause of the difference in the amount of milk produced is the amount of feed that cows are able to consume and use above maintenance requirements." There is little doubt that high levels of milk production are accompanied by great appetites. It is also true, however, that the variation from cow to cow in this regard is very great. Not all cows that have a greater ability for milk production demonstrate greater appetites. The result is that some cows produce milk with great losses in body weight, while others are able to more nearly meet their energy requirements with increased intake (Flatt, 1967). A Pennsylvania cow (Kreig, 1975) produced over 50,000 pounds of milk in one lactation. During this time it was calculated that she was consuming over 7 percent of her body weight in DMI per day.

Seasonal Influences on Intake

Environmental temperatures have predictable results on feed intake. Homeotherms increase feed intake in the cold and decrease intake in the heat. There is a difference in temperature effect on younger and older animals and also between lactating and non-lactating animals (Baumgardt, 1969).

Estimating Voluntary Intake

Conrad and his co-workers (1964) at the Ohio experiment station published the results of the factors which influence the dry matter intake of dairy cows. The basic equation they derived was:

$$\text{Total DMI} = \text{Weight}/1000 \cdot 10.7/(1 - \%\ \text{digested})^{*}$$

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*Percent digested expressed as a decimal fraction.

The equation assumes that cows excrete a maximum of 10.7 lbs of indigestible dry matter per day (McCullough, 1973). This estimate has since been challenged by Bull et al. (1976) who propose a value of 13.2. Using 10.7 as a base value, Conrad accounted for a major portion of the variability when requirements for maintenance and milk production were added to the equation. When this was done, the equation for calculating maximum feed intake was:

$$\text{Max. DMI} = 10.7 \cdot \text{Weight}/1000 + .58\ \text{Weight}^{0.73} + .33\ \text{Milk} + .53$$

Brown and Chandler (1978) derived an intake prediction equation from data assembled from nineteen experiments conducted at eleven universities across the country. Each observation represented the average daily intake per cow during a twenty-eight day period. The data set included 4,135 Holstein records and 704 Jersey records. The regression equation developed had an R^2 value of .74, and an average error or 12.5% when predicted values were compared to actual observed values.

The equation reads as follows:

$$\ln \text{DMI} = b_0 + \text{Season} + b_1(\text{DIL}) + b_2(\ln \text{DIL}) + b_3(\ln \text{Milk}) + b_4(\text{BF}) + b_5(\text{BW}) + b_6(\text{CF}) + b_7(\text{CF})^2$$

where: DMI = dry matter intake, kilograms per day.

DIL = the average number of days into lactation for a cow or a group of cows

Milk = kilograms of milk produced per day by a cow or group of cows

BF = the kilograms of butterfat produced per day

BW = the body weight in kilograms

CF = crude fiber, percent of ration dry matter

CF^2 = crude fiber squared

Season = season of the year

ln = natural logarithm

b_0 and b_1 = parameters

The estimated parameters were:

b_0 = .5198

Season = .0418 (Fall and Winter)
-.0041 (Spring)
-.0376 (Summer)

b_1 = -.00827 (DIL) b_5 = .000675 (BW)

b_2 = .148073 (ln DIL) b_6 = .018001 (CF)

b_3 = .339220 (ln Milk) b_7 = -.000557 (CF^2)

b_4 = .099266 (BF)

Hillman et al. (1973) developed an intake equation using mean data of Slack et al. (1960) which incorporates characteristics of the diet such as net energy and moisture content of the ration. The moisture factor was intended to account for the negative impact of fermented feed on intake, the quality of fermentation being influenced by the moisture content.

The equation reads as follows:

$$Y = 1.021 + (-.003)X_1 + (.0187)X_2 + (1.476)X_3$$

where: Y = dry matter intake/100 lbs of body weight

X_1 = percent moisture in the ration

X_2 = lbs of milk

X_3 = estimated net energy (ENE) in mcal/lb of DM

The $\bar{R}^2$ value for the equation is .78.

General Observations Concerning Feed Intake During the Lactation Cycle

Intake is relatively low immediately postpartum. Dry matter consumed can be below 2% of body weight of the animal at this time (Jorgenson, 1978). Intake begins to rise sharply during the first few weeks of lactation and usually peaks between weeks 7 and 12 (Hillman, 1973). At this time it will be 30-40% greater than it was immediately postpartum. Peak intake occurs after peak production, usually following within a couple of weeks. Once peak consumption has occurred, intake progressively declines in a linear fashion with milk yield. The relationship ranges between .02 and .07 lbs of dry matter per lb of milk produced.

Nutrient Requirements

With the onset of lactation, there is initiated a tremendous nutrient sink, the mammary gland, which requires acquisition of energy and protein as well as certain vitamins and minerals in quantities far exceeding maintenance levels in order to achieve an output of milk commensurate with the genetic ability of the animal. Only that level of milk production which can be supported by the most limiting nutrient available will be attained.

Peak production level significantly affects total milk yield of a given lactation. Therefore, attention to the nutritional status of the animal during the period extending from freshening to peak daily production is of critical biological and economic significance. This situation is aggravated by the fact that although early lactation requirements are greater than at any other stage of lactation, intake levels are the lowest.

Mobilization of Nutrients from Body Stores

Animals meet their needs by absorption of nutrients from the digestive tract. However, mobilization of body stores can contribute significantly in meeting certain demands, particularly in early lactation (Flatt *et al.*, 1967). This is especially true in regard to energy. Energy mobilization from fat stores is typical for high-producing dairy cows. It is not unusual for cows to lose 100-200 lbs of body weight during the first 75 days of lactation; some cows have been noted to lose over 400 lbs (Moe, 1971). The famous "Lorna" cow (Flatt *et al.*, 1967) mobilized an average of 20 Mcal of body reserves per day during the first four weeks of lactation. This quantity represents over 40% of her daily energy requirements during that period. During early lactation (weeks 1-8) her production ranged from 35 to 27 Mcal of milk energy per day. Figure 4 illustrates Lorna's energy balance throughout lactation.

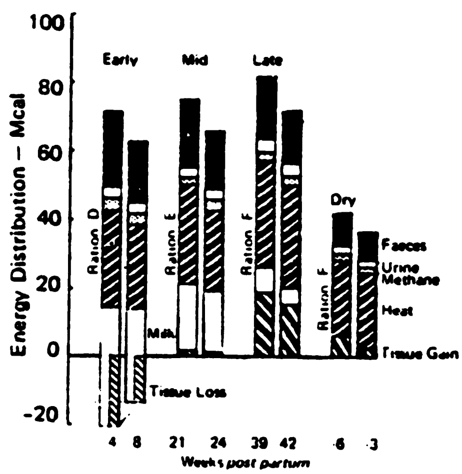
Parameters concerning the specific relationship of energy mobilization with genetic potential, body condition and ration composition are not explicitly defined, however the following observations are presented:

(1) Hickman _et al_. (1971) found that animals which lost the most weight or recovered weight most slowly were the higher producers. Poos _et al_. (1978) noted that mature cows lost more weight than first lactation animals. These observations suggest that higher producers have a greater capacity for fat mobilization.

(2) Davenport and Ricks (1969) noted body weight losses in early lactation for cows given a specified feeding level, were greater for fat versus thin cows but not for medium conditioned animals versus thin animals.

(3) Flatt _et al_. (1967) related energy mobilization to the roughage concentration of the ration of cows whose peak milk yield ranged from 25 to 40 kg per day. Cows on the high roughage ration (60% alfalfa) mobilized an average of 10.1 Mcal of body tissue per day during the first 8 weeks of lactation while those on the 40 or 20% alfalfa rations only mobilized 7.0 and 3.5 Mcal respectively. Production during this period was 22.4

Mcal of milk energy daily for cows receiving the 60% alfalfa ration as compared with 19.0 and 14.4 Mcal by cows consuming 40 or 20% of the ration dry matter as hay. The average body tissue lost during early lactation was 6.9 Mcal/day. The effect of restricting intake during early lactation was to reduce milk yield rather than increase tissue loss.



The utilization of energy by Lorna (cow 3884), a high producing dairy cow. She produced 8,768 kg 4% fat corrected milk during this 305-day lactation and her average body weight was 643 kg. Each bar represents the mean of two 5-day total energy balance trials. The extension of a bar below the base line indicates loss of body tissue. Rations D, E and F were 60:40, 40:60 and 20:80 alfalfa:concentrate respectively. The balance trials were conducted 4, 8, 21, 24, 39, 42 weeks *post partum*. The measurements when she was dry and pregnant were made 6 to 3 weeks *pre-partum*.

Figure 4. Energy Utilization of Lorna Cow.

Source: Flatt, W. P. et al. 1967. Energy Utilization by High Producing Dairy Cows. II. Summary of Energy Balance Experiments with Lactating Holstein Cows. Energy Metabolism of Farm Animals. (Oriel Press Limited: Newcastle Upon Tyne, England). Edited by K. L. Blaxter, p. 225.

Energy and Fiber Requirements

Maintenance requirements of lactating cows was found to be 73 Kcal/kg of body weight$^{.75}$ (Moe et al., 1972). Because maintenance requirements depend on the level of activity, an allowance of 10% is included in the 1978 NRC requirements. Blaxter (1962) found that the yield of milk exhibits diminishing marginal return as the level of energy consumed increases. This could be partially due to decreased digestibility of the ration as the level of energy consumed increases. Reid (1965) and Tyrell and Moe (1974) suggest digestibility of high concentrate rations is inversely related to the level of energy intake, amounting to an average decrease in digestibility of 4% for each multiple of maintenance requirements ingested. The digestibility decreases as the proportion of grain increases when hay or haylage is the only forage. Cellulose and hemicellulose digestibility appear to be affected most, possibly due to a negative effect on the cellulolytic bacterial population exerted by a decrease in pH when high levels of grain are fed (Kaufman, 1976). Decreased pH is also believed to negatively affect starch digestibility (Wheeler et al., 1976). According to Kaufmann there is a direct relationship between crude fiber in the ration and pH in the rumen as illustrated in Figure 5.

Crude fiber is a rough estimate of chewing time of feed or rumination. Chewing in turn results in salivation.

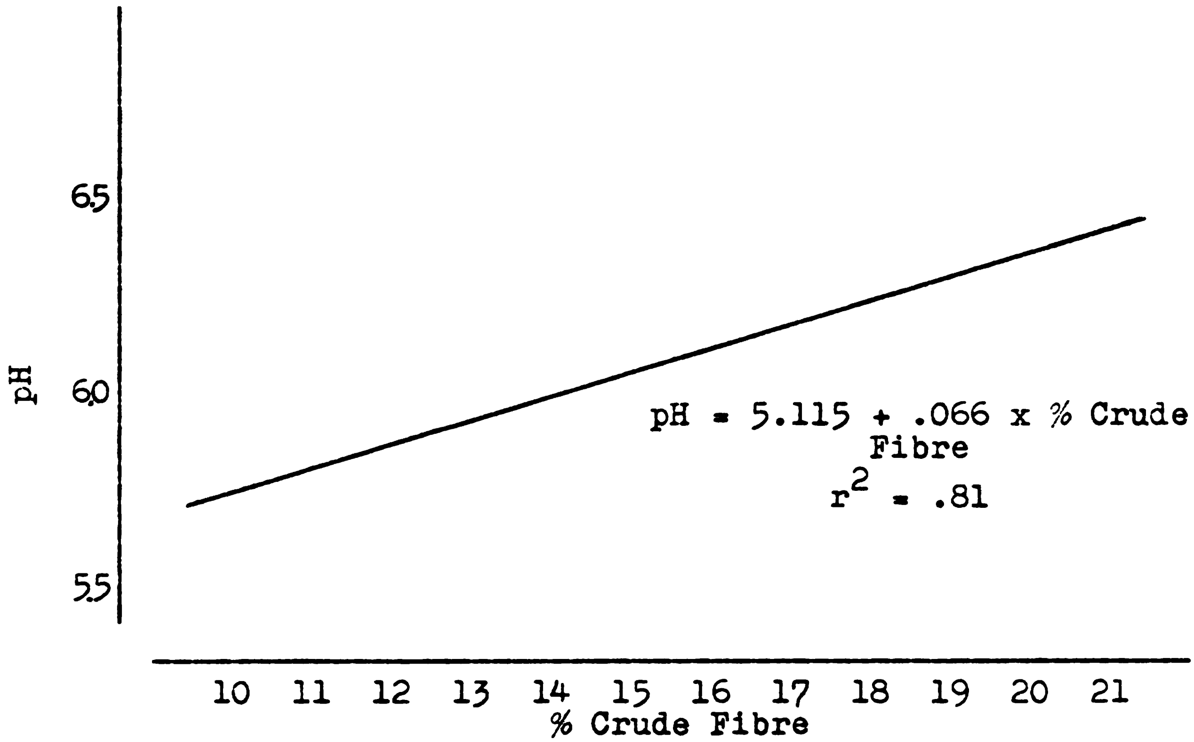


Figure 5. Relationship of Crude Fibre Content (%) in the Ration and pH in the Rumen.

Ruminant saliva contains large quantities of bicarbonate which acts as a buffer to prevent a decrease in the pH (Emery, 1979). The pH of the rumen influences the ratio of acetic:propionic acid produced which in turn influences the fat content of the milk (Kaufman, 1976). When the ratio of acetate to propionate decreases as is the case in high grain rations, it is believed to be influential in partitioning energy from milk to body fat synthesis. Thus, ruminal pH is an important consideration in terms of ration digestibility and milk yield. Kaufmann (1976) recommends at least 20% crude fiber (CF) in the ration to maintain proper rumen function and avoid lactic acidosis. With 2 times a day feeding he lowers the limit to 17.5% of the ration dry matter as crude fiber.

Dean et al. (1969) used a value of 15% as a minimum level of CF in the California computer ration balancing program but have since changed the limit to 17% as a result of problems with cows going off feed.

Along with the quantity of fiber, the quality of fiber must also be considered. Roughages that are finely chopped or fermented exert a less pronounced effect in maintaining an optimally functioning rumen than is indicated by the amount of crude fiber contained (Thomas, 1979). The "effective" fiber capacity of corn cob meal, on the other hand, is greater than that of alfalfa hay, although the actual crude fiber content is much lower (Van Soest, 1969).

Energy Requirements vs. Genetic Potential

Bath et al. (1971) reported that cows with greater inherent potential utilize feed more efficiently and consume more feed per unit of body weight than low producers. Their observations are presented in Table . Blaxter (1966) and Broster et al. (1969) have also shown that cows with a great capacity for milk production respond by giving more milk per unit of feed as compared to cows of lower capacity.

Protein Requirements

Protein requirements of dairy cattle are not well defined due to the complexity of the digestive process of ruminants. Proteins entering the rumen can be either digested by the rumen microflora or bypass to the lower G.I. tract. Most bacteria in the rumen first deaminate dietary protein subsequently using the ammonia released in the process to build bacterial protein. Because bacteria can synthesize protein from ammonia, non-protein nitrogen (NPN) which is converted to ammonia can be added as a source of nitrogen in some instances to support protein anabolism. The concentration of ammonia in the rumen is a determinant in the rate of microbial growth when energy is not limiting (Satter, 1978b). However, there is a maximum concentration of ammonia in the rumen after which additional amounts are of no benefit as far as microbial activity is concerned. Satter and Roffler (1975) suggest this maximum is achieved when the ammonia concentration in the rumen exceeds 5 mg %. On typical dairy cattle rations this would be equivalent to 12 to 13% crude protein (CP) in the diet. Huber (1976) proposes NPN to be of benefit for predominantly corn silage rations when requirements are as high as 14 to 14.5% CP. In vitro studies by Helferich et al. (1976) have shown that net protein synthesis does not reach a maximum until the ammonia concentration is 15 to 20 mg %. Orskov (1976) has shown that the ammonia level in sheep facilitating optimum rumen synthesis is greater than 5 mg %.

The concentration of ammonia from the degradation of dietary proteins will determine the additional amounts of NPN which could additionally benefit microbial protein synthesis. Factors affecting the rate of degradation of dietary protein include: physical characteristics of the protein, the amount of readily fermentable carbohydrates, the pH of the rumen and other factors affecting the nutritional environment, as well as retention of the feed in the rumen (Satter, 1978a).

Protein requirements are met by microbial protein synthesized in the rumen and undegraded digestible protein that has escaped fermentation and to a limited extent by protein mobilization from body stores during early lactation (Satter, 1978b). In the lower GI tract of ruminants the quality or amino acid array presented is important as well as total amounts. Microbial protein has a relatively high biological value in this regard (Satter, 1978) and is therefore an excellent complement to the undegraded dietary protein in meeting the amino acid requirement of dairy cattle under most conditions.

Foldager (1977) tested the requirements of protein and the efficacy of NPN addition to diets using 68 Holsteins during the first 20 weeks post-partum. Seventeen cows were assigned to each of the 4 treatment groups. The first two groups received rations of only plant protein containing 12-13% CP in DM (group NC) and 15-16% (group PC). The other two groups were also fed rations with 15-16% CP, but approximately 25% of the total nitrogen came from NPN as urea (group U) or ammonia (group AU). It was concluded that high yielding cows fed rations of corn, corn silage and limited hay require no more than 13% CP in DM, which is approximately equal to 80-90% of 1971 NRC standards. Poos et al. (1978) found that 11-12% CP is an adequate level to support first calf heifers in early lactation but is not adequate for mature cows. Cressman et al. (1977) obtained similar results.

Daily body weight losses in Foldager's experiment (1977) averaged -.954, -1.843, -.692 and -1.200 kg for groups NC, PC, U and AU respectively. Taking a value of .954 kg/day of weight loss for the NC groups, it is possible to estimate a feasible amount of body protein that was possibly mobilized based on 1978 NRC.

.954 kg/day x 320 g protein/kg body tissue mobilized (1978 NRC) = 305 g protein. Estimating intake at 19.75 kgs DM (Foldager, 1977) the following is postulated:

$$\frac{\text{305 g protein}}{\text{19.75 kg feed consumed}} = 1.5\%\ \text{CP}$$

This means that the calculation for CP could be off by 1.5% CP and it would be masked by protein mobilization.

Lamb *et al*. (1973) found that cows fed rations containing 15.1 or 16.1% CP in the ration showed no difference in milk yield. Van Horn *et al*. (1968) found no significant difference in performance between groups of cows fed 15.5% CP and 13.2% CP using soybean meal as a source of protein supplement.

Growth

Heifers entering the milking herd are still growing, and will continue to do so at a decreasing rate until they approach 84 months of age. McDaniel and Legates (1965) derived a cubic regression of weight on age within-year-season on 1,593 Holstein cows. The equation is:

$$Y = 757 + 20.91\ M - 0.2036M^2 + .00066M^3$$

where: Y = estimated weight

M = age in months

Mature equivalent factors relating weight to age can be established by using weight at 84 months as a mature weight to compare with weights at different ages. Data of Matthews and Fohrman (1954) were analyzed similarly. Table 3 lists the mature equivalent factors derived from both sets of data. Almost identical factors result from both studies.

Table 3. Mature Equivalent (ME) Factors for Body Weight Derived from Two Studies.

McDaniel and Legates			Matthews and Fohrman	
Age (Months)	Fraction of Mature Wt.	ME[1] (Weight)	Fraction of Mature Wt.	ME (Weight)
24	.784	1.275	.775	1.290
28	.816	1.225	.810	1.235
32	.844	1.185	.841	1.189
36	.870	1.149	.868	1.152
40	.892	1.121	.892	1.121
44	.912	1.096	.913	1.095
48	.930	1.075	.931	1.074
52	.945	1.058	.947	1.056
56	.957	1.045	.960	1.042
60	.968	1.033	.971	1.030
64	.977	1.024	.980	1.020
68	.984	1.016	.986	1.014
72	.990	1.010	.992	1.008
76	.995	1.005	.996	1.004
80	.998	1.002	.998	1.002
84	1.000	1.000	1.000	1.000

[1]Mature weight = weight at 84 months of age.

Sources: McDaniel, B. T. and J. E. Legates. 1965. Associations Between Body Weight Predicted from Heart-Girth and Production. Journal of Dairy Sci. 48:947.

Matthews, C. A. and M. H. Fohrman. 1974. Beltsville Growth Standards for Holstein Cattle. Technical Bulletin No. 1099, U.S. Dept of Agric., Washington, D.C.

Expected Herd Life

The average dairy heifer freshens at approximately 27 months of age and leaves the herd at 65 months, completing 3 lactations.

Disappearance of cows from the herd occur as a consequence of mandatory (involuntary) or voluntary reasons. Knowledge of removal for involuntary reasons will provide an estimate of the potential lifetime of animals in the herd and thus can be used as a weighting index in determining economic value.

Stewart et al. (1977) define involuntary removal as that which is due to such reasons as: calving problems, disease, foot and leg injury, and reproductive problems such as sterility. Voluntary removal includes cows with low milk or fat production, bad temperament, other faults of the mammary system or general confirmation weaknesses.

Table 4 presents the probability of failure of cows by lactation number as found by the various studies cited. As indicated in the table the probability of removal increases with lactation number in a relatively linear fashion. Stewart et al. (1977) derived a prediction equation based on data collected by Burnside et al. (1971) estimating the probability of involuntary removal as: .0373 + .0170 (Li), where Li refers to the lactation number. Probability of death was estimated separately as: .0075 + .0043 (Li).

Table 4. Probability of Failure (Involuntary) of Cows by Lactation Number

Authors:	Stewart et al., 1977		Jenkins, Halter, 1962			Giaver, 1966	Smith, 1971	Dayton, 1966
Place:	Canada		Pennsylvania			California	Florida	Michigan
No. Animals:	19,337 Records		10,000 Records			702 (Jerseys)	369 (Jerseys)	7,839 Records
			Butterfat Level					
Lactation No.	Estimated	Observed	350 lbs	350-400 lbs	450 lbs			
1	.0543	.0611	.0438	.0543	.0674	.071	.0593	.05
2	.0713	.0674	.0662	.0755	.0835	.055	.0764	.08
3	.0883	.0806	.0825	.0937	.1222	.086	.0935	.08
4	.1053	.1110	.0927	.1196	.1438	.082	.1107	.14
5	.1223	.1197	.1027	.1350	.1678	.107	.1278	
6	.1393	.1370	.1393	.1557	.1751	.113	.1450	
7	.1563	.1605	.1322	.1576	.1813			
8			.1821	.1662	.1947			
9			.1614	.1358	.1336			
10			.1189	.1578	.1527			
11			.1243	.1245	.0927			

Stewart considers death separately from involuntary removal.

Smith & Giaver consider involuntary removal as sickness being the primary reason of removal; breeding trôuble was considered voluntary.

Stewart included cows failing to conceive to 3 services as involuntary removals. Voluntary removal includes low prod., mammary system reasons, typle fault and failure to conceive 3 services.

Reasons for Removal

Many studies have dealt with the reasons for disposal of dairy animals including: Arnold *et al*. (1958), Dayton (1966), O'Bleness and VanVleck (1962), White and Nichols (1962), Renkema *et al*. (1977) and Gurtle and Smith (1970). Table 5 compares their findings.

The most important reasons for culling among the studies noted above were: low production, sterility and reproductive disorders, teat and udder troubles and mastitis.

Low production is by far the largest single classification, however this category is frequently used as a catch-all for animals whose production has been reduced by other conditions such as mastitis, milk fever, hard milkers as well as nonbreeders in late lactation (Dayton 1966).

Table 6 enumerates the reasons for disposal for different age groups found by Dayton (1966). O'Bleness and VanVleck (1962) and Dayton (1966) found that disposal for sterility increases with age. White and Nichols (1962) found only a slight increase due to sterility as age increased. The following observations were drawn from these studies:

1) Low production, sterility, udder trouble and dairy purposes are the major reasons for disposal across all age groups.
2) Udder and mastitis troubles become more prevalent with increasing age.

Table 5. Reasons for Dairy Cattle Replacement.

Authors	O'Bleness & Van Vleck		Arnold & Beecher	White & Nichols	Gurtle & Smith	Dayton
Location	New York	Netherlands	Florida	Pennsylvania	California	Michigan
Date of Study	1962		1957-1958	1958-1963	1968-1969	1957-1962
# Cows	7,362		3,447	7,317	1,704	7,839 Holsteins
Annual rate of culling	25%[1]	22%	Not Given	Not Given	30.8%	Not Given
REASON:[2]						
1) Reproduction		24.0	15.8		36	
2) Sterility	16.1			15.66		11.3
3) Low Prod	27.1	18.0	25.2	36.87	40	40.2
4) Dairy	14.2			09.65		11.2
5) Udder	06.1	18.0	19.8[4]	13.48	12	
6) Mastitis	08.3			05.81		09.9
7) Legs & feet	02.8	06.0				
8) Type	02.0					
9) Behavior		01.0-02.0				
10) Milk ability	02.5	04.0				02.4
11) Other		09.0-10.0	02.3	09.79	05	
12) Unstated			09.7			00.5
13) Died	10.1		14.2	02.86		04.9
14) Accident		02.0	02.5		05.0	
15) Disease	01.9[3]	08.0	03.0			03.9[7]
16) Injury	04.2			04.74	02.0[6]	12.2[8]
17) Age	03.6	09.0	04.7	00.6		01.8
Total	98.8%	100%	100%[5]	99.46%	100%	

1 25% culled if herds are registered; 33% if herds not registered.

2 Reasons were not uniform across studies; some reasons cover the same subject as others (ie. death = disease + accidents, sterility reproduction).

3 Brucellosis & T.B. reactors

4 Udder & mastitis

5 An additional 2.8% was a combination of reproduction & udder & low prod.

6 Hardware disease

7 Sold because of bangs & T.B.

8 The high number in this category is probably because legs & feet & type were excluded as reasons

Table 6. Percent of Total Culls By Lactation Number.

	Lactation Number		
Reason	1	2	3
Dairy	18.1	10.3	6.3
Low Prod	46	47.1	32.1
Physical Injury	10.2	11.6	15.7
Mastitis	4.2	8.6	16.7
Disease	3.8	4.5	2.9
Milk Ability	3.9	2.6	2.5
Sterility	7.9	10.7	12.4
Old Age	0.2	0.1	5.7
Death	5.7	5.0	5.7

Source: Dayton, A. 1966. Differential Removal of Daughters Among A.I. Series. Unpublished M.S. Thesis. Michigan State University, East Lansing.

3) Low production is the major reason for disposal for cows under 6 years of age. After this time, udder and mastitis troubles are the primary reasons for disposal.

Longevity and High Producing Cows

Some dairymen believe that high producing heifers "burn themselves out" early in life. Gibson (1977) examined the records of 317,301 cows to test this hypothesis. The cows were equally divided into 4 groups according to deviations from herdmates during their first lactations. The average percent removed for each class was calculated through the

Table 7a. Proportion of Cows Removed from the Herd during the Second through Sixth Lactation when Divided into Four Groups According to First Lactation Production.

Yield Class	No. Having 1st Record	Percent Lost By The 2nd Rec.	3rd Rec.	4th Rec.	5th Rec.	6th Rec.
Top ¼	87,409	16	33	50	65	78
Third ¼	83,467	11	39	57	69	80
Second ¼	73,211	25	48	65	75	84
Bottom ¼	73,214	47	68	80	87	92

Source: Gibson, D. 1977. Green Mountain Newsletter. Univ. of Vermont, Burlington.

Table 7b. Percent of Cows Removed from the Herd <u>of Those Surviving the Previous Lactation</u> when Divided into Four Groups According to First Lactation Production.

Yield Class	No. Having 1st Record	Percent Lost of Those Surviving The 1st Rec.	2nd Rec.	3rd Rec.	4th Rec.	5th Rec.
Top ¼	87,409	16	20	25	30	34
Third ¼	83,467	20	20	26	30	36
Second ¼	73,211	25	30	30	30	36
Bottom ¼	73,214	45	42	40	35	38

Source: Meadows, C. July 1977. Cow Losses. Dairy Notes. Michigan State Univ., East Lansing.

sixth lactation. The results presented in Tables 7a, b demonstrate that survival is highest in the top quarter and lowest in the bottom.

The majority of the culling in the first few lactations is due to low production, therefore Meadows (1977) converted Gibson's values to percent lost of those surviving the previous record. His calculations still show a small trend favoring survival of the high group but he concluded there was not much difference in total removals. As expected, as cows get older, a higher proportion are removed.

Conclusions Drawn from the Literature Review

A biological model employed for the prediction of milk production and feed disappearance is only as good as the parameter estimates which define the system. From the review presented in the previous pages the following factors should be further investigated to define more precisely the input-output biological relationships of the dairy cow:

1) Prediction of dry matter intake.
2) Prediction of milk yield over time.
3) Protein requirements.
4) Protein metabolism and quantitative limits defining the use of supplemental NPN in rations.
5) The ability of cows to mobilize nutrient stores (particularly energy) in early lactation.
6) The effect of pregnancy on persistency of milk production.

The model presented in the following chapter can be easily amended as new information becomes available. Expected herdlife and other variables that will change with time can be updated when necessary.

THE DAIRY COW MODEL

This chapter presents the specifications of the model and the framework of the subsystems. The Fortran computer code is presented in the appendix. Figure 7 presents a flowchart for the model.

Economic Decision Rules

One of the important objectives of the dairyman is to maximize average net returns per unit of time. Figure 6 will be used to illustrate this concept under the assumption of nonstochastic relationships. The slope of a line from the origin to any point on the curve (e.g. line OD)

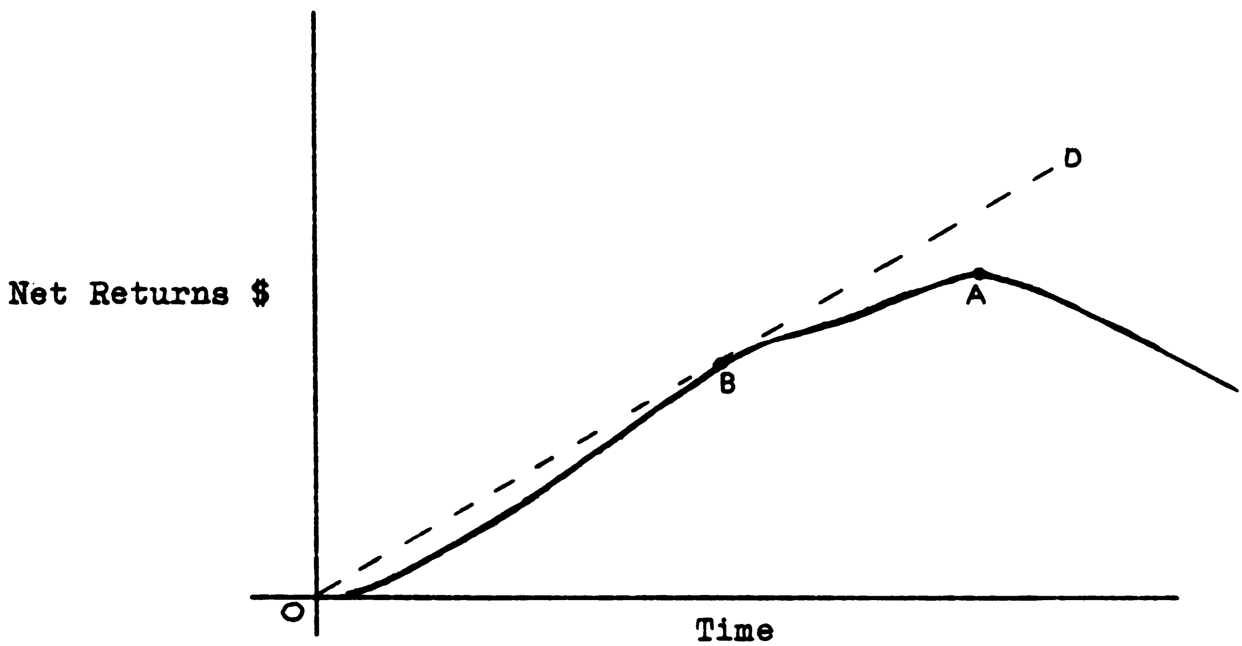


Figure 6. Net Revenue vs Time.

gives the average net revenue per unit of time for a process terminated at that point in time (e.g. cow culled from the herd). The maximum net revenue (e.g. cumulative net returns over the lifetime of a cow) occurs at point "A," while the maximum average net revenue occurs at point "B," where the steepest line from the origin is tangent to the curve. Point "B" therefore represents the maximum average net revenue per unit of time. As time continues beyond point "B," the decreasing additions to revenue begin to pull down the average net revenue per unit of time. Thus if all cows were of equal ability and if relationships were nonstochastic, they would be culled at the age implied by point "B."

Animals are not all of equal ability. Thus, a criteria must be developed to compare an existing animal, "the defender," against the potential replacement animal, "the challenger." The rule is: "Keep if the marginal returns per unit of time for the defender equals or exceeds the average net returns per unit of time of the challenger, otherwise replace" (Faris 1960).

The estimation of the future value of a dairy cow is complicated by their long lifespan. For this reason future revenues must be discounted using the opportunity cost of equity capital. For example, if the discount rate were 10% per annum, the dairyman would be indifferent between receiving $1.00 today or $1.10 a year from now. Therefore $1.10 a year from now is only worth $1.00 in terms of today's dollars. Putting future returns into today's dollars is referred to as estimating the "net present value (NPV)" (Nelson et al., 1973). Because we are concerned with comparing revenues relative to the present time when the replacement decision is being made, estimated NPV's are calculated. Average revenue per unit of time must be determined once the net present value of a cow has been calculated, since the choice criteria involves maximizing average net returns per unit of time. The average net revenue per unit of time is comparable to an annuity payment (Faris, 1960). Thus it is possible to compare cows with different expected times in the herd based upon their expected annualized net returns.

The decision could involve, for example, replacing a 6-year-old mature cow producing 15,000 pounds of milk with a heifer whose mature equivalent is 17,000 pounds. The time for replacement occurs when the marginal revenue of the "defender" is less than the annualized net revenue of the challenger.

Future gross revenues are projected based on milk production and the milk price subsystems. Costs are projected based on feed disappearance, price, and other variable costs such as veterinary expenses subsystems. Costs and returns considered identical for both the "challenger" and the "defender" are ignored. It is differences in costs and returns that will determine which animal belongs in the herd. Past incomes and expenses are ignored as we are concerned with maximizing future income.

The dairy cow replacement problem is complicated by the fact that the relevant relationships are stochastic. In particular, the probability of a cow surviving from one lactation to the next is less than 100 percent (Stewart *et al.*, 1977). The rule becomes: "Keep if the expected (in a Probalistic sense) marginal returns per unit of time for the defender equal or exceed the expected (in a probalistic sense) average returns per unit of time of the challenger."

The net present value (NPV) and annualized net present value (ANPV) calculations, in a probalistic environment are calculated as follows:

1. Calculate the NPV and ANPV for each potential lifespan of the cow, j = 1, . . ., J.
2. Solve for the age, j, which maximizes ANPV.
3. Calculate the expected NPV (ENPV) and expected ANPV (EANPV). That is:

$$ENPV = \sum_{j=1}^{j} (NPV_j)\ (P_j)$$

and

$$EANPV = \sum_{j=1}^{J} (ANPV_j)\ (P_j)$$

where P_j is the probability that the cow will survive j lactations, $P_j = 1$.

Salvage values must be included in NPV calculations. However, they are ignored in EANPV calculations for making replacement decisions since either the defender or the challenger will be sold. More generally, their salvage value differential, if any, should be included.

Introduction to the Model

This program was designed to simulate the costs and returns for individual dairy cows through time from the present moment onward until the end of lactation 7.

The investigator inputs: age, calving interval, mature equivalent milk production, percent butterfat, mature equivalent weight, milk and feedstuffs prices, opportunity cost on capital and the number of lactations to consider. Model outputs include: predicted milk yield for each lactation and average daily milk for each month within each lactation; amounts of each feedstuff necessary to balance a diet to meet nutrient requirements in a least cost way for each month within each lactation; amount of weight lost or gained for each month within each lactation; net present value of the animal and annualized net present value of the animal.

Revenue is calculated for each lactation. Lifetime milk production and feed disappearance are generated and salvage value appropriate variable costs and probabilities of involuntary removal from the herd are accounted for. The model provides an economic basis for making voluntary culling decisions. Past expenses and revenues are ignored as the model is concerned with future revenues.

Where:

- i = lactation number
- ø = lactation number at the beginning of the analysis
- p = ultimate lactation number thus far considered
- 7 = maximum number of lactations considered
- j = month within the calving interval
- n = number of months within the calving interval

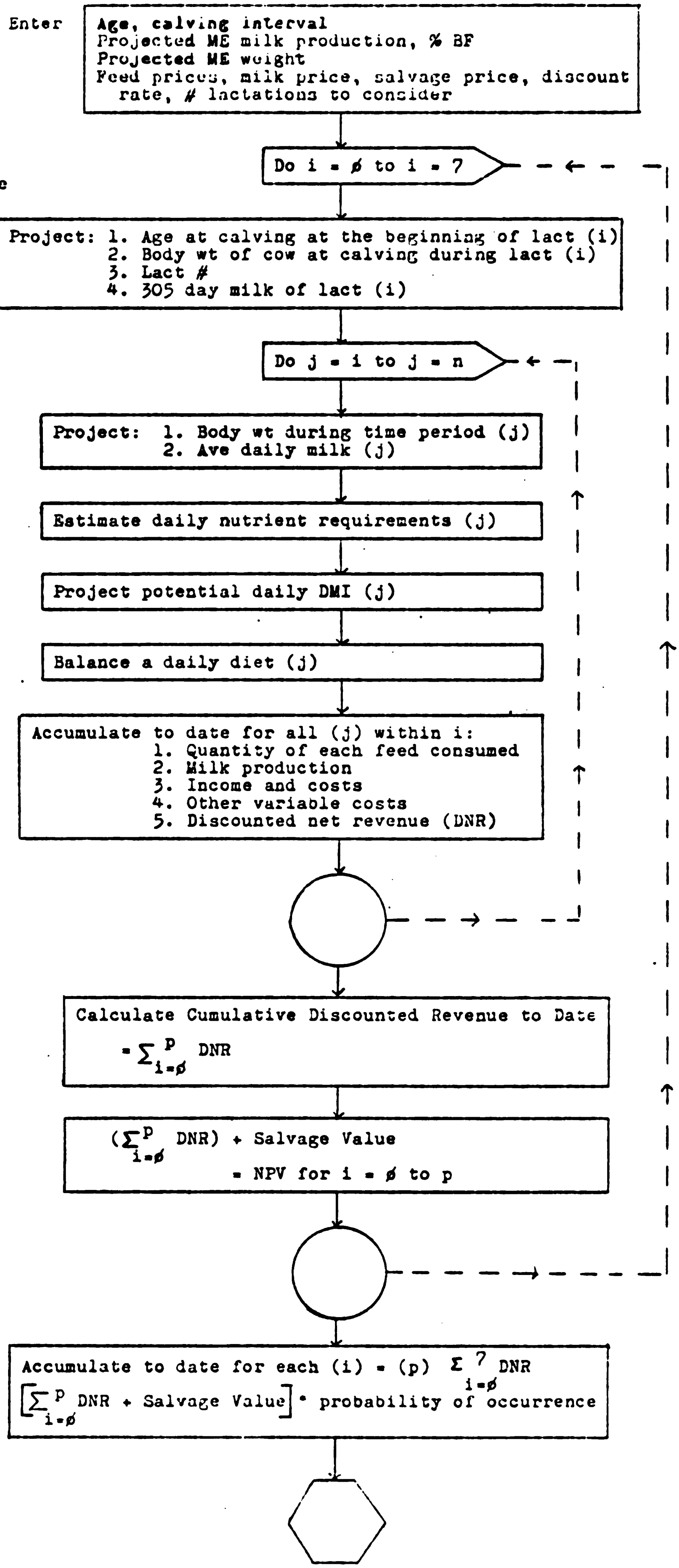


Figure 7 Flow Chart of the Model

Feed and other variable costs are estimated in the subroutine:

<u>Cost</u>

Other variable costs are based upon production level considering Michigan farm data analyzed by Nott (1974), adjusted to current price levels using a multiplier of 1.75 (Black 1978).

Costs are subtracted from milk income to estimate the revenue generated during each lactation cycle. Revenue is discounted using present value factors consistent with the interest rate and the time period being considered.

The discounted net returns (DNR) are accumulated for all time periods considered (i.e., if considering a cow which is presently in her third lactation, accumulate the expected revenue for lactation 3, then for the period considering lactations 3 + 4, then for 3 + 4 + 5, 3 + 4 + 5 + 6, and finally for the period 3 + 4 + 5 + 6 + 7).

The accumulated discounted net returns, including each time period are subsequently weighted by the marginal probability of their occurrence, thus estimating the variable net present value for each time period considered.

Net present value is converted to annualized net present value using the formula below

$$\text{NPV} \times \text{rate}\ (1 + \text{rate})^{I} / \ (1 + \text{rate})^{I} - 1$$

where

I = lactation number

rate = interest rate.

Subsystem: Milk Production

The model projects average daily milk production of a cow for each month within each lactation from the present moment onward until the end of lactation 7. Factors that are important to consider in projecting milk yield include: 1) genetic potential and environment, 2) age and lactation number, 3) season of calving, 4) feed intake and ration quality and 5) health of the animal.

Genetic potential and environment are taken into account using DHIA (1974) mature equivalent (ME milk) factors which project the 305-day yield of the cow if she were mature (approximately 24 mos of age). They are primarily used to compare the producing capacity of contemporary herdmates during the present year. These factors take into account breed, regional location in the United States and represent the expected phenotypic character of the animal within a given environment. Using these factors thus implies relatively constant environmental conditions across all lactations.

Projected mature equivalent milk production is adjusted by age and season of calving correction factors enabling prediction of the total milk yield for the entire lactation for animals of any age calving at various seasons of the year.

DHIA (1974) age and season of calving correction factors were fitted to reciprocal curves resulting in equations for total milk with age as the dependent variable and read as follows:

If age $\leq$ 70 months, the mature equivalent (XME_{milk}) factor for milk equals:

$$XME_{milk} = .809 + (10.68 \div \text{age in months})$$

If age > 70 and $\leq$ 94 months:

$$XME_{milk} = .96$$

If age > 94 months:

$$XME_{milk} = .96 + .0016 \times (\text{age in months} - 94)$$

Table 8. Average Season Effects on ME Milk.

Month	Jan.	Feb.	March	April	May	June
Factor	0	1.005	1.00625	1.0194	1.0368	1.0719

Month	July	Aug.	Sept.	Oct.	Nov.	Dec.
Factor	1.09625	1.095	1.0625	1.036	1.0194	1.0156

Adapted from: Norman, H. et al. 1974. USDA-DHIA. Factors for Standardizing 305-Day Lactation Records for Age and Month of Calving. ARS-NE-40. Agricultural Research Service, US Dept of Agr., p. 48.

The effect of season of calving was adjusted for using DHIA monthly factors averaged across all age groups for the months January through December and are listed in Table 8.

Once milk yield for the total lactation is estimated, average daily milk yield for each month within a lactation is projected using Wood's model (1969):

$$Y_n = an^b e^{-cn}$$

where: Y_n = milk yield in week n

n = weeks into lactation

e = base of the natural logarithm

a, b, c = the parameter estimates

Wood's equation (1969) was adapted for use in the model employing Shultz's (1974) standard values for the parameters "a," "b," and "c." (See subroutine:

X LACT (AGE, WEEK, SEASON, PRODYR, PRODDY).

The parameter "a" defines the level of peak production while "b" and "c" characterize the shape of the curve for the age and season of calving subgroups.

The parameter "a" can be estimated for any level of production using the equation:

$$a' = \text{"a"} + \ln (Z/Y)$$

In this equation a' is the adjusted value for "a," where "a" is the standard value built into the model. Z is the actual level of production (in our model, Z is the 305-day predicted ME_{milk} production level). Y is the accumulated production level of the standard (in our model Y equals the 305-day total for the standard cow).

The following example illustrates these calculations for a 2-year old heifer with a mature equivalent of

15,200 pounds of milk and calving in January.

Step 1: Divide the mature equivalent by DHIA age and season of calving factors

$$\frac{15{,}200 \text{ lbs}}{1.24} \text{ of milk/305 days} = 12{,}2\overset{58}{85} \text{ lbs of milk/305 days}$$

Step 2: The lactation curve parameters applicable to this heifer are within the subclass of age (-2) and season of calving (January-February). The standard value for "a" is 3.574, "b" is (.202) and "c" is (.00562). The adjusted value of "a" equals:

$$3.574 + \ln\,(12{,}258 \text{ lbs of milk}/12{,}633 \text{ lbs of milk}) = 3.544$$

Therefore, the lactation equation for this particular heifer in her first lactation is defined by the equation:

$$Y_n = an^b e^{-cn}$$

In this case:

$$Y_n = 3.544\,(n)^{.202} e^{-(.00562)\,(n)}$$

Estimating Lifetime Production

Production in future lactations is calculated in the following manner:

1. Estimate the season of calving.

   If the calving interval is 13 months, the season of calving shifts one month with each successive lactation (i.e. if the first calving occurs in January the second will be in February, the third in March, etc.). If the calving interval is 14 months, the season of calving will shift 2 months with each successive lactation.

2. Age at second calving is equal to age at first calving + length of the calving interval.

3. Total milk production is projected by adjusting the ME by the reciprocal of the appropriate DHIA age and season of calving factor.

4. The appropriate standard parameters of the lactation curve are now defined by the age and season of calving factors.

5. An adjusted value for "a" is calculated as explained on page 63.

6. The appropriate parameters of the lactation equation are applied and average daily milk is projected for every month of lactation 2.

The process is continued for lactations 3, 4, 5, 6, and 7 to calculate weekly production during the lactation cycle. The process is terminated after lactation 7 because the probability of a cow remaining in the herd beyond this length of time is very small (<2%) (Andrus _et al_., 1970).

Subsystem: Dry Matter Intake

Development of the Dry Matter Intake Equation

Equations used in the model are based upon statistical analysis of the experimental data of Foldager (1978) and the literature. Foldager's experiment was designed to estimate protein requirements in early lactation. Weekly intake data for 68 Holsteins during the first 20 weeks of lactation were available. Regression methods were used to estimate the parameters of dry matter intake per day equations including testing hypotheses about linearity of the impacts of milk production potential and weight. Chandler and Brown's (1976) study and the literature were used in the selection of explanatory variables; variables include age, season of calving, milk produced per day and weeks into lactation.

There was no evidence to support the hypothesis that weight at calving and milk production potential are nonlinearly related to dry matter intake. The resultant equation when WTCLF2 and MILK2(6-8) are excluded is presented in Table 9. Dry matter intake was influenced by the protein system; cows receiving the 13-15% CP diet unsupplemented with NPN and both NPN supplemented diets had lower intakes than the cows receiving 12-13% CP diets unsupplemented with NPN. While the hypothesis that intakes were equivalent was rejected, there was no evidence that a difference existed between 2nd, 3rd and 4th treatments.

$DMI_{i,j}$		Daily dry matter intake for the i^{th} cow during the j^{th} week, pounds/day
AGE:		
AGE 2	=	1 if two years old 0 otherwise
AGE 3	=	1 if 3 years old 0 otherwise
AGE 4	=	1 if 4 years old 0 otherwise
TIME:		
WEEK		Weeks into lactation
WEEK2		Week squared
WEEK3		Week cubed
PRODUCTION:		
$MILK(6\text{-}8)_i$		Daily milk production for the i^{th} cow during the 6^{th} through 8^{th} weeks, pounds per day, a proxy for production potential.
$MILK2(6\text{-}8)_j$		Milk(6-8) squared
$MILK_{i,j}$		Daily milk production for the i^{th} cow during the j^{th} week, pounds per day.
$MILK2_{i,j}$		$MILK_{i,j}$ squared
WEIGHT:		
WTCLF		Weight at one week post partum
WTCLF2		WTCLF squared
SEASON:		
SEASON 1	=	1 if December, January or February 0 otherwise
SEASON 2	=	1 if March or April 0 otherwise
SEASON 3	=	1 if May or June 0 otherwise

SEASON 4	=	1	if July, August, or Sept.
		0	otherwise
SEASON 5	=	1	if October or November
		0	otherwise

PROTEIN TREATMENTS:

TREAT 1	=	1	if cow received 12-13% crude protein diet; no supplemental NPN
		0	otherwise
TREAT 2	=	1	if cow received 15-16% crude protein diet; no supplemental NPN
		0	otherwise
TREAT 3	=	1	if cow received 15-16% crude protein diet; urea added at .65% of corn silage, fresh basis
		0	otherwise
TREAT 4	=	1	if cow received 15-16% crude protein diet; ammonia added at .40% of corn silage, fresh basis
		0	otherwise

The initial equation estimated was:

$$
\begin{aligned}
\mathrm{DMI}_{i,j} = \; & + {}_{2}\,\mathrm{SEASON}\ 2 + {}_{3}\,\mathrm{SEASON}\ 3 + {}_{4}\,\mathrm{SEASON}\ 4 + {}_{5}\,\mathrm{SEASON}\ 5 \\
& + {}_{3}\,\mathrm{AGE}\ 3 + {}_{4}\,\mathrm{AGE}\ 4 \\
& + {}_{2}\,\mathrm{TREAT}\ 2 + {}_{3}\,\mathrm{TREAT}\ 3 + {}_{4}\,\mathrm{TREAT}\ 4 \\
& + S_1\,\mathrm{WEEK} + S_2\,\mathrm{WEEK2} + S_3\,\mathrm{WEEK3} \\
& + O_1\,\mathrm{WTCLF}_{i,j} + O_2\,\mathrm{WTCLF2}_{i,j} \\
& + N_1\,\mathrm{MILK(6\text{-}8)}_{i,j} + N_2\,\mathrm{MILK2(6\text{-}8)}_{i,j} \\
& + u_{i,j}
\end{aligned}
$$

where $u_{i,j}$ is a random error. A subsequent model was formulated in which the data were divided into two groups, two year olds and cows at least three years old.

Table 9. Regression Coefficients Defining Dry Matter Intake/Day During the First Twenty Weeks of Lactation.

$\bar{R}^2 = .5970$

Standard Error of Estimate = 2.2476

Regression Coefficient Description	Value	Significance Level
Constant	1.8049	.016
T 2	-.6669	.0005
T 3	-.5535	.002
T 4	-.7418	.0005
S 2	.0639	.815
S 3	-.2423	.252
S 4	.9728	.020
S 5	.6107	.001
A 2	1.0784	.0005
A 3	.7350	.007
Week	2.0906	.0005
$Week^2$	-.1831	.0005
$Week^3$	.004	.0005
Milk(6-8)	.2072	.0005
Wt at Calf	.0065	.0005

Regressions are based on 1320 cases of individual animal data.

Source: Foldager, J. 1977. Protein Requirements and Non-Protein Nitrogen for High Producing Cows in Early Lactation. Ph.D. Thesis, E. Lansing, Michigan, Michigan State University.

Twenty-two of the 68 cows in the experiment were first calf heifers; previous studies have suggested the intake curve for heifers is "flatter" than that of other cows. Thus, cows were sorted into two groups; cows 2 years of age and cows at least 3 years of age. Table 10 depicts the regression equation for 2, ≥3, and the combined data, respectively. The first step is to test the hypothesis that first calf heifers and cows have equivalent intake equations against the alternative that they do not. The appropriate test (Madalla, G. S., 1977, p. 460) is:

$$\frac{Q_3/K}{Q_2/(m+n-2K)}$$

where

Q_1 = SS_E of combined data sets
Q_2 = SS_E of $\leq$2-yr olds + SS_E of $\geq$3-yr olds
Q_3 = $Q_1 - Q_2$
K = # of regression coefficients

(m+n) = # of observations on 2-yr olds (m) + # of observations on 3-yr olds (n).

The ratio is distributed as an $F_{d,K,m+n-2K}$. Here,

Q_1 = 6947
Q_2 = 6205
Q_3 = 742
K = 12
m+n = 1360

and

$$F = \frac{742/12}{6205/(1360-24)} = 13.32$$

a significance level .001. Thus, the hypothesis that the intake equations are equivalent was rejected.

Table 10. Regression Coefficients Characterizing Intake by Age In Early Lactation

			Standard Error of the Estimate							
			2.4735		2.2711		2.2318			
	R^2 = .4854		R^2 = .4728		R^2 = .5885		R^2 = .6026		R^2 = .5970	
	Age									
Age:	2	Sig.	3	Sig.	All	Sig.	All	Sig.	All	Sig.
Constant	1.2842	.179	3.5940	.001	.8546	.162	3.428	.0005	1.8049	.016
T_2	.0147	.945	-.9407	.0005	-.7318	.0005	-.7344	.0005	-.6669	.0005
T_3	.2106	.316	-.8829	.001	-.4989	.005	-.5634	.001	-.5534	.002
T_4	.1721	.460	-.9379	.0005	-.6714	.0005	-.7142	.0005	-.7418	.0005
S_2	.0000	1.000	-.0823	.793	.4506	.090	.0420	.875	.0638	.815
S_3	1.1673	0.0005	-1.3706	.0005	-.1675	.420	-.1666	.414	-.2423	.252
S_4	.8309	.001	.7647	.009	.5003	.014	.5146	.010	.4728	.020
S_5	.7980	.012	.7543	.001	.7145	.0005	.6761	.0005	.6107	.001
W	1.4099	0.0005					1.9038	.0005		
W^2	-.1254	0.0005					-.1735	.0005		
W^3	+.0032	0.0005					.0046	.0005		
W			2.5120	.0005			2.2063	.0005		
W^2			-.2189	.0005			-.1891	.0005		
W^3			.0056	.0005			.0047	.0005		
W					2.0906	.0005			2.0906	.0005
W^2					-.1831	.0005			-.1831	.0005
W^3					.0047	.0005			.0047	.0005
Milk(6-8)	.1588	.0005	.1954	.0005	.2444	.0005	.2060	.0005	.2072	.0005
WTCLF	.0112	.0005	.0042	.001	.0070	.0005	.0047	.0005	.0064	.0005
Age 2									1.08	.0005
Age 3									.735	.007

Data Source: Foldager, J. 1977. Protein Requirements and Non-Protein Nitrogen for High Producing Cows in Early Lactation. Ph.D. Thesis. E. Lansing, Michigan. Michigan State University

There are several differences in the equations. Protein treatment system had little impact on the DMI of 2-year heifers, as contrasted to a substantial impact on cows at least 3 years old. The seasonal impacts are similar except for the May-June period when the impacts were in the opposite direction. The most important difference is that the DMI curve is much flatter for the two-year olds than for the older cows. DMI of the older cows was more sensitive to production potential when it was relatively more sensitive to weight for the 2-year olds.

The analysis indicated that protein treatments 2, 3, and 4 be combined and that seasons 1 and 2 be combined as well as seasons 4 and 5. This reduced the total number of variables to 8. However, separate equations should be considered for two-year olds vs. older cows.

Use of the proxy variable for genetic potential ($MILK(6-8)_j$) resulted in a lower $\bar{R}^2$ than use of average daily production during the week ($MILK_i$), .588 vs. .6519. These regressions are presented in Table 11. These results must be interpreted with caution, however, since use of $MILK_{ij}$ will result in biased estimators if $MILK_{ij}$ and DMI_{ij} are simultaneously determined (Dean, et al., 1972). Single equation estimators sometimes result in better forcasts than those derived from systems of equations, even when simultaneity is present (Madalla, 1977). However, biased estimators are inappropriate for managerial decision making.

Table 11. Milk (Average Daily) vs Milk (Weeks 6-8). 1360 Cases.

	Milk (Average Daily)	Milk (Weeks 6-8)
$\bar{R}^2$	.6519	.588
Standard Error of the Estimate	2.09	2.27
Constant	1.401	.783
T 2	- .545	- .615
S 3	.190	- .264
S 4	.776	.511
Milk	.308	0
Milk (6-8)	0	.243
Weeks	1.161	2.091
(Weeks)^2	- .091	- .183
(Weeks)^3	.002	.0047
Wt at Calf	.007	.007

The regressions described above pertain to data collected over the first 20 weeks of lactation. Extrapolating the regressions beyond that point in time resulted in absurd estimates.

Impact of Fermented Feeds

The equations presented in Table 12 illustrate the impact of fermented feeds on dry matter intake per cwt. of body weight based on an analysis of monthly treatment mean data from Brown et al. (1965) involving 40 cows and 4 different roughage rations. During the experiment corn silage was fed ad libitum to groups 1, 2 and 3. Average quality alfalfa was fed at the rate of 0, 10, 20 and ad lib pounds to groups 1, 2, 3 and 4 respectively.

The regressions involved 2 independent variables: months into lactation and moisture percent of the ration (which is used as a proxy variable indicating the degree of fermentation). The $\bar{R}^2$ value of the analysis was .93. A second equation was run containing moisture, the square root of moisture as well as months. Including non-linear relationships did not improve the analysis. A second series of regressions were run excluding the first 10 weeks into lactation, thus removing the confounding effects of early lactation on intake. This analysis involved 32 cases of mean data and is reported in Table 13. The results are similar to those presented in Table 12; however there is

Table 12. Regression Coefficients Defining Dry Matter Intake in Relation to Moisture and Time

Variables	$\bar{R}^2 = .931$		$\bar{R}^2 = .934$	
		Significance Level		Significance Level
Constant	3.6731	.0005	3.219	.0005
Month	-.0177	.0005	-.0169	.0005
Moisture	-.0176	.0005	-.0360	.005
$\text{Moisture}^{.5}$			.1873	.137

Where: Month = months in lactation
Moisture = % moisture of the ration
$\text{Moisture}^{.5}$ = (% moisture of the ration)$^{.5}$

Regressions are based on 36 cases of mean data.

Source: Brown, L. D., et al. 1965. Effect of Feeding Various Levels of Corn Silage and Hay with High Levels of Grain to Lactating Dairy Cows. Journal of Dairy Science, 48:816, abs.

Table 13. Regression Coefficients Characterizing the Influence of Weeks Into Lactation and Moisture Percent of the Ration on DMI/cwt.

	All Data		10 Weeks Into Lactation		Weeks 10-19		20 Weeks		Interaction of Mois. and Week 10 Weeks Into Lactation	
Cases	36		32		12		20		32	
R^2	.9314		.9372		.7784		.9879		.9613	
Standard Error of the Estimate	.0927		.0888		.1033		.0392		.0697	
		Sig.		Sig.		Sig.		Sig.		Sig.
Constant	3.6731	.0005	3.7405	.0005	3.5639	.0005	3.9732	.0005	3.3874	.0005
Week	-.0177	.0005	-.0194	.0005	-.0203	.042	-.0236	.0005	-.00732	.009
Moisture	-.0177	.0005	-.0181	.0005	-.0126	.0005	-.0201	.0005	-.0063	.064
Week x Mois.									-.0004	.0005

Data Source: Brown, L. D., *et al*. 1965. Effect of Feeding Various Levels of Corn Silage and Hay with High Levels of Grain to Lactating Dairy Cows. J. Dairy Science, 48:816, abs.

less evidence for a non-linear relationship.

The hypothesis that the impact of fermented feeds might be different at various stages of lactation was examined. The data were divided into 2 periods: $WEEKS_{10-19}$ and $WEEKS_{20}$. The following hypothesis was tested:

$$H_o : B_{10-19} = B_{20}$$

vs

$$H_A : H_o \text{ false}$$

where: B_{10-19} = regression coefficients characterizing intake during weeks 10-19 of lactation.

B_{20} = regression coefficient characterizing intake during weeks 20 of lactation.

The appropriate F statistic is

$$F = \frac{Q_3/k}{Q_2/M + N - 2k)}$$

where: F = F statistic

Q_1 = SS_E of the regression characterizing intake for weeks 10 into lactation.

Q_2 = SS_E of the regression characterizing intake for weeks 10-19 + SS_E of the regression characterizing intake for weeks 20.

$Q_3 = Q_1 - Q_3$

k = # variables considered in the regression.

(M + N) = # cases for weeks 10-19 (M) + # cases for weeks 20 (N).

SS_E(< 10 WEEKS) = .228818
SS_E(10-19 WEEKS) = .096018
SS_E(≥ 20 WEEKS) = .026088
k = 2
M = 12
N = 20
F = 12.2336
F critical .05 (2,28) = 4.22
.01 (2,28) = 6.44
F exceeds F critical.

Therefore, we can reject H_o (pr ≤ .000005); there is not enough evidence contained in Brown's data to show that the regression coefficients are the same for weeks 10-19 and weeks 20 into lactation when characterizing intake by weeks into lactation and moisture content of the diet.

The evidence does indeed suggest that the impact of fermented feeds affects dry matter intake and changes with time during the lactation.

Impact of Energy Density and Crude Fiber Content of the Ration

The impacts of energy density and crude fiber content of the ration on dry matter intake per cwt. of body weight were analyzed using period mean data of Lamb *et al*. (1973). The regression coefficients are presented in Table 14. Regressions including either energy or crude fiber as variables provide similar $\bar{R}^2$'s indicating they are good substitutes for one another and are highly related. The best fit regressions included as variables net energy (NE_L), $(NE_L)^2$ and crude fiber demonstrating a curvilinear response of intake as energy density increases.

Table 14. Regression Coefficients Defining Energy, Crude Fiber and Milk per Day on Dry Matter Intake (DMI/Cwt)

	$\bar{R}^2$									
	.9001		.9121		.9167		.9382		.9672	
	Standard Error of the Estimate									
	.0766		.0728		.0709		.0610		.0445	
VARIABLES	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
Constant	2.3749	.0005	1.2490	.059	2.4227	.0005	8.5246	.002	-13.5959	.037
Milk	.0185	.0005	.0148	.005	.01397	.0005	.0102	.001	.0047	.064
NE_L/lb			1.7610	.080					74.8724	.001
$(NE_L/lb)^2$							-13.7935	.018	-76.8432	.0005
Crude Fiber					.1451	.047	1.6481	.011	3.0663	.0005

Regressions are based on 20 cases of mean data. The first 10 weeks of lactation are excluded from the regressions.

Source: Lamb, R. C., et al. Response to Concentrates Containing Two Percents of Protein Fed at Four Rates for Complete Lactations. Journal of Dairy Sci., 57:811.

<u>Subroutines: DMILAC and DMIDRY</u>

The subroutine:
DMILAC (AGE, WEEK, PROD, PRODDY, PRODLG, WEIGHT, DMI, DMILAG) is used to estimate dry matter intake over the lactation. Cows are differentiated on the basis of age (i.e. animals - 2 yrs of age at freshening and those $\geq$ 3 yrs old at freshening).

The intake equation estimated from the analysis of Foldager's data (1977) was used to characterize the intake response curve in early lactation (weeks $\leq$ 10). An upward adjustment of .5 was added to the constant providing a more reasonable estimate of intake.

It is assumed that peak intake has occurred by week 10 into lactation. Intake for weeks > 9 is projected based on intake during the previous month (DMILAG) and adjusted downward to account for decreasing intake as the level of milk production declines (PRODLG - PRODDY). PRODLG refers to average daily milk produced during the previous period and PRODDY refers to daily milk production per day during the present period.

A value of .2 is used as the coefficient characterizing the influence of the change in milk production on dry matter intake. This value was derived from analysis of Lamb's data (1973) presented in Table 14.

Hillman's analysis of Slack's data (1973) yields a coefficient of .0187 x milk when expressing intake as a percent of bodyweight. Assuming an average bodyweight of 1350 lbs the coefficient becomes:

$$.0187 \times 13.5 = .25245 \times (\text{milk, lbs})$$

The coefficient found by analyzing Foldager's (1977) data was:

$$.2578 \times (\text{milk, lbs}) \text{ for cows} \leq 2 \text{ yrs old}$$

$$.2740 \times (\text{milk, lbs}) \text{ for cows} \geq 3 \text{ yrs old}$$

When estimating lbs of dry matter intake, Broster (1978) found the coefficient of:

$$.158 \times \text{milk (lbs)}$$

The average of the above coefficients is .228. The value used in the model, .2 x milk (lbs), compares favorably with the average value of the coefficients.

Intake during the dry period is estimated in the subroutine:

DMIDRY (AGE, WEEK, PROD, PRODDY, PRODLG, WEIGHT, DMI, DMILAG)

Maximum intake is defined as being equal to intake one period (month) prior to the dry period.

Table 15 defines how maximum intake is estimated in the model.

Table 15. Estimated Maximum Dry Matter Intake

	For Weeks 1 $\leq$ 9 into Lactation
DMI, (lbs/day) =	$2.30 + 1.03 \times (\text{Age} \leq 2) + .74 \times (\text{Age} \geq 3) + .0064649 \times (\text{Weight, lbs} \div 2.2) + .20719 \times (\text{Production, lbs of milk per day}) + 2.0906 \times (\text{Week, into lactation}) - .133139 \times \text{Week}^2 + .0046634 \times \text{Week}^3 \times 2.2$
	For Weeks 10 - 40
DMI, (lbs/day) =	Dry matter intake during the previous month (DMILAG) - .20 x Change in milk production, (PRODLG - PRODDY)
	For The Dry Period
DMI, (lbs/day) =	DMILAG

Characteristics of the Diet

The effects on dry matter intake of characteristics of the diet such as fermented feeds and energy density are calculated in subsystem:

REQLAC (AGE, WEEK, PRODDY, WEIGHT, GROWTH, WTCHG, ITPCHG, DMI, EN, CP, CA, PHOS, SALT, XNPN, CAPHLB, CAPHUB, FMIMP, ENIMP, CF)

DMI is a function of age, week into lactation, milk production potential, energy density of the diet, and an index of fermintation. The equation used is

$$\frac{DMI}{WTCLF} = \begin{cases} \text{-- -- ? WEEK -.007 MOISTURE \% -.0039 WEEK-MOISTURE \% if WEEK 40.} \\ \text{-- -- ? WEEK -.023 if WEEK 40.} \end{cases}$$

The impact of the fermentation interaction term is equivalent to the most severe declension on intake due to fermented feeds noted by Hillman <u>et</u> <u>al</u>. (1973). The interaction term may explain differences in the slope $\frac{DMI}{FI}$ found by Hillman <u>et</u> <u>al</u>. (1973) ranging from -.017 to -.023. In the model the impact of fermented feeds is designated as FMIMP.

The relationship of DMI and energy density was derived from Lamb's data: It is estimated that

$$\frac{(DMI/CTCLF)}{(NE_L/lb)} = 1.48.$$

This compares with Hillman, <u>et</u> <u>al</u>.'s estimate of 1.76 when estimated net energy (ENE) was used.

The impact of energy density is designated as ENIMP in the program. Energy density does not begin to exert a negative effect on intake until energy density exceeds .72 Mcal NE_L/lb of dry matter (see Baumgardt 1970).

Subsystem: Requirements

Maintenance requirements are estimated as a function of metabolic size, $wt_{kg}^{.75}$, while production requirements are a linear function of milk production and the percent fat contained in the milk. Lactation requirements are described in the subroutine:

REQLAC (AGE, WEEK, PRODDY, WEIGHT, EN, CP, XNPN, CA, PHOS, XCAPH, SALT)

while dry cow requirements are described by the subroutine:

REQDRY (AGE, WEEK, WEIGHT, EN, CP, XNPN, CA, PHOS, XCAPH, SALT).

Requirements for growth are based on gain per day.

Protein and Energy

The protein subsystem is relatively crude. Since there is little consensus upon the appropriate conceptual framework, NRC requirements were used in conjunction with an upperbound on supplemental NPN use and NPN as a percent of the total protein. There is controversy concerning protein requirements and utilization of supplementary NPN as a source of protein for high producing cows in early lactation. As there is no evidence demonstrating beneficial effects of supplemental NPN in rations of cows whose requirements exceed 14% CP in the ration, supplemental NPN is not permitted as a source of protein if requirements exceed this level. Supplemental NPN was restricted to a maximum of 30 percent of the total crude protein requirement.

It is not clearly established that energy requirements per pound of milk produced decreases as a cow's genetic potential increases as proposed by Smith (1975) and Blaxter (1962); therefore constant partial efficiencies are included in the model.

High producing cows in early lactation have the ability to mobilize significant quantities of body stores thereby helping to meet energy demands when dry matter intake levels are low. This ability appears to be related to the level of milk produced (Poos et al. 1978, Flatt et al. 1967). Calculations in table 16 suggest this relationship may be approximated by expressing mobilization capacity as a function of the level of milk produced. Amounts of energy available through fat mobilization are not precisely defined; however, based on experiments of Flatt and Moe (Flatt et al. 1967, Flatt 1966, Moe 1971) as well as general observations of amounts of body weight lost during early lactation (Trimberger et al. 1972), the following assumptions are incorporated in the analysis:

1. Body fat can be used as a source of energy during the first 8 weeks of lactation with up to 30% of daily energy requirements being met during the first 4 weeks of lactation. During weeks 4-8, 15% of requirements can come from body stores. The body fat used in early lactation must be replenished during mid and late lactation.

Table 16 Energy Mobilization in Early Lactation Proposed as a Percent of Requirements

	30% of NE_L (1) Requirements	Estimated Daily Weight Loss (2)	% Body Weight Lost in 30 Days	20% of NE_L Requirements	Estimated Daily Weight Loss	% Body Weight Lost in 30 Days
Pounds of Milk	Mcal	Lbs.	%	Mcal	Lbs.	%
100	12.34	5.53	11.8	8.22	3.69	7.9
90	11.40	5.11	10.9	7.60	3.41	7.3
80	10.48	4.70	10.0	6.98	3.13	6.7
70	9.55	4.28	9.1	6.36	2.85	6.1
60	8.62	3.86	8.3	5.74	2.58	5.5
50	7.69	3.45	7.3	5.14	2.30	4.9
40	6.76	3.02	6.4	4.50	2.02	4.3

	15% of NE_L Requirements	Estimated Daily Weight Loss	% Body Weight Lost in 30 Days	10% of NE_L Requirements	Estimated Daily Weight Loss	% Body Weight Lost in 30 Days
Pounds of Milk	Mcal	Lbs.	%	Mcal	Lbs.	%
100	6.17	2.77	5.9	4.11	1.84	3.9
90	5.70	2.55	5.5	3.80	1.71	3.6
80	5.24	2.35	5.0	3.49	1.56	3.3
70	4.77	2.14	4.6	3.18	1.43	3.0
60	4.31	1.93	4.1	2.87	1.29	2.8
50	3.84	1.72	3.7	2.56	1.15	2.5
40	3.34	1.51	3.2	2.25	1.01	2.2

(1) Requirements are based on a 1400 lb. cow producing 3.5% fat milk.

(2) Energy per pound of body weight is estimated from 1978 NRC as 2.23 Mcal of NE_L per pound.

2. Fat is assumed to contain 9.0 Mcal of energy per kilogram. Conversion from fat to milk is considered to be .86 efficient (Moe, P. and W. Flatt 1969); therefore it is assumed to contain 7.56 Mcal per kg or 3.4 Mcal per pound.
3. Moe (1971) states that efficiency of gain in mid and late lactation is the same as for milk production; therefore Mcal required to replenish fat stores can be estimated using NE. Replenishment of body stores is assumed to occur during weeks 12 to 40 of lactation. By week 12 animals should have reached their maximum dry matter intake, and milk production is beginning to decline. After week 40 the animal is approaching the dry period and fattening in the dry period is not recommended. Fat will be replaced evenly during this period by averaging the amount of weight lost over this 196-day period.

Energy requirements can be stated as follows:

Period 1: 1st 4 weeks of lactation

$$NE_{\ell}^{r} = \alpha BW + \beta \text{ Milk} - \gamma \text{ Body Weight Loss}$$

Period 2: Weeks 4 - 8

$$NE_{\ell}^{r} = \alpha BW^{.75} + \beta \text{ Milk} - \gamma \text{ Body Weight Loss}$$

Period 3: Weeks 8 - 12

$$NE_{\ell}^{r} = \alpha BW^{.75} + \beta \text{ Milk}$$

Period 4: Weeks 12 - 40

$$NE_{\ell}^{r} = \alpha\, BW^{.75} + \frac{(\Sigma \text{ Mcal mobilized})}{196}$$

Period 5: Week 40 to Dry

$$NE_{\ell}^{r} = \alpha\, BW^{.75} + \beta \text{ Milk}$$

where:

NE^r is in Mcal per day;

BW is in kilograms;

Milk is in kilograms per day; and

α, β, γ are parameters, all 0.

Table 17 shows how the model accounts for changes in body weight.

Calcium and Phosphorus

The Ca/Phos ratio during lactation must be less than 2.5 but greater than two to reduce the incidence of milk fever (Hillman *et al*. 1973). During the dry period, Jorgensen (1978) recommends that calcium intake not exceed 100 grams per day. Also, the Ca/Phos ratio is set $\lesssim$ 1.5 to insure that excess phosphorus is not incorporated in the diet.

Crude fiber

The level of crude fiber in the ration is set $\geq$ 16% DMI in order to assure adequate rumen function.

Requirements for growth

Requirements for growth are not clearly established for a heifer once she enters the milking herd although cows do not reach maturity until an age of approximately 7 years (Foldager *et al*. 1972). NRC recommends increasing the

Table 17 Restriction on Maximum Energy Mobilization and Re-conditioning During Lactation

Time Period	Change in Body Weight
Week $\leq$ 4	Max Δ Body Weight = [(energy required for maintenance, milk and growth) x .3] + 3.4
4 < Week $\leq$ 8	Max Δ Body Weight = [energy required for maintenance, milk and growth) x .15] + 3.4
8 < Week $\leq$ 12	Max Δ Body Weight = 0
12 < Week $\leq$ 40	Mcal NE_L for Reconditioning = $[(\sum_{week=1}^{8}$ Mcal NE_L mobilized) + 196] x .8
Week > 40	Mcal NE_L for Reconditioning = 0

maintenance allowance for all nutrients by 20% during the first lactation and 10% during the second to allow for growth.

Requirements in this study are based upon the animal's growth rate which is estimated in the subroutine:

WT (MNTAGE, WTME, WEIGHT, GROWTH).

Values of 2.32 Mcal NE and .50 lbs. protein were used per pound of gain for growing lactating cattle based on 1978 NRC.

Tables 18 and 19 show how the model accounts for nutrient requirements.

TABLE 18. NUTRIENT REQUIREMENT SPECIFICATIONS FOR LACTATING COWS.

Daily

DMI	$\Sigma x_j \leq DMI^{max}$
ENERGY	$\Sigma En_j^a x_j \geq En^r$ Milk + En^r Maintenance + En^r Growth $\pm$ En^r Δ Body Weight
CRUDE PROTEIN	$\Sigma CP_j^a x_j \geq CP^r$ Milk + CP^r Maintenance + CP^r Growth
CALCIUM & PHOSPHORUS	$\Sigma Ca_j^a x_j \geq Ca^r$ Milk + Ca^r Maintenance $\Sigma Phos_j^a x_j \geq Phos^r$ Milk + $Phos^r$ Maintenance $2.5 \geq \frac{Ca_j^a x_j}{Phos_j^a x_j} \geq 2.0$
SALT	$\Sigma Salt_j x_j = Salt^r$ Milk + $Salt^r$ Maintenance
SUPPLEMENTAL NON-PROTEIN NITROGEN	$\Sigma XNPN_j^a x_j = 0$ if $CP^r > .14 \Sigma x_j$ $\Sigma XNPN_j^a x_j \leq .3\ CP^r$
CRUDE FIBER	$\Sigma Cf_j^a x_j \geq .16\ x_j$

Where:

The superscript a indicates the amount of that variable in feed x_j;

x_j indicates the amount of individual feedstuffs considered dry matter basis; and

superscript r indicates the amount of that variable that is required for the function stated.

TABLE 19. NUTRIENT REQUIREMENT SPECIFICATIONS FOR DRY COWS

Dry Cow Requirements

DRY MATTER INTAKE	$x_j \leq$ DMI of ultimate week of lactation
ENERGY	$En_j^a \geq En^r$ Maintenance and Pregnancy
CRUDE PROTEIN	$CP_j^a \geq CP^r$ Maintenance and Pregnancy
CALCIUM & PHOSPHORUS	$Ca_j^a \geq Ca^r$ Maintenance and Pregnancy $Phos_j^a \geq Phos^r$ Maintenance and Pregnancy $Ca_j^a < 100$ g. $\frac{Ca_j^a}{Phos_j^a} \leq 1.5$
SALT	$\Sigma\, Salt_j^a = Salt^r$ Maintenance and Pregnancy

Where:

The superscript a above a variable indicates the amount of that variable in feed x_j;

x_j indicates the amount of individual feedstuffs considered on a dry matter basis; and

superscript r indicates the amount of that variable that is required for the function stated.

Subsystem: Balancing the Ration

Using a linear programming (LP) subsystem titled:
BAL (DMI, EN, CP, XNPN, CA, PHCS, XCAPH, SALT,
F, P, IOPTI)

a ration is balanced to meet the daily nutrient requirements of dairy cattle taking into account the nutrient composition of feedstuffs, feed prices and dry matter intake, and weight change. The source of the nutrient composition of feedstuffs was Teleplan 31, a computer dairy ration balancing program, developed by Harsh, Hillman and Black (1973). Table 20 illustrates the matrix layout of the ration balancing subsystem and the restrictions that are incorporated.

TABLE 20. **Linear Programming Balance Matrix**

Row	Restriction	Corn Grain 01	Corn Silage 02	Alfalfa 03	Soy 44 04	Urea 05	Di-Cal 06	Limestone 07	Salt 08	FMIMP 09	ENIMP 10	WEIGHT Δ 11	
01	Dry matter intake (DMI) lb	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	A	B	0.000	$\Sigma X_j + \beta_1 fMIMP + \beta_2\ ENIMP < DMI^{max}$
02	Net $Energy_L$ (Mcal) (NE_1)	0.950	0.700	0.440	0.870	0.000	0.000	0.000	0.000	0.000	0.000	C	$\Sigma NE_j{}^a X_j + \beta_3 \Delta BW \geq NE_L^r$ milk + NE_L^r maintenance + NE_L^r growth
03	Crude Protein (lb) (CP)	0.101	0.080	0.169	0.508	2.810	0.000	0.000	0.000	0.000	0.000	0.000	$\Sigma CP_j{}^a X_j \geq CP^r$ milk + CP^r maintenance + CP^r growth
04	Crude fiber (lb) (CF)	-.137	0.0414	0.149	-.010	-.160	-.160	-1.60	-1.60	0.000	0.000	0.000	$\Sigma(CF_j{}^a - .16)\ X_j \geq 0$
05	Calcium (lb) (Ca)	0.0002	0.0028	0.013	0.0028	0.000	0.231	0.338	0.000	0.000	0.000	0.000	$\Sigma Ca_j{}^a X_j \geq Ca^r$ milk + Ca^r maintenance
06	Phosphorus (lb) (P)	0.0026	0.0020	0.0020	0.0064	0.000	0.186	0.000	).000	0.000	0.000	0.000	$\Sigma Phos_j{}^a X_j \geq Phos^r$ milk + $Phos^r$ maintenance
07	Salt	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	$\Sigma Salt_j{}^a X_j \geq Salt^r$ milk + $Salt^r$ maintenance
08	Calcium:Phosphorus upper bound Ca:P	-.005	-.0012	0.009	-0.01	0.000	-.141	0.338	0.000	0.000	0.000	0.000	$Ca_j{}^a X_j - 2\ Phos_j{}^a X_j \geq 0$
09	Calcium:Phosphorus upper bound Ca:P	-.0063	-.0022	).008	-.0132	).000	-.234	0.338	0.000	0.000	0.000	0.000	$Ca_j{}^a X_j - 2.5\ Phos_j{}^a X_j \leq 0$

[A] FMIMP = (.007 + .0039* week) x (weight, if week $\leq$ 40; if week >40 = .023* weight/100)

[B] ENIMP = 1.76 x (weight/100)

[C] WT Δ = 3.4 if week $\leq$ 8; -4.8 if week >8

TABLE 20 (continued) Linear Programming Balance Matrix

Row	Restriction	01 Corn Grain	02 Corn Silage	03 Alfalfa	04 Soy 44	05 Urea	06 Di-Cal	07 Limestone	08 Salt	09 FMIMP	10 ENIMP	11 WEIGHT Δ	
10	Supplemental NPN: Crude Protein (NPN)	-.0303	-.024	-.0507	-.1524	1.967	0.000	0.000	0.000	0.000	0.000	0.000	$\Sigma(X\ NPN_j^a - .3\ CP_j^a) \leq 0$; if $CP^r \geq .14\ \Sigma X_j$ then $X\ NPN_j^a\ X_j = 0$
11	Impact of NE/lb (ENIMP)	D	D	D	D	D	D	D	D	0.000	-1.000	0.000	$\Sigma(NE_{L_j}^a - .72)/DMI - ENIMP \leq 0$
12	Impact of Fermented Feeds on DMI(FIMP)	E	E	E	E	E	E	E	E	-1.000	0.000	0.000	$\Sigma\ (Mois_j^a \times 100) - 20)\ /DMI - FMIMP \leq 0$
13	Upper Bound on Weight Loss, 1st 8 wk	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-1.000	Upper bound on wt Δ $\leq .3$ (NE^r milk + NE^r maintenance + NE^r growth) + 3.4 for week ≤ 4 $\leq .15$ (NE^r milk + NE^r maintenance + NE^r growth) + 3.4 for weeks $>4 \leq 8$ = 0 for weeks $>8 \leq 12$ = Σwt lost during week 1-8 + 196 for weeks $>12 \leq 40$ = 0 for weeks >40
14	Constraints on percentage of corn silage and alfalfa forages	0.000	+1.000	-2.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	Corn silage/alfalfa ≥ 2.0

DE Coefficients of cells outlined with heavy lines are calculated for each month within the lactation cycle. In the right hand side equations: the superscript "a" above a variable indicates the amount of that variable in feed X_j. "X_j" indicates the amount of the individual feedstuff considered. The superscript "r" above a variable indicates the amount of that variable that is required.

RESULTS AND DISCUSSION

The results of the simulation model are presented including daily feed requirements for cows with varying productive capacity, per lactation budgets, and ENPV and AENPV. Feed prices per lb of dry matter were: shelled corn, \$.042; corn silage, \$.023; alfalfa hay, \$.030; soybean meal 44, \$.090; urea, \$.080; dicalcium phosphate, \$1.25; limestone, \$.035; and salt, \$.04. Output prices included the cow's salvage value at \$.40/lb and 3.5% milk at \$9.25/cwt.

Before showing expected value results generated by the model, examples of the rations generated throughout lactation as well as across the lifespan of cows with varying productive capacity will be presented.

Table 21 presents performance characteristics of cows with various production abilities at 3 different ages. Looking across lactation feed summaries presented in Table 22, it was found that as production level increases more corn, soybean meal and alfalfa hay are incorporated in the ration while less corn silage and urea are included. The reason less urea is utilized is due to the restriction that urea cannot be included in rations when crude protein exceeds 14% of the dry matter. The concentrate to forage ratio also increases with production level, ranging from .29 to .49.

Beyond a level of 22,000 lbs of milk the computer will not balance for rations during months 2 to 3 into lactation. As there are herd averages above this level it is apparent that either parameters estimating intake are incorrect or energy requirements are not constant for cows of different production levels.

The feed summary of the cow producing 12,500 lbs milk includes 69 lb urea.

69 lb urea x 2.81 lb protein/lb urea = 194 lb protein
194 lb protein/.44 lb protein/lb soybean meal =
441 lb of soybean meal that were spared by including urea in the ration.

69 lb urea x $.08/lb = $5.52 for urea
441 lb soybean meal x $.09/lb 2 $39.70 for soybean meal

This amounts to a savings of approximately $34.00/cow/yr. Even at the highest level of production 32 lb of urea were utilized. This amount of urea could substitute for over 200 lb of soybean meal amounting to a savings of approximately $15.80/cow/yr. Thus, contrary to popular belief, urea serves as a source of protein for cows exhibiting high levels of production. (A note of caution is needed here in interpreting these results; actual farm situations should not permit balancing diets for each month within each lactation.)

Table 21. Performance Characteristics of Cows of Various ME Milk Production Levels at 3 Different Ages.

Age	Week 7 Milk Yield[1] (lbs)	Projected Milk Yield[2] (lbs)
	ME = 15,000 lbs	
2	52.9	11,962
4	66.0	14,452
6	70.9	15,625
	ME = 17,500 lbs	
2	61.7	13,955
4	77.0	16,966
6	82.7	18,229
	ME = 20,000 lbs	
2	70.6	15,949
4	88.0	19,389
6	94.5	20,833
	ME = 22,500[3] lbs	
2	79.4	17,943
4	98.9	21,813
6	106.3	23,438

[1]Week 7 milk yield is an indication of peak yield.

[2]This assumes a 12-month calving interval (production for 305 days).

[3]The model cannot solve beyond a level of 22,500 lbs, suggesting that the amount of energy required per pound of milk might not be constant as proposed by WRC.

Table 22. Lactation Feed Summary For Cows Producing Various Levels of Milk[1]

ME Milk	Predicted Milk	Feeds[2] Corn	Corn Silage	Alfalfa Hay	Soybean Meal	Urea	Di-cal	Limestone	Total[3] Dry Matter	Grain:Forage[4]
		50 bu[5]			320 lb	69 lb	58 lb	26 lb		
12,500	12,100	1.4 T[6]	7.2 T	1.2 T	.16 T				4.7 T	.29
		64 bu			750 lb	60 lb	62 lb	29 lb		
15,000	14,500	1.8 T	6.9 T	1.2 T	.37 T				5.1 T	.37
		82 bu			1020 lb	54 lb	48 lb	46 lb		
17,500	17,000	2.3 T	5.6 T	1.5 T	.5 T				5.6 T	.44
		91 bu			1600 lb[7]	32 lb	38 lb	53 lb		
20,000	19,400	2.6 T	4.8 T	1.7 T	.8 T				6.0 T	.49

[1]Estimated for animals 4 yrs of age weighing 1300 lbs, producing 3.5% fat milk, during lactation 2.

[2]Feed quantities are on an as fed basis; dry matter content is: .86, .32, .884, .9, 1.0, 1.0, 1.0 for feeds from left to right, respectively.

[3]Estimated total dry matter consumption during lactation; it is estimated that cows will consume between .8 and .9 tons of dry matter during the dry period.

[4]Grain to forage ratio.

[5]Bushels

[6]Tons

[7]The amount of soybean meal for this run is overestimated; the computer pulled in excessive soybean meal as a source of fiber and energy for the ration.

Looking within lactations presented in Tables 23, 24, 25, 26, amounts of corn and hay in the diet increase until mid lactation and then begin to decline while corn silage exhibits an opposite trend. Amounts of soybean meal steadily decline as lactation progresses until about mid-lactation subsequently being substituted for by urea. This suggests that cows grouped by stage of lactation could utilize urea in diet formulation for cows producing at high levels of milk in late lactation. Cows producing at 17,500 and 19,400 lb are nearly able to meet calcium and phosphorous requirements during mid lactation with little mineral supplementation. The largest amount of weight was lost by the cow producing at 19,400 lbs of milk. This amounted to an average daily loss of -2.33 lb for the first 4 week period and -.95 lb for weeks 4-8.

$$
\begin{aligned}
-2.33 \text{ lb} \times 28 \text{ days} &= 65.24 \text{ lb} \\
-.95 \text{ lb} \times 28 \text{ days} &= \underline{26.6} \text{ lb} \\
& 91.84 \text{ lb}
\end{aligned}
$$

Thus 91.8 lb were lost during the first 8 weeks of lactation. This amount of weight loss lies within range of that expected (See Trimberger _et al_. 1972).

Table 23. Feed Consumption of a Cow Producing 12,100 lbs of 3.5% Milk[1]

WEEK[2]	MILK[3]	WT[4]	Corn[5]	Corn Silage	Alfalfa Hay	Soybean Meal	Urea	Di-cal	Limestone	Max.[6] DMI	Act.[7] DMI
2	53.4	-.85	9.2	11.0	5.5	5.5	0	.21	.28	2.5	2.4
6	55.3	0	8.5	16.8	8.4	4.1	0	.20	.17	3.1	2.9
11	51.9	0	11.8	16.2	8.1	0	.562	.27	.13	3.0	2.8
15	47.4	.13	11.5	15.8	7.9	0	.471	.24	.12	3.0	2.8
19	42.7	.13	9.9	15.8	7.9	0	.39	.22	.08	2.9	2.6
24	38.1	.13	8.4	15.9	7.9	0	.31	.19	.05	2.8	2.5
28	33.9	.13	7.0	15.8	7.9	0	.23	.17	.02	2.7	2.4
32	30.0	.13	5.9	15.7	7.8	0	.17	.15	0	2.7	2.3
37	26.4	.13	5.0	15.5	7.7	0	.11	.13	0	2.6	2.2
41	23.2	0	3.1	15.6	7.8	0	.07	.13	0	2.5	2.0

[1]This assumes a cow 4 yrs of age weighing 1300 lbs.

[2]Weeks into lactation.

[3]Average daily milk yield.

[4]Change in weight.

[5]Feeds are estimated as pounds of dry matter.

[6]Maximum dry matter intake.

[7]Actual dry matter intake.

Table 24. Feed Consumption of a Cow Producing 14,500 Lbs of 3.5% Milk[1]

WEEK[2]	MILK[3]	WT[4]	Corn[5]	Corn Silage	Alfalfa Hay	Soybean Meal	Urea	Di-cal	Limestone	Max.[6] DMI	Act.[7] DMI
2	64.0	-1.34	8.8	11.7	5.9	7.1	0	.26	.33	2.7	2.6
6	66.3	0	12.4	15.1	7.5	5.7	0	.22	.30	3.3	3.2
11	62.3	0	11.3	15.4	7.7	5.2	0	.21	.26	3.2	3.1
15	56.9	.21	12.1	14.5	7.3	4.4	0	.19	.25	3.1	3.0
19	51.3	.21	14.2	14.7	7.3	0	.55	.26	.17	3.0	2.9
24	45.8	.21	12.1	14.9	7.5	0	.45	.23	.13	2.9	2.7
28	40.6	.21	10.4	15.0	7.5	0	.35	.20	.09	2.8	2.6
32	36.0	.21	8.8	15.0	7.5	0	.27	.18	.06	2.8	2.4
37	31.7	.21	7.5	15.0	7.5	0	.20	.16	.03	2.7	2.3
41	27.9	0	4.8	15.5	7.7	0	.16	.15	0	2.6	2.2

[1]This assumes a cow 4 yrs of age weighing 1300 lbs.

[2]Weeks into lactation.

[3]Average daily milk yield.

[4]Change in weight.

[5]Feeds are estimated as pounds of dry matter.

[6]Maximum dry matter intake.

[7]Actual dry matter intake.

Table 25. Feed Consumption of a Cow Producing 17,000 Lbs of 3.5% Milk[1]

WEEK[2]	MILK[3]	WT[4]	Corn[5]	Corn Silage	Alfalfa Hay	Soybean Meal	Urea	Di-cal	Limestone	Max.[6] DMI	Act.[7] DMI
2	74.7	-1.84	8.4	12.4	6.2	8.7	0	.30	.39	2.9	2.8
6	77.4	- .42	12.4	15.1	7.6	7.3	0	.27	.37	3.5	3.3
11	72.7	0	14.7	14.0	7.0	6.6	0	0	.24	3.4	3.3
15	66.4	.10	17.6	6.0	15.1	4.0	0	0	0	3.3	3.3
19	59.8	.32	17.1	5.8	14.6	3.9	0	0	0	3.2	3.2
24	53.4	.35	17.7	9.6	10.8	0	.42	.25	.11	3.0	3.0
28	47.4	.35	14.6	13.7	6.9	0	.48	.23	.18	2.9	2.8
32	41.9	.35	12.4	14.1	7.0	0	.37	.20	.13	2.8	2.6
37	37.0	.35	10.7	14.2	7.1	0	.28	.18	.09	2.8	2.5
41	32.5	0	6.4	15.3	7.7	0	.24	.18	.02	2.7	2.3

[1] This assumes a cow 4 yrs of age weighing 1300 lbs.

[2] Weeks into lactation.

[3] Average daily milk yield.

[4] Change in weight.

[5] Feeds are estimated as pounds of dry matter.

[6] Maximum dry matter intake.

[7] Actual dry matter intake.

Table 26. Feed Consumption of a Cow Producing 19,400 Lbs of 3.5% Milk[1]

WEEK[2]	MILK[3]	WT[4]	Corn[5]	Corn Silage	Alfalfa Hay	Soybean Meal	Urea	Di-cal	Limestone	Max.[6] DMI	Act.[7] DMI
2	85.4	-2.33	8	13	6.5	10.3	0	.34	.44	3.1	3.0
6	88.4	- .95	12.4	16	8	9	0	.31	.43	3.6	3.5
11	83.1	0	18.6	12	6	8	0	0	.36	3.5	3.5
15	75.9	0	20	6.2	13.4	5.2	0	0	.10	3.4	3.4
19	63.8	.04	17.8	6.0	15	4.0	0	0	0	3.3	3.3
24	61.0	.29	17.2	5.9	14.7	4.0	0	0	0	3.2	3.2
28	54.2	.50	13.5	5.9	13.6	7.48[8]	0	0	.08	3.0	3.1
32	47.9	.50	17.0	9.9	9.8	0	.34	.21	.11	2.9	2.9
37	42.3	.50	14.4	13.0	6.5	0	.38	.21	.17	2.9	2.7
41	37.2	0	8.2	15.1	7.6	0	.33	.20	.06	2.8	2.4

[1]This assumes a cow 4 yrs of age weighing 1300 lbs.

[2]Weeks into lactation.

[3]Average daily milk yield.

[4]Change in weight.

[5]Feeds are estimated as pounds of dry matter.

[6]Maximum dry matter intake.

[7]Actual dry matter intake.

[8]Protein requirement was 5.63 lbs; provided = 7.87 lbs. It appears soybean meal is being drawn into the diet as a source of energy and fiber.

Once feed costs and income from milk are determined the program proceeds to generate estimated variable net present value (ENPV). Income is then weighted by the probability of survival. Expected income is converted to an annuity amount (average yearly value over the lifespan of the animal).

The first question to address when considering the replacement question is that of determining the optimum time of keeping a cow in the herd assuming she has no challenger to contend with.

Figure 8 presents the expected variable annualized net returns of a heifer whose ME is 15,000 lbs of 3.5% milk, starting with lactation 1 and continuing through lactation 7, taking into account probability of expected life at each stage.

Net returns increase with age up until lactation 5 at which time they begin leveling off. By lactation 7 average net returns are actually beginning to decrease due to decreasing milk production as age progresses past maturity.

The optimum length of time to keep an animal in the herd ranges between 5 and 7 lactations. The differences in income at these ages is not significant.

The replacement question can be addressed from 2 different standpoints depending upon where we are situated in regard to the production curve. If we are considering a cow at an age where annualized net returns are decreasing with age then the proper comparison is that of marginal net returns of the current asset (over the next production period) with the maximum annualized net returns of the replacement candidate.

If we are considering a cow at an age where annualized net returns are increasing with age, we should compare maximum annual returns of the existing cow with maximum annual returns of a replacement candidate.

Suppose we have a 6-yr old cow whose $ME_{(Milk)}$ is 15,000 lbs, should she be kept or replaced? Figure illustrates that the cow is at an age where she has maximized average net returns. Therefore, it is proper to compare her marginal net returns for the next lactation cycle with the maximum average net returns of the replacement candidate. According to the analysis, at age 6 (lactation 5) annual variable net returns are approximately $930. Therefore any heifer whose variable annualized net income exceeds $930 should replace the defender.

Table 27 Projected Annualized Variable Net Present Value of Replacement Heifers.

Production level (ME_{Milk})	Annualized Variable Net Earnings
12,500	$643
15,000	890
17,500	930
20,000	1066

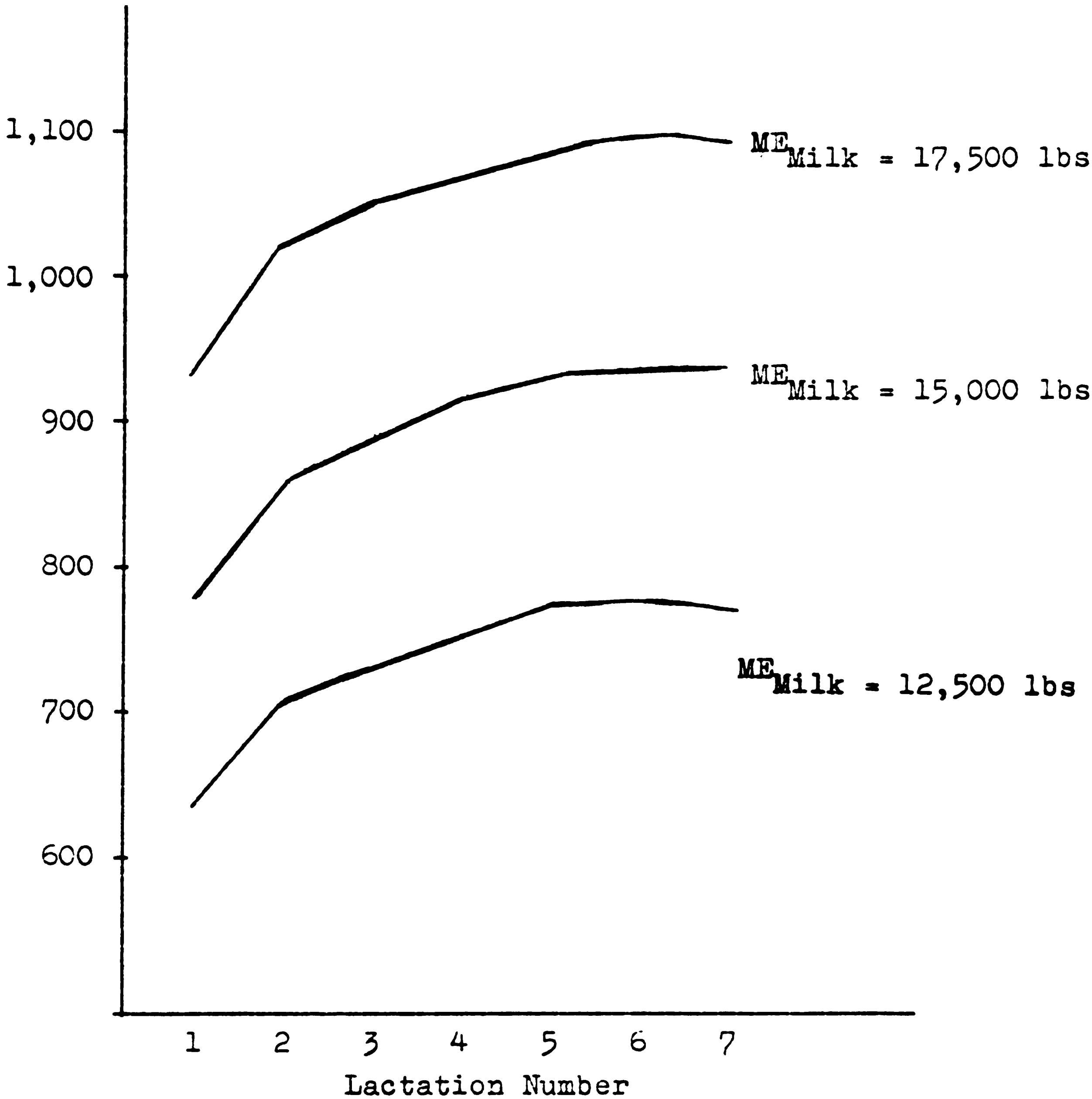


Figure 8. Expected Annualized Variable Net Present Value.

From Table 27 it appears that any heifer whose ME_{Milk} is $\geq$ 17,500 lbs would replace the defender. To more accurately access whether or not a cow should be replaced, differences in salvage value should be accounted for.

This is a first endeavor in modelling the dairy cow and it is realized that many parameters need to be defined more precisely especially in regard to projecting milk production and feed intake, estimating protein and energy requirements across cows with differing genetic potential.

Important factors that the model fails to account for include economic losses due to mastitis as well as the probability of occurrence of mastitis with age. Although DHIA mature equivalents are used to predict lifetime milk production their reliability for use for this purpose is questionable. The further into lactation when the ME is estimated the more reliable it will be. Genetic merit of dams or calves in improving herd average production through time is not accounted for.

SUMMARY AND CONCLUSIONS

The objective of this research was to initiate development of a model to simulate the biological parameters defining any particular dairy cow, and subsequently applying appropriate economic evaluation to ascertain the relative worth of any animal in relation to possible replacement candidates.

The biological model:

1. Projects animal growth until the age of 7 years, at which time the cow is considered fully mature.
2. Estimates average daily milk yield for each month within each lactation until the end of lactation 7.
3. Estimates daily nutrient requirements based on body size, projected milk yield, % fat in the milk and growth.
4. Projects potential daily dry matter intake considering: age, body weight and milk yield.

The model balances the diet for each month within each lactation considering nutrient requirements and restrictions placed on nutrient parameters, feed ingredients and their composition, and estimated dry matter intake which is adjusted to account for the effects of fermentation and energy density of feed ingredients on dry matter intake.

Because of the impossibility of meeting energy needs of high-producing cows in early lactation, body fat is considered as a source of energy in early lactation which is subsequently replenished in later lactation.

Assembly of the biological model revealed several areas of research which require further investigation to increase the accuracy of the model and make it more dynamic including:

1. Defining energy requirements across cows of differing production levels across lactations.
2. Defining more accurately the relationship of the energy status of the animal and weight loss in early lactation.
3. Quantitatively defining how nutrient deficiencies affect the lactation curve.
4. Accurately defining protein requirements and quantitatively accounting for protein and amino acid metabolism to incorporate maximum use of non-protein nitrogen as a less expensive source of protein.
5. Estimating dry matter intake and the relationships of energy density and the impact of fermented feeds upon intake.
6. Quantifying the interactions of differing combinations of feed ingredient on the nutrient value of feedstuffs.

7. Quantifying how the level of intake affects nutrient value of feedstuffs.
8. Predicting the shape of the lactation curve more accurately and estimating milk production with a greater degree of reliability.
9. Estimating the probability of mastitis and the incidence of mastitis with age.
10. Estimating the effect of days open on the lactation curve.

The economic analysis:

1. Calculates the cumulative discounted variable net revenue (DNR) for all time periods under consideration taking into account income from milk, feed cost and variable veterinary expenses.
2. Weights the DNR for each time period by the probability of occurrence.
3. Converts weighted income to an annuity amount for comparisons of animals.

Factors in the economic analysis which require further investigation include:

1. Defining the appropriate way of handling salvage value in the analysis.
2. Estimating the market value of calves depending upon performance of sire progeny and the dam.
3. Defining more accurately the probabilities associated with herd life.

Statistically, methods should be developed to:

1. Integrate information from various studies into a complete biological model.
2. Explore models that are based upon a time series of cross sections, e.g. cows over time.

Modelling the dairy cow has tremendous potential in teaching, research and extension and should be developed at these levels consistent with the audience which it addresses (i.e., simpler models illustrating basic principles for teaching purposes; sophisticaled biological integrated systems for research and an integrated economic analysis for extension). The model to date has many weaknesses; however it logically organizes current knowledge into a complete system which when integrated illustrates what information is still lacking and where inconsistencies in information exists and where further research is necessary.

This is a first endeavor in modelling the dairy cow and it is realized that many parameters need to be defined more precisely especially in regard to projecting milk production and feed intake, estimating protein and energy rewuirements across cows with differing genetic potential.

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APPENDIX

THE DAIRY COW REPLACEMENT MODEL

ONCE THE USER HAS SIGNED ON HE/SHE SHOULD ENTER : $RUN FSUB

```
$LIST MOD6+NWT+NMATEQ+NXLACT+NDMI+NREQ+TBAL+NNUT+$LP+COST+REV
>     CC **** MAIN ****
>     CC THIS PROGRAM CALCULATES THE FEED DISAPPEARANCE, REVENUE,
>     CC COST, DISCOUNTED NET PRESENT VALUE, AND THE ANNUALIZED NET
>     CC PRESENT VALUE OVER THE COURSE OF THE LIFETIME OF A COW.
>     CC THE FAILURE RATE -- THE ODDS THAT A COW DOESN'T MAKE IT
>     CC FROM YEAR T TO T+1 -- ARE EXPLICITY ACCOUNTED FOR. AS A
>     CC CONSEQUENCE, RESULTS ARE STATED ON AN "EXPECTED VALUE"
>     CC BASIS.
>     CC
>     CC DEVELOPED BY JOE HLUBIK, DAIRY SCIENCE, MICH STATE UNIV
>     CC AND J.ROY BLACK,AG.ECONOMICS,MICH STATE UNIV.
>     CC0000000000000000000000000000000000000000000000000000000000000000
>     CC       TO EXECUTE THE PROGRAM USER SHOULD ENTER:
>     CC                     1)NUMBER OF LACTATIONS TO CONSIDER
>     CC                       01 TO 07
>     CC                     2)MONTHS IN MILK/LACTATION
>     CC                       09 TO 15
>     CC                     3)AGE OF THE COW AT THE BEGINNING OF ANALYSIS
>     CC                       02. YEARS TO 08.YEARS
>     CC                     4)MONTHS OF AGE AT THE BEGINNING OF ANALYSIS
>     CC                       20 TO 96
>     CC                     5)ME LBS OF MILK
>     CC                       10000. TO 20000.
>     CC                     6)ESTIMATED MATURE WEIGHT
>     CC                       1200. TO 1800.
>     CC                     7)SALVAGE PRICE($/LB FOR CULL BEEF)
>     CC                       .00 TO ?.00
>     CC                     8)DOES USER WANT NUTRIENT OUTPUT?
>     CC                       01=NO,03=YES
>     CC                     9)DOES USER WANT OUTPUT OTHER THAN MILK
>     CC                       PRODUCTION AND ESTIMATED WEIGHT?
>     CC                       01=YES,00=NO
>     CC0000000000000000000000000000000000000000000000000000000000000000
>     CC OUTPUT:
>     CC    OUTPUT IS INCLUDED FOR EACH MONTH WITHIN EACH LACTATION.
>     CC A SUMMARY OF LACTATION FEED DISAPPEARANCE AND ECONOMICS FOR
>     CC EACH LACTATION AS WELL AS THE EXPECTED ANNUALIZED NET PRESENT
>     CC VALUE(CONSIDERING PROBABLE HERD LIFE) CONCLUDES EACH ANALYSIS.
>     CC
#
>     CC NUTRITION OUTPUT FOR EACH MONTH WITHIN EACH LACTATION INCLUDES:
>     CC   LINE 1: RESULTS ARE______(COST OF RATION)
```

```
CC   LINE 2: LBS OF EACH FEEDSTUFF DELIVERED(SHELLED CORN,CORN
CC           SILAGE,ALFALFA HAY,SOY MEAL44,UREA,DICAL,LIMESTONE,
CC           SALT)
CC   LINE 3: NUTRIENT REQUIREMENTS AND RESTRICTIONS(DMI,NE,CP,CF,
CC           CA,PHOS,CA:PHOS-LB,CA:PHOS-UB,SUPPLEMENTAL NPN,ENIMP,
CC           FMIMP,WT LOSS,CONSTRAINTS ON ROUGHAGES)
CC   LINE 4: REQUIREMENTS DELIVERED (LP SOLUTION).
CC
CC ECONOMIC OUTPUT FOR EACH MONTH WITHIN EACH LACTATION INCLUDES:
CC   LINE 1: FEED SUMMARY FOR THE MONTH
CC   LINE 2: LACTATION FEED SUMARY TO DATE
CC   LINE 3: FEED COST,OTHER COSTS,TOTAL COSTS,GROSS REVENUE,NET
CC           REVENUE,DISCOUNTED NET REVENUE(CALCULATED AT THE END
CC           OF THE LACTATION).
CC ECONOMIC SUMMARY AT THE END OF THE ANALYSIS INCLUDES:
CC     NET PRESENT VALUE,SALVAGE VALUE,ANNUALIZED NPV(EXCLUDING
CC     ODDS) AND A FEED SUMMARY FOR EACH LACTATION.FINALLY EXPECTED
CC     ANNUALIZED NET PRESENT VALUE,INCLUDING PROBABLE HERD LIFE,
CC     IS ESTIMATED.
CC0000000000000000000000000000000000000000000000000000000000000000
CC
CC DEFINITIONS:
CC       MNTAGE       AGE IN MONTHS(.GE.24)
CC       MNTCLF       MONTH OF CALVING(1...12)
CC       XMEMLK       MILK/305 DAY LACTATION,DHIA ME BASIS
CC       PRODYR       MILK/305 DAY LACTATION,LBS PROJECTED FOR
CC                       LACTATION J.
CC       WTME         ESTIMATED MATURE WEIGHT,LBS
CC       PRODDY       MILK YIELD,LBS/DAY
CC       PROD         MILK YIELD,LBS/DAY
CC       PRODLG       MILK YIELD,PREVIOUS MONTH
CC       WEIGHT       BODY WEIGHT AT CALVING,FOR LACTATION J.
CC       GROWTH       WEIGHT GAINED,LBS/DAY AS A FUNCTION OF
CC                       GROWING OLDER
CC       DMI          DRY MATTER INTAKE,LBS/DAY
CC       DMILAG       DRY MATTER INTAKE,LBS/DAY,PREVIOUS MONTH
CC       CTFEED       FEED COST
CC       CTOTHR       OTHER COSTS
CC       CTTOT        TOTAL COSTS
CC       RATE         DISCOUNT RATE
CC       P            PRICE
CC       F            FEED
CC       TF           TOTAL FEED
CC       GTF          GRAND TOTAL FEEDS
CC       GREV         GROSS REVENUE
CC       DNREV        DISCOUNTED NET REVENUE
CC       XNPV         NET PRESENT VALUE
CC       ANPV         ANNUALIZED NET PRESENT VALUE
CC       IOPT1        DECISION WHETHER OR NOT NUT INFO SHOULD
CC                      BE LISTED
CC       IOPT2        DECISION WHETHER OR NOT INFO OTHER THAN
CC                     BODY WEIGHT AND MILK YIELD SHOULD BE LISTED
CC
CC       NOLAC        NUMBER OF LACTATIONS TO CONSIDER
CC       MNLAC        NUMBER OF MONTHS COWS MILK/LACTATION
CC       AGEINT       AGE IN YEARS AT THE BEGINNING OF THE ANALYSIS
CC       MNTAGE       MONTHS OF AGE AT THE BEGINNING OF THE ANALYSIS
CC       PRODME       PRODUCTION MATURE EQUIVALENT(MILK)
CC       WTME         ESTIMATED MATURE WEIGHT
CC       PRSAL        SALVAGE PRICE/LB OF CULL BEEF
CC
CC00000000000000000000000000000000000000000000000000000000000000000
CC
CC CURRENT VERSION IS AS OF 28 NOVEMBER, 1977.
CC JULY 8, 1978 REVISION
CC
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          DIMENSION FEED(13,8),CTFEED(13),CTOTHR(13),
         + CTTOT(13),GREV(13),XNREV(13),DNREV(13),
         + XNPV(13),ANPV(13),GTF(8),TF(13,8),F(8),P(8)
CC
          DATA P/.042,.0235,.0300,.0900,.0800,.125,.035,.04/
CC
          DO 308 I=1,13
          CTFEED(I)=0.
          CTOTHR(I)=0.
          CTTOT(I)=0.
          GREV(I)=0.
          XNREV(I)=0.
          DNREV(I)=0.
          XNPV(I)=0.
      308 ANPV(I)=0.
CC
          DO 280 I=1,8
      280 GTF(I)=0.
CC
          DO 282 I=1,13
          DO 282 J=1,8
      282 TF(I,J)=0.
CC
      640 FORMAT(/)
CC
          READ 1,NOLAC
          READ 1,MNLAC
          READ 2,AGEINT
          READ 1,MNTAGE
          READ 2,PRODME
          READ 2,WTME
          READ 2,PRSAL
CC
          READ 1,IOPT1
          READ 1,IOPT2
CC
        2 FORMAT(F10.0)
        1 FORMAT(I2)
          AGE=AGEINT
          RATE=.12
          MONTH=MNLAC+2
          TIME=0.
          MTHCLF=1
CC
          PRINT 640
CC
          DO 300 I=1,NOLAC
          CALL XMATEQ(MNTAGE,MTHCLF,XMEMLK,XMEFAT)
          PRODYR=PRODME/XMEMLK
          CALL WT(MNTAGE,WTME,WEIGHT,GROWTH)
          CALL XLACT(AGE,7.,PRODYR,PROD)
CC
          PRINT 600,AGE
      600 FORMAT(1X,'AGE:',F10.0)
          PRINT 620,WEIGHT
      620 FORMAT(1X,'WEIGHT:',F10.0)
          PRINT 610,PRODYR
      610 FORMAT(1X,'PRODUCTION:',F10.0)
          PRINT 640
CC
          WTLOSS=0.
CC
          DO 340 J=1,MONTH
CC
          TIME=TIME+1.
CC
```

```
          WEEK=((J+(J-1))/2.)*4.3
CC
          IF(IOPT2.EQ.0)GO TO 683
          PRINT 680,WEEK
      680 FORMAT(1X,'WEEK:',F10.0)
          PRINT 682,TIME
      682 FORMAT(1X,'MONTHS SINCE ENTERING HERD',F10.0)
CC
CC TEST WHETHER IN LACTATION OR DRY PERIOD
      683 IF(J.GT.MNLAC)GO TO 684
CC
          IF(WEEK.GT.8.)PRODLG=PRODDY
          CALL XLACT(AGE,WEEK,PRODYR,PRODDY)
          PRINT 1092,PRODDY
     1092 FORMAT(1X,'DAILY MILK',F10.2)
          IF(WEEK.GT.8.)DMILAG=DMI
          CALL DMILAC(AGE,WEEK,PROD,PRODDY,PRODLG,WEIGHT,
         &  DMI,DMILAG)
          PCT=(DMI/WEIGHT)*100.
          CALL REQLAC(AGE,WEEK,PRODDY,WEIGHT,GROWTH,
         &  WTCHG,ITPCHG,DMI,EN,CP,CA,PHOS,SALT,XNPN,CAPHLB,
         &  CAPHUB,FMIMP,ENIMP)
          IF(WEEK.GT.8. .AND. WEEK .LT. 12.)WTCHG=0.
          IF(WEEK .GE. 12. .AND. WEEK .LE. 40.)WTCHG=WTLOSS/196.
          IF(WEEK.GT.40.)WTCHG=0.
          CALL BAL(DMI,EN,CP,CA,PHOS,SALT,XNPN,CAPHLB,
         +  CAPHUB,FMIMP,ENIMP,WTCHG,ITPCHG,F,P,IOPT1)
          IF(WEEK.LE.8.)WTLOSS=WTLOSS+WTCHG*30.
          GO TO 686
CC
      684 PRODDY=0.
          DMILAG=DMI
          CALL DMIDRY(AGE,WEEK,PROD,PRODDY,PRODLG,WEIGHT,
         &  DMI,DMILAG)
          PCT=(DMI/WEIGHT)*100.
          CALL REQDRY(AGE,WEEK,PRODDY,WEIGHT,GROWTH,
         &  WTCHG,ITPCHG,DMI,EN,CP,CA,PHOS,SALT,XNPN,CAPHLB,
         &  CAPHUB,FMIMP,ENIMP)
          CALL BAL(DMI,EN,CP,CA,PHOS,SALT,XNPN,CAPHLB,
         +  CAPHUB,FMIMP,ENIMP,WTCHG,ITPCHG,F,P,IOPT1)
          WTCHG=0.
      686 CALL REVNUE(PRODDY,REV)
          CALL COST(PRODME,OVC)
CC
          DO 312 K=1,8
      312 FEED(I,K)=0.
CC
          DO 380 K=1,8
          FEED(I,K)=FEED(I,K)+F(K)*30.
          TF(I,K)=TF(I,K)+FEED(I,K)
      380 CTFEED(I)=CTFEED(I)+F(K)*P(K)*30.
          CTOTHR(I)=CTOTHR(I)+OVC
          CTTOT(I)=CTFEED(I)+CTOTHR(I)
          GREV(I)=GREV(I)+REV
          XNREV(I)=GREV(I)-CTTOT(I)
          IF(J.EQ.MONTH)DNREV(I)=XNREV(I)/((1.+RATE)**I)
CC
          IF(IOPT2.EQ.0)GO TO 343
          PRINT 800,(FEED(I,K),K=1,8)
          PRINT 800,(TF(I,K),K=1,8)
          PRINT 800,CTFEED(I),CTOTHR(I),CTTOT(I),GREV(I),XNREV(I),
         + DNREV(I)
          PRINT 640
      800 FORMAT(1X,14F8.2)
CC
      343 MNTAGE=MNTAGE+1
```

```
CC
  340 CONTINUE
CC
      AGE=AGE+1
      PRINT 640
      PRINT 640
  300 CONTINUE
CC
CC
      EVALUE=0.
      CUMODD=1.
      AGE=AGEINT
CC
      DO 500 I=1,NOLAC
      J=I-1
      IF(I.LT.NOLAC)ODDS=1.-(.95-.0183*AGE)
      IF(I.LT.NOLAC)CUMODD=CUMODD-ODDS
      IF(I.EQ.NOLAC)ODDS=CUMODD
      IF(I.EQ.1)XNPV(I)=DNREV(I)
      IF(I.GT.1)XNPV(I)=XNPV(J)+DNREV(I)
      XX=(1.+RATE)**I
      SALVG=WEIGHT*PRSAL/XX
      ANPV(I)=(XNPV(I)+SALVG)*(RATE*XX/(XX-1.))
      PRINT 807,XNPV(I),SALVG,ANPV(I),ODDS
      PRINT 800,(TF(I,K),K=1,8)
  807 FORMAT(1X,5F10.2)
      EVALUE=EVALUE+ODDS*ANPV(I)
  500 AGE=AGE+1
      PRINT 804,EVALUE
  804 FORMAT(1X,'EXPECTED ANNUALIZED NPV IS:',F10.1)
CC
      END
      SUBROUTINE WT(MNTAGE,WTME,WEIGHT,GROWTH)
CC
CC
CC CALCULATES WEIGHT BASED ON EXPECTED MATURE WEIGHT(ENTERED BY THE
CC     USER) AND MONTHS OF AGE.
CC BASED UPON:MC'DANIEL,B.T. AND J.E.LEGATES,"ASSOCIATIONS
CC     BETWEEN BODY WEIGHT PREDICTED FROM HEART GIRTH AND
CC     PRODUCTION,J.DAIRY SCI.,48:947.1965.
CC
CC DEFINITIONS:
CC      MNTAGE        AGE IN MONTHS
CC      WTME          ESTIMATED MATURE WEIGHT
CC
CC0000000000000000000000000000000000000000000000000000000000000000
CC
CC
      IF(MNTAGE.GE.84) GO TO 10
      AGE=MNTAGE
CC
      TEMP=.5161+.01423*AGE-.000139*AGE*AGE+.00000045*AGE
     &   *AGE*AGE
      WEIGHT=TEMP*WTME
CC
CC SECTION TO CALCULATE THE GROWTH RATE, LBS/DAY.
CC CALCULATED BY CALCULATING THE CHANGE IN WEIGHT OVER THE
CC PERIOD OF A MONTH AND DIVIDING THAT RESULT BY 30 DAYS.
CC
      AGETMP=AGE-1.
      TEMP1=.5161+.01423*AGETMP-.000139*AGETMP*AGETMP+
     &  .00000045*AGETMP*AGETMP*AGETMP
      WT1=TEMP1*WTME
CC
      GROWTH=(WEIGHT-WT1)/30.
CC
```

```
CC
      RETURN
   10 GROWTH=0.
      WEIGHT=WTME
      RETURN
CC
      END
CC0000000000000000000000000000000000000000000000000000000000000000
CC0000000000000000000000000000000000000000000000000000000000000000
      SUBROUTINE XMATEQ(MNTAGE,MONTH,XMEMLK,XMEFAT)
CC
CC COMPLETED ON JULY 4,1978
CC
CC CALCULATES THE ADJUSTMENT FACTOR TO TAKE A COW OF ANY
CC AGE AND CONVERT HER TO A "MATURE EQUIVALENT" BASIS.
CC BASED ON: NORMAN,P.ET.AL."USDA-DHIA FACTORS FOR STANDARDIZING
CC 305-DAY LACTATION RECORDS FOR AGE AND MONTH OF CALVING"ARS-NE-40
CC 1974.THE DATA FOR XMNMLK AND XMNFAT ADJUST MILK YIELD FOR
CC MONTH OF CALVING USING JANURARY AS A STANDARD REFERENCE.
CC
CC DEFINITIONS:
CC   AGEMNT: AGE IN MONTHS
CC   XMEMLK: MATURE EQUIVALENT FACTOR FOR MILK
CC   XMEFAT: MATURE EQUIVALENT FACTOR FOR BUTTER FAT
CC   XMNMLK: MONTH OF CALVING ADJUSTMENT FACTOR FOR MILK
CC   XMNFAT: MONTH OF CALVING ADJUSTMENT FACTOR FOR BUTTER FAT
CC
CC0000000000000000000000000000000000000000000000000000000000000000
      DIMENSION XMNMLK(12),XMNFAT(12)
      DATA XMNMLK/0.,.02,.02,.04,.06,.09,.12,.12,.08,.04,.02,.02/
      DATA XMNFAT/0.,.01,.02,.04,.06,.08,.1,1.,.05,.02,.0,.0/
CC
      AGEMNT=MNTAGE
CC
      IF(AGEMNT.LE.70.)XMEMLK=.809+(10.68/AGEMNT)
      IF(AGEMNT.GT.70..AND.AGEMNT.LE.94.)XMEMLK=.96
      IF(AGEMNT.GT.94.)XMEMLK=.96+.0016*(AGEMNT-94.)
      XMEMLK=XMEMLK+XMNMLK(MONTH)
CC
      IF(AGEMNT.LE.73.)XMEFAT=.817+(10.276/AGEMNT)
      IF(AGEMNT.GT.73..AND.AGEMNT.LE.80.)XMEFAT=.96
      IF(AGEMNT.GT.80.)XMEFAT=.96+.0014*(AGEMNT-80.)
      XMEFAT=XMEFAT+XMNFAT(MONTH)
CC
      RETURN
       END
CC 000000000000000000000000000000000000000000000000000000000000000
CC0000000000000000000000000000000000000000000000000000000000000000
      SUBROUTINE XLACT(AGE,WEEK,PRODYR,PRODDY)
CC^CALCULATES MILK/DAY FROM LACTATION CURVE
CC DEFINITIONS:
CC      AGE      LACTATION NUMBER
CC      WEEK     WEEKS INTO LACTATION
CC      PRODYR   ANNUAL PRODUCTION,LBS MILK
CC      PRODY    AVERAGE DAILY PRODUCTION FOR WEEK N INTO
CC                     LACTATION
CC0000000000000000000000000000000000000000000000000000000000000000
      DIMENSION A(3,3)
      DATA A/3.661,.093,.00291,
     +       3.708,.129,.00486,
     +       3.593,.165,.00486/
      DAY=WEEK*7.
      IAGE=AGE
      IF(AGE.GE.3)IAGE=3
CC
CC ADJUST INTERCEPT OF EQUATION FOR THE PRODUCTION OF THE
```

```
CC COW RELATIVE TO THE "STANDARD - 12,000 LB" COW. SEE: SHULTZ
CC A.A., "FACTORS AFFECTING THE SHAPE OF THE LACTATION
CC CURVE AND ITS MATHEMATICAL DESCRIPTION,MASTER'S THESIS,
CC U OF WISCONSIN,1974.
CC
      TEMP=A(1,IAGE)+ALOG(PRODYR/12000.)
CC
      PRODDY=EXP(TEMP+A(2,IAGE)*ALOG(DAY)-A(3,IAGE)*DAY)
      RETURN
      END
CC0000000000000000000000000000000000000000000000000000000000000000
CC0000000000000000000000000000000000000000000000000000000000000000
      SUBROUTINE DMILAC(AGE,WEEK,PROD,PRODDY,PRODLG,WEIGHT,
     &  DMI,DMILAG)
CC
CC0000000000000000000000000000000000000000000000000000000000000000
CC          POTENTIAL DRY MATTER INTAKE
CC
CC
CC **** OBJECTIVE ****
CC ESTIMATES DAILY DRY MATTER INTAKE.THE REGRESSION ESTIMATING
CC  INTAKE DURING EARLY LACTATION(WEEKS 1 TO 9),IS BASED ON
CC  DATA OF: FOLDAGER,J."PROTEIN REQUIREMENT AND NON PROTEIN NITROG
CC  FOR HIGH PRODUCING COWS IN EARLY LACTATION,"PH.D.THESIS,MICH.
CC  STATE UNIV.,E.LANSING.1977.   INTERCEPT ADJUSTMENT(UPWARD)WAS
CC  INCORPORATED BASED ON: TRIMBERGER,G.W., ET AL. CORNELL BULLETIN
CC  NO.8,1972.
CC  BEYOND WEEK 9 INTO LACTATION INTAKE IS ADJUSTED DOWNWARD
CC  CONSIDERING THE IMPACT OF CHANGE IN MILK YIELD ON DRY MATTER
CC  INTAKE(DMI).THIS ADJUSTMENT IS BASED ON DATA OF:SLACK,S. ET AL.
CC  BULLETIN NO.957,CORNELL UNIV.AGRIC.EXP.STA.,ITHACA,NEW YORK
CC  1960.    FOLDAGER,J.,PH.D.THESIS,MSU,1977.   AND   LAMB,R.C.
CC  ET AL.,J.DAIRY SCI.57:811.1973.
CC  THE IMPACTS OF ENERGY DENSITY AND FERMENTATION UPON DMI IS
CC  ACCOUNTED FOR IN THE L.P. MATRIX.
CC
CC **** DEFINITIONS ****
CC   WEEK        NUMBER OF WEEKS INTO THE LACTATION
CC   PROD        MILK PRODUCTION, LBS/DAY DURING WEEKS 6 TO 8
CC   PRODDY      MILK PRODUCTION,LBS/DAY
CC   PRODLG      PRODUCTION IN PREVIOUS PERIOD,LBS/DAY
CC   WEIGHT      COW'S BODY WEIGHT AT CALVING, LBS
CC   DMI         DRY MATTER INTAKE, LBS/DAY
CC   DMILAG      DRY MATTER INTAKE IN PREVIOUS PERIOD,LBS/DAY
CC   AGE         A2 IS TWO YR OLD
CC               A3 IS THREE YEAR OLD
CC0000000000000000000000000000000000000000000000000000000000000000
CC
CC
      IF(AGE.LE.2)AGE2=1.
      IF(AGE.GT.2)AGE2=0.
      IF(AGE.EQ.3)AGE3=1.
      IF(AGE.NE.3)AGE3=0.
CC
      DMI=2.30+1.08*AGE2+.74*AGE3
     &  +.0064649*(WEIGHT/2.2)+.20719*(PROD/2.2)
CC
      IF(WEEK.LE.9.)DMI=(DMI+2.0906*WEEK-.183139*WEEK*WEEK
     &  +.0046684*WEEK*WEEK*WEEK)*2.2
CC
      IF(WEEK.GT.9.)DMI=DMILAG-.20*(PRODLG-PRODDY)
CC
      RETURN
      END
CC
CC
```

```
      SUBROUTINE DMIDRY(AGE,WEEK,PROD,PRODDY,PRODLG,WEIGHT,
     &  DMI,DMILAG)
CC
      DMI=DMILAG
CC
      RETURN
      END
CC000000000000000000000000000000000000000000000000000000000000000
CC000000000000000000000000000000000000000000000000000000000000000
CC
      SUBROUTINE REQLAC(AGE,WEEK,PRODDY,WEIGHT,GROWTH,
     &  WTCHG,ITPCHG,DMI,EN,CP,CA,PHOS,SALT,XNPN,CAPHLB,
     &  CAPHUB,FMIMP,ENIMP)
CC
CC
CC BASED UPON THE 1978 DAIRY NRC
CC
CC IMPACT OF FERMENTED FEEDS AND ENERGY DENSITY OF THE
CC RATION ADDED DURING OCT.1978.
CC
CC IMPACT OF ENERGY MOBILIZATION FROM BACKFAT DEVELOPED
CC DURING SEPTEMBER 1978.
CC DEFINITIONS:
CC          EN         NET ENERGY FOR LACTATION,MCAL/DAY
CC          CP         CRUDE PROTEIN,LBS/DAY
CC          CA         CALCIUM,LBS/DAY
CC          PHOS       PHOSPHORUS,LBS/DAY
CC          CAPHLB     MINIMUM CALCIUM TO PHOSPHORUS RATIO
CC          CAPHUB     MAXIMUM CALCIUM TO PHOSPHORUS RATIO
CC          SALT       SALT REQUIREMENT,LBS/DAY
CC          CF         CRUDE FIBER,LBS/LB OF DRY MATTER
CC          FMIMP      IMPACT ON DRY MATTER INTAKE(DMI)PER CWT
CC                       OF BODY WEIGHT OF A ONE PERCENT INCREASE
CC                       IN THE MOISTURE CONTENT OF THE DIET.MOISTURE
CC                       ACTS AS A PROXY FOR THE IMPACT OF FERMENTED
CC                       FEEDS.BASED ON DATA OF:BROWN,L.D. ET AL.,
CC                       "EFFECTS OF FEEDING VARIOUS LEVELS OF CORN
CC                       SILAGE AND HAY WITH HIGH LEVELS OF GRAIN
CC                       TO LACTATING DAIRY COWS," J.DAIRY SCI.,
CC                       48:816.1965.
CC          XNPN       UPPER BOUND ON SUPPLEMENTAL NPN AS A FRACTION
CC                       OF CRUDE PROTEIN
CC          FATPCT     PERCENT BUTTER FAT IN THE MILK
CC          WTCHG      CHANGE IN THE AMOUNT OF BODY FAT/COW/DAY.THE
CC                       COW IS PERMITTED TO LOOSE WEIGHT DURING THE
CC                       FIRST EIGHT WEEKS OF LACTATION.THE WEIGHT
CC                       MUST BE REGAINED DURING WEEKS 13 THROUGH 40.
CC                       BASED ON:FLATT,W.P. ET AL."ENERGY UTILIZATION
CC                       BY HIGH PRODUCING DAIRY COWS.II.SUMARY OF
CC                       ENERGY BALANCE EXPERIMENTS WITH LACTATING
CC                       HOLSTEIN COWS."ENERGY METABOLISM OF FARM
CC                       ANIMALS.(ORIEL PRESS LTD.:NEWCASTLE UPON TYNE
CC                       ENGLAND)1967.P.235.  AND   TRIMBERGER,G.W.
CC                       ET AL."EFFECTS OF LIBERAL CONCENTRATE FEEDING
CC                       ON HEALTH,REPRODUCTIVE EFFICIENCY,ECONOMY
CC                       OF MILK PRODUCTION AND RELATED RESPONSES OF
CC                       THE DAIRY COW."FOOD AND LIFE SCIENCES BULL.
CC                       #8.CORNELL UNIV.ITHACA,NEW YORK.1972.
CC         ITPCHG      FLAG TO DEPICT WHETHER WTCHG IS A GAIN OR LOSS.
CC         WTLOSS      TOTAL FAT LOSS OVER THE FIRST 60 DAYS OF LACT.
CC                       LOSS IS REGAINED DURING THE 196 DAYS OF WEEKS
CC                       13 THROUGH 40.
CC         ENIMP       IMPACT ON DRY MATTER INTAKE PER CWT OF BODY
CC                       WEIGHT OF A ONE MCAL CHANGE IN NET ENERGY
CC                       OF LACTATION PER LB OF DRY MATTER.BASED ON
CC                       DATA OF: LAMB,R.C. ET AL."RESPONSE TO
```

```
>         CC                       CONCENTRATES CONTAINING TWO PERCENTS OF
>         CC                       PROTEIN FED AT FOUR RATES FOR COMPLETE
>         CC                       LACTATIONS," J.DAIRY SCI.,57:811.1973.
>         CC0000000000000000000000000000000000000000000000000000000000000000
>         CC
>         CC
>               FATPCT=3.5
>               WTKG=WEIGHT/2.2
>               WTMTKG=WTKG**.75
>         CC
>               EN=.07996*WTMTKG+(.31+.0429*(FATPCT-3.5))*PRODDY
>              &  +GROWTH*2.32
>               CP=.00908*WTMTKG+(.082+.0107*(FATPCT-3.5))*PRODDY
>              &  +GROWTH*.5
>               CA=.00038*WTMTKG+(.0026+.00022*(FATPCT-3.5))*PRODDY
>               PHOS=.0003*WTMTKG+(.0018+.000067*
>              &  (FATPCT-3.5))*PRODDY
>               SALT=.00009031*WEIGHT+.00022*PRODDY
>         CC
>               IF(WEEK.LE.4.)WTCHG=(EN*.3/3.4)
>               IF(WEEK.GT.4..AND.WEEK.LE.8.)WTCHG=(EN*.15/3.4)
>               IF(WEEK.LE.8.)ITPCHG=1
>               IF(WEEK.GT.8.)ITPCHG=2
>         CC
>               PCTCP=CP/DMI
>               IF(PCTCP.GT..14)XNPN=0.
>               IF(PCTCP.LE..14)XNPN=.30
>         CC
>               CAPHLB=2.
>               CAPHUB=2.5
>         CC
>               IF(WEEK.LE.40.)FMIMP=(.007+.00039*WEEK)*(WEIGHT/100.)
>               IF(WEEK.GT.40)FMIMP=.023*(WEIGHT/100.)
>               ENIMP=1.76*(WEIGHT/100.)
>               CF=.16
>         CC
>         CC
>               RETURN
>               END
>         CC
>         CC
>               SUBROUTINE REQDRY(AGE,WEEK,PRODDY,WEIGHT,GROWTH,
>              &  WTCHG,ITPCHG,DMI,EN,CP,CA,PHOS,SALT,XNPN,CAPHLB,
>              &  CAPHUB,FMIMP,ENIMP)
>         CC
>         CC VERSION AS OF JULY 26,1978
>         CC
>               WTKG=WEIGHT/2.2
>               WTMTKG=WTKG**.75
>         CC
>               EN=.1040*WTMTKG+GROWTH*2.32
>               CP=.017*WTMTKG+GROWTH*.5
>               CA=.00066*WTMTKG
>               PHOS=.00046*WTMTKG
>               SALT=(.041*WEIGHT)/454.
>         CC
>               WTCHG=0.
>               IF(WEEK.LE.8.)ITPCHG=1
>               IF(WEEK.GT.8.)ITPCHG=2
>         CC
>               CAPHLB=1.
>               CAPHUB=1.5
>         CC
>               XNPN=.3
>         CC
>         CC
```

```
      FMIMP=.023*(WEIGHT/100.)
      ENIMP=1.76*(WEIGHT/100.)
      CF=.25
CC
      RETURN
      END
CC0000000000000000000000000000000000000000000000000000000000000000
CC0000000000000000000000000000000000000000000000000000000000000000
      SUBROUTINE BAL(DMI,EN,CP,CA,PHOS,SALT,XNPN,CAPHLB,
     +  CAPHUB,FMIMP,ENIMP,WTCHG,ITPCHG,F,P,IOPT1)
CC VERSION: JULY 5,1978
CC BALANCES A RATION IN A LEAST COST MANNER CONSIDERING:
CC  NUTRIENT REQ.,NUT.RESTRICTIONS,POTENTIAL DRY MATTER INTAKE
CC  (DMI),THE EFFECTS OF ENERGY DENSITY AND FERMENTATION OF FEEDS O
CC  DMI AND THE ABILITY OF COWS TO DRAW UPON FAT RESERVES IN EARLY
CC  LACTATION. BODY FAT IS PRICED AT A RELATIVELY HIGH PRICE AND IS
CC  DRAWN IN AS A SOURCE OF ENERGY WHEN THE RATION WILL NOT
CC  OTHERWISE BALANCE(DURING EARLY LACT.)
CC0000000000000000000000000000000000000000000000000000000000000000
CC
CC
      COMMON/LP/DPM(16,36),RHS(16),ISACOL(16),INACT(16),
     +  IRWTY(16),OBJ(36),ZC(36)
      COMMON/NUT/A(8,9)
      DIMENSION B(16), F(8),P(8),ACT(36)
      DIMENSION TEMP(16)
      DOUBLE PRECISION DPM,RHS,OBJ,ZC
CC
CC F IS THE % OF EACH FEED IN THE DIET DRY MATTER (8 FEEDS)
CC P IS THE PRICE OF FEEDSTUFF, $/LB
CC
CC RECALL, IBM READS DATA ACCORDING TO A(1,1), A(2,1),
CC   A(2,2),ETC.
CC
CC *****MATRIX LAYOUT FOR DPM***
CC
CC ROWS:
CC     1 - DM INTAKE, LBS.
CC     2 - NET ENERGY, MCAL
CC     3 - CRUDE PROTEIN, LBS.
CC     4 - CRUDE FIBER, LBS
CC     5 - CA
CC     6 - PHOS
CC     7 - SALT
CC     8 - CALCIUM:PHOSPHOROUS RATIO (LOWER BOUND)
CC     9 - CALCIUM:PHOSPHOROUS RATIO (UPPER BOUND)
CC    10 - SUPPLEMENTAL NPN:CRUDE PROTEIN RATIO
CC    11 - IMPACT OF NET ENERGY/LB ON DRY MATTER INTAKE
CC    12 - IMPACT OF FERMENTATED FEEDS ON DRY MATTER INTAKE
CC    13 - UPPER BOUND ON WEIGHT LOSS DURING 1ST 8 WEEKS.
CC           MEASURES WEIGHT GAIN THEREAFTER.
CC    14 - CONSTRAINTS ON %AGES OF CORN SILAGE AND ALFALFA
CC            IN THE 'ROUGHAGE'
CC
CC COLUMNS:
CC     1 - CORN GRAIN
CC     2 - CORN SILAGE
CC     3 - ALFALFA
CC     4 - SOY 44
CC     5 - UREA
CC     6 - DICAL
CC     7 - LIMESTONE
CC     8 - SALT
CC     9 - IMPACT OF FERMENTED FEEDS ON DRY MATTER INTAKE, LBS
CC    10 - IMPACT OF NET ENERGY/LB ON DRY MATTER INTAKE, LBS.
CC    11 - WEIGHT LOSS (GAIN)
CC
```

```
      NROW=14
      JREAL=11
      JCOL=11
CC
CC ZERO OUT ACT(J),OBJ(J)
      DO 17 J=1,36
      ACT(J)=0.
   17 OBJ(J)=0.
CC
CC^ZERO OUT DPM
      DO 20 I=1,16
      DO 20 J=1,36
   20 DPM(I,J)=0.
CC
      DO 16 J=1,8
   16 OBJ(J)=-P(J)
      IF(ITPCHG.EQ.1)OBJ(11)=-.20
      IF(ITPCHG.EQ.2)OBJ(11)=.20
CC
CC^LOAD DPM
      DO 30 J=1,8
      DPM(1,J)=A(J,1)
      DPM(2,J)=A(J,2)
      DPM(3,J)=A(J,3)
      DPM(4,J)=A(J,4)-.16
      DPM(5,J)=A(J,5)
      DPM(6,J)=A(J,6)
      DPM(7,J)=A(J,7)
      DPM(8,J)=A(J,5)-CAPHLB*A(J,6)
      DPM(9,J)=A(J,5)-CAPHUB*A(J,6)
      DPM(10,J)=A(J,9)-XNPN*A(J,3)
      DPM(11,J)=(.72-A(J,2))/DMI
      DPM(12,J)=(A(J,8)*100.-20.)/DMI
   30 CONTINUE
CC
      DPM(14,2)=-1.
      DPM(14,3)=-2.
CC
      DPM(12,9)=-1.
      DPM(1,9)=FMIMP
CC
      DPM(11,10)=-1.
      DPM(1,10)=ENIMP
CC
      IF(ITPCHG.EQ.1)DPM(2,11)=3.4
      IF(ITPCHG.GE.2)DPM(2,11)=-4.8
      DPM(13,11)=1.
CC
CC^LOAD RESTRICTIONS
      RHS(1)=DMI
      RHS(2)=EN
      RHS(3)=CP
      RHS(4)=0.
      RHS(5)=CA
      RHS(6)=PHOS
      RHS(7)=SALT
      RHS(8)=0.
      RHS(9)=0.
      RHS(10)=0.
      RHS(11)=0.
      RHS(12)=0.
      RHS(13)=WTCHG
      RHS(14)=0.
CC
      IRWTY(1)=1
      IRWTY(2)=2
      IRWTY(3)=3
```

```
      IRWTY(4)=3
      IRWTY(5)=3
      IRWTY(6)=3
      IRWTY(7)=3
      IRWTY(8)=3
      IRWTY(9)=1
      IRWTY(10)=1
      IRWTY(11)=1
      IRWTY(12)=1
      IF(ITPCHG.EQ.1)IRWTY(13)=1
      IF(ITPCHG.GE.2)IRWTY(13)=2
      IRWTY(14)=1
CC
      DO 93 I=1,NROW
CC^B(I) ARE THE RESTRICTIONS
   93 B(I)=RHS(I)
CC
CC^FILL IN SLACKS AND ARTIFICIALS
      DO 90 I=1,NROW
   90 CALL ROWSET(I,JCOL)
CC
      IF(IOPT1.EQ.2)CALL LPDUMP(NROW,JCOL)
CC
CC^CALL SOLUTION ALGORITHM(SIMPLEX)
      CALL LPSOL(NROW,JCOL,ISOLTY,OBJV)
CC
CC^SET ACTIVITIES IN ASCENDING ORDER
      DO 100 I=1,NROW
      DO 110  J=1,JCOL
      IF(INACT(I).NE.J)GO TO 110
      ACT(J)=RHS(I)
      GO TO 100
  110 CONTINUE
  100 CONTINUE
CC
      DO 2040 J=1,8
 2040 F(J)=ACT(J)
      WTCHG=ACT(11)
CC
CC
      DO 2008 I=1,NROW
      IF(IRWTY(I).LE.2)TEMP(I)=B(I)-ACT(ISACOL(I))
CC^TEMP REFERS TO THE AMMOUNT OF REQUIREMENTS DELIVERED
      IF(IRWTY(I).GT.2)TEMP(I)=B(I)+ACT(ISACOL(I)+1)
 2008 CONTINUE
CC
      IF(IOPT1.LT.2)GO TO 2020
CC
      PRINT 2004
 2004 FORMAT(/)
      PRINT 2002
 2002 FORMAT(1X,'**RESULTS ARE**')
CC
      PRINT 2000,ISOLTY,OBJV
 2000 FORMAT(1X,I5,3F10.3)
      PRINT 2004
CC
      PRINT 2060,(ACT(J),J=1,11)
 2060 FORMAT(1X,11F7.3)
CC
      PRINT 2004
      PRINT 2070,(B(I),I=1,NROW)
      PRINT 2070,(TEMP(I),I=1,NROW)
 2070 FORMAT(1X,14F6.2)
      PRINT 2004
CC
```

```
      2020 RETURN
           END
CC000000000000000000000000000000000000000000000000000000000000000000
CC000000000000000000000000000000000000000000000000000000000000000000
CC
CC
           BLOCK DATA
CC
CC               NUTRIENT DENSITY OF THE FEEDSTUFFS
CC CONTAINS THE NUTRIENT DENSITY OF THE FEEDS BASED ON: HARSH
CC  S. ET AL."TELPLAN 31:LEAST COST RATION,"MICH.STATE UNIV.,E.
CC  LANSING.1971.
CC000000000000000000000000000000000000000000000000000000000000000000
CC
           COMMON/NUT/A(8,9)
CC  FEEDSTUFFS(COLUMNS)
CC   1-CORN
CC   2-CORN SILAGE
CC   3-ALFALFA
CC   4-SOY 44
CC   5-UREA
CC   6-DICAL
CC   7-LIMESTONE
CC   8-SALT
CC  ROWS
CC   1-WEIGHT
CC   2-NE
CC   3-CP
CC   4-CRUDE FIBER
CC   5-CA
CC   6-PHOS
CC   7-SALT
CC   8-MOISTURE
CC   9-NPN PROTEIN
           DATA A/1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,
          +       0.950,0.700,0.440,0.870,0.000,0.000,0.000,0.000,
          +       0.101,0.080,0.169,0.508,2.810,0.000,0.000,0.000,
          +       0.023,0.259,0.309,0.060,0.000,0.000,0.000,0.000,
          +       .0002,.0028,0.013,.0028,0.000,0.231,0.338,0.000,
          +       .0026,.0020,.0020,.0064,0.000,0.186,0.000,0.000,
          +      0.,0.,0.,0.,0.,0.,0.,1.0,
          +       0.140,0.680,0.108,0.100,0.000,0.000,0.000,0.000,
          +       0.000,0.000,0.000,0.000,2.810,0.000,0.000,0.000/
CC
           END
CC000000000000000000000000000000000000000000000000000000000000000000
CC000000000000000000000000000000000000000000000000000000000000000000
CC
CC
           SUBROUTINE ROWSET(I,JCOL)
CC
CC
CC THESE SUBROUTINES ARE USED IN THE BALANCE SUBROUTINE TO
CC  FORMULATE A LEAST COST RATION.
CC
CC000000000000000000000000000000000000000000000000000000000000000000
CC
CC
           COMMON/LP/DPM(16,36),RHS(16),ISACOL(16),INACT(16),
          +  IRWTY(16),OBJ(36),ZC(36)
           DOUBLE PRECISION DPM,RHS,OBJ,ZC
           JCOL=JCOL+1
           INACT(I)=JCOL
           ISACOL(I)=JCOL
           DPM(I,JCOL)=1.
           IF(IRWTY(I).GT.1) GO TO 202
```

```
      OBJ(JCOL)=0.
      GO TO 140
  202 OBJ(JCOL)=-(9*(10**5))
      IF(IRWTY(I).EQ.2) GO TO 140
      JCOL=JCOL+1
      DPM(I,JCOL)=-1
      OBJ(JCOL)=0.
  140 RETURN
      END
      SUBROUTINE LPSOL(NOROW,NOCOL,ISOLTY,OBJV)
CC
C     A SUBROUTINE TO SOLVE LINEAR PROGRAM PROBLEMS
CC    DEVELOPED BY STEVE HARSH, DEPT OF AGR. ECON.,
CC    MICH. STATE UNIV., EAST LANSING, 48824
CC    FOLLOWS BASIC OUTLINE OF CHURCHMAN, ET. AL.
CC
      COMMON/LP/DPM(16,36),RHS(16),ISACOL(16),INACT(16),
     +  IRWTY(16),OBJ(36),ZC(36)
      DOUBLE PRECISION DPM,RHS,OBJ,ZC
      DOUBLE PRECISION COLKEY,R,RMIN,R1,R2,X,ZCMX,Z
      DIMENSION COLKEY(16)
      OBJV=0.
      MXITER=NOROW*4
      NOITER=-1
  200 NOITER=NOITER+1
      JZCMX=0
      ZCMX=0.
      JZCMX=0
      ZCMX=0.
      DO 101 J=1,NOCOL,1
      Z=0.
      DO 102 I=1,NOROW,1
      K=INACT(I)
  102 Z=Z+(DPM(I,J)*OBJ(K))
      ZC(J)=Z-OBJ(J)
      IF(ZC(J))103,101,101
  103 IF(ZC(J)-ZCMX)104,101,101
  104 ZCMX=ZC(J)
      JZCMX=J
  101 CONTINUE
      IF(JZCMX .GT. 0)GO TO 110
      IF(NOITER.GT.0) GO TO 112
      ISOLTY=6
      RETURN
  600 ISOLTY=2
      RETURN
  112 X=-(9*(10**5))
      DO 115 I=1,NOROW,1
      J=INACT(I)
      IF(RHS(I).LT..0001)GO TO 113
      IF(OBJ(J) .EQ. X)GO TO 600
  113 IF(IRWTY(I).EQ.1)GO TO 115
      J=ISACOL(I)
      ZC(J)=ZC(J)+X
  115 CONTINUE
      OBJV=0.
      DO 120 I=1,NOROW,1
      K=INACT(I)
  120 OBJV=OBJV+(RHS(I)*OBJ(K))
      ISOLTY=1
      RETURN
  110 IF(NOITER.LT.MXITER)GO TO 145
      ISOLTY=4
      RETURN
  145 RMIN=9999999999.
      NKR=0
      DO 150 I=1,NOROW,1
```

```
      IF(DPM(I,JZCMX))150,150,151
  151 R=RHS(I)/DPM(I,JZCMX)
      IF(R-RMIN)155,156,150
  155 RMIN=R
      NKR=I
      GO TO 150
  156 DO 160 J=1,NOCOL,1
      R1=DPM(NKR,J)/DPM(NKR,JZCMX)
      R2=DPM(I,J)/DPM(I,JZCMX)
      IF(R2-R1)155,160,150
  160 CONTINUE
      ISOLTY=5
      RETURN
  150 CONTINUE
      IF(NKR.GE.1)GO TO169
      ISOLTY=3
      RETURN
  169 INACT(NKR)=JZCMX
      DO 171 I=1,NOROW,1
  171 COLKEY(I)=DPM(I,JZCMX)
      DO 170 J=1,NOCOL,1
  170 DPM(NKR,J)=DPM(NKR,J)/COLKEY(NKR)
      RHS(NKR)=RHS(NKR)/COLKEY(NKR)
      DO 175 I=1,NOROW,1
      IF(I .EQ. NKR)GO TO 175
      RHS(I)=RHS(I)-(RHS(NKR)*COLKEY(I))
      IF(COLKEY(I) .EQ. 0)GO TO 175
      DO 176 J=1,NOCOL,1
      IF(DPM(NKR,J) .EQ. 0)GO TO 176
      DPM(I,J)=DPM(I,J)-(DPM(NKR,J)*COLKEY(I))
      IF(DPM(I,J).GT. .0000000001)GO TO 176
      IF(DPM(I,J).GT. -.0000000001)DPM(I,J)=0.
  176 CONTINUE
  175 CONTINUE
      GO TO 200
CC
CC
      END
      SUBROUTINE LPDUMP(NROW,NCOL)
      COMMON/LP/DPM(16,36),RHS(16),ISACOL(16),INACT(16),
     +  IRWTY(16),OBJ(36),ZC(36)
      DOUBLE PRECISION DPM,RHS,OBJ,ZC
   10 FORMAT(//)
      PRINT 20
   20 FORMAT(1X,'PRINT OUT OF RHS VALUES AND A(I,J) S')
      PRINT 10
      PRINT 30,NROW
   30 FORMAT(4X,'ROWS    ', I5)
      PRINT 40,NCOL
   40 FORMAT(4X,'COLUMNS',I5)
      PRINT 10
      PRINT 50
   50 FORMAT(1X,'RHS INFORMATION')
      PRINT 60
   60 FORMAT(1X,'  NO  TYPE SLACK INACT       VALUE')
      DO 70 I=1,NROW
   70 PRINT 75,I,IRWTY(I),ISACOL(I),INACT(I),RHS(I)
   75 FORMAT(1X,I4,3I5,F15.4)
      PRINT 10
      PRINT 120
  120 FORMAT(1X, 'OBJ FN AND LOCATION INFORMATION')
      PRINT 125
  125 FORMAT(1X,'COLUMN VALUE')
      DO 130 J=1,NCOL
  130 PRINT 135,J,OBJ(J)
  135 FORMAT(1X,I5,2F12.3)
```

```
>              PRINT 10
>              PRINT 80
>           80 FORMAT(1X,'A(I,J) INFORMATION')
>              DO 100 I=1,NROW
>              PRINT 90,I
>           90 FORMAT(1X,'ROW',I5)
>              DO 110 J=1,NCOL
>              IF(DPM(I,J))105,110,105
>          105 PRINT 108,J,DPM(I,J)
>          108 FORMAT(1X,I10,F15.4)
>          110 CONTINUE
>          100 CONTINUE
>               PRINT 10
>               PRINT 10
>              RETURN
>              END
>              SUBROUTINE COST(PRODME,OVC)
>       CC
>       CC CC VERSION IS: JULY 8,1978
>       CC
>       CC ESTIAMTES COSTS FOR VET AND BREEDING BASED ON
>       CC PRODUCTION LEVEL. BASED UPON S.B. NOTT, 1974, TELFARM ANALYSES
>       CC BY PRODUCTION LEVEL FOR MICHIGAN SPECIALIZED DAIRY FARM IN
>       CC 1973, AG ECON STAFF PAPER 74-34, MICH STATE UNIV.
>       CC
>       CC THE "1.75" REFLECTS AN ADJUSTMENT FOR INFLATION
>              OVC=((-18.50+.00362*(PRODME/.91))/12.)*1.75
>       CC
>              RETURN
>              END
>              SUBROUTINE REVNUE(PRODDY,REV)
>              REV=.0925*PRODDY*30.
>              RETURN
>              END
#END OF FILE
```