Grouping and Feeding Policies for Lactating Dairy Cows

by

Steven Robert Pecsok

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APPROVED:

Michael L. McGilliard, Chairman

Robert E. James

Charles C. Stallings

David M. Kohl

Thomas G. Johnson

William E. Vinson, Department Head

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(ABSTRACT)

Data from the University of New Hampshire were used to analyze dry matter intake and milk production in Holstein dairy cows. Equations predicting 4% FCM and dry matter intake were derived from this data using ordinary least squares. Days in milk, available nutrients, calving date, and previous period 4% FCM accounted for 90% of the variation in 4% FCM for heifers and 93% of the variation in 4% FCM for cows with previous lactations. Days in milk, acid detergent fiber, calving date, and dry matter intake from the previous 28 day period accounted for 71% of the variation in heifer dry matter intake and 79% of the variation in dry matter intake for the older cows. First period dry matter intake was predicted from first period 4% FCM, cow body weight, and acid detergent fiber of the ration. The lower R^2 for the first period dry matter intake (41% for heifers and 43% for cows with previous lactations) indicated that dry matter intake for a cow within a lactation was much more predictable than dry matter intake between different cows.

Rations were balanced for absolute amounts for simulated lactating cows using NRC requirements and 4% FCM and dry matter intake generated from the prediction equations. Relationships between 4% FCM and nutrient concentrations were determined for heifers and multiparous cows. These recommendations suggest maximum feeding of nutrients to groups producing at least 35 kg of 4% FCM daily.

The effect of grouping and individual feeding on 4% FCM were analyzed. Independent variables included nutrient concentration, dry matter intake, groups, calving interval, variability of 305 day milk production within the herd, and level of feeding. Holding dry matter intake and nutrient concentrations constant, increasing number of groups from one to two increased 4% FCM by 0%-3%, two groups to three groups by 0-2%, and three groups to four groups by 0-1%. Changing from one group to individual feeding increased 4% FCM by 2%-4% and two group to individual feeding increased 4% FCM by 0%-3%. The range of figures was influenced by herd production level, calving interval, and variability of within herd production. High variability of production favored additional groups, while high calving intervals favored individual feeding. To estimate expected change in profitability due to a change in grouping or feeding methods, multiply previous milk revenue by expected percentage change and subtract the increased cost of feeding.

Feeding less than the group average for nutrients was not found conducive for increasing profitability. In fact, production response to protein suggested that the low producing groups in multiple group feeding systems should be increased in protein slightly.

Individual feeding had the most potential for profitability, although group feeding compared favorably under some circumstances. If cows were grouped, a minimum of two groups was generally preferable. If the high producing group did not satisfy the needs of the high producing cows, or the drop in nutrients between groups was substantial, a three group system would appear more favorable.

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Chapter I

INTRODUCTION

The structure of the dairy industry has changed drastically over the latter part of the twentieth century. At the turn of the century there were over 2.2 million dairy farmers, many with small numbers of cows. As late as 1959 there were 600,000 dairy farmers in the United States. This number had dwindled to less than 200,000 by 1983, and by the end of the dairy termination program in 1987 was approximately 160,000.

Indicative of the increase in cow numbers per farm was the fact that the number of dairy farms in the U. S. in 1986 had dwindled to less than 7% of the number of dairy farms in 1900, yet the total number of dairy cows only dropped by one-third over this period. With this increase in herd size has been a corresponding increase in productivity of individual cows. Modern nutritional management necessary for higher producing and larger herds is not compatible with low technology feeding systems typical of older and smaller dairy farms.

Problem Statement and Justification

The earliest form of feeding on a dairy farm probably meant individual feeding of both forages and concentrates to the few cows present. As dairies grew and became more specialized, forages were more often fed to cows as a group, while concentrates were fed individually. As herds continued to grow in size, feeding systems frequently were no longer conducive to individual feeding of concentrates and a total mixed ration was adopted. In this, its purest form, the total mixed ration entails mixing one or more rations for the herd of milk cows. All forages, concentrates, and minerals are mixed in a stationary or mobile blender and fed to the dairy cows. Coppock (13) pointed out several advantages and disadvantages of using this type of feeding system. The advantages listed were:

1. No expression of choice is permitted. Consequently, each bite consumed is uniform and definable.

2. Free choice mineral supplements are unnecessary.

3. A complete ration with a forage base of silage serves to dilute and mask the flavor of unpalatable ingredients such as urea.

4. Some reduction in labor required for feeding grain may accrue through this system.

5. Grain feeding in the parlor is not necessary. The benefits of this would include savings on parlor feeding equipment, less defecation in the parlor by cows, time

saved dispensing grain, less feed dust in the parlor, and quicker movement from the parlor.

The disadvantages described were:

1. Long stem hay must be chopped before being mixed.

2. Mixer wagons and electronic equipment are expensive.

3. It may not be economically feasible to feed on a small farm.

Coppock also summarized some advantages and disadvantages of grouping cows. His list of advantages included:

1. Grouping by production allows cows to move to higher forage and lower energy diets as lactation progresses and production declines.

2. Production groups allow lower producing cows to be fed a less expensive diet when energy and protein are less costly in forages and low energy by-products.

3. The higher producing group can be fed a diet with a higher concentration of those nutrients for which the cow has limited storage. A high-energy diet fed in early lactation should minimize the period of negative energy balance and perhaps result in higher conception.

4. Heat detection and other features of herd management are simplified if cows are grouped by production and/or stage of lactation.

Disadvantages to grouping of cows were:

1. Labor and time are required periodically to regroup cows.

2. Not all facilities can accomodate multiple groups of cows.

3. More time is required to formulate more than one ration.

4. Milk production decreases significantly when cows switch groups. This is partially due to social behavior, but primarily is attributable to a rapid change of nutrient concentrations in rations.

A 1983 survey of Virginia dairy farms showed that a little over half of those surveyed fed some sort of total mixed ration to their dairy cows. With the total mixed ration, the cows are often divided into two or more groups, with each group receiving its own blended ration. Thirty-one percent of the respondents to the Virginia survey fed a total mixed ration to one group of cows only, 17% to two groups, and 4% to three groups.

Those dairy producers who are feeding total mixed rations need to be aware of the economic consequences of their feeding system. Increasing the number of groups should improve allocational efficiency of nutrients to the cows, but may have a negative effect on profitability due to the additional time spent feeding or costs of forming additional groups. On the other hand, the most profitable number of cow groups may extend beyond current physical limitations of present facilities. A decrease in feed costs and/or an increase in milk revenues from increasing the number of groups could pay for higher labor costs as well as any changes in physical facilities needed to accomodate additional numbers of groups. Estimates of the costs and benefits of additional cow groups would be particularly helpful to dairy managers who would need to make capital investments to group their cows.

The issue of an optimal number of groups needs to be addressed in conjunction with a determination of an economically optimal level at which to balance a ration for a particular group of cows. Balancing a ration for the production level of the average cow may seem the logical choice, but it may not be the most profitable strategy for the dairy farmer to follow. This policy would mean that half the cows in the group would be underfed. An increase in nutrient allowance could economically justify overfeeding a majority of the group to ensure that higher producing cows receive nutrients adequate for their production.

The effect that alternative concentrate delivery systems, such as computerized feeders, could have on a feeding policy should not be overlooked. Alternative concentrate delivery systems can allow for a more precise allotment of nutrients to an individual cow. The same factors that affect the optimal grouping policy for a pure total mixed ration may also affect the optimal feeding policy with alternative methods of feeding concentrates. Individual feeding, where the number of groups is equal to the number of cows, should be considered as an alternative to regular grouping.

Objectives and Procedures

There are three primary objectives in this study. It is necessary to accomplish these objectives in their stated order because the achievement of each of the later objectives is dependent upon the solution of the immediately preceding objective. The first of these is to recommend dietary nutrient concentrations for lactating cows. The second objective is to predict dry matter intake and milk response to a change in grouping policies, whether this change concerns the number of groups or the feeding level. The third and final objective is to make recommendations concerning feeding and grouping cows based on economic conditions.

National Research Council (41) has recommendations concerning nutrient requirements of lactating animals defined in kilograms and grams of maintenance, growth, and lactational requirements. To convert absolute terms to percentages, it is necessary to have estimates of dry matter intake available. Therefore, the procedure to determine recommended concentrations involves prediction of dry matter intake as well as milk production for lactating dairy cows. Once a relationship between dry matter intake and milk production has been established, guidelines concerning nutrient concentrations can be made.

Information simulated from the first objective and procedure will be used to feed lactating cows in a 100 cow dairy. Cows will be fed individually as well as in one, two, three, and four groups. When not grouped, cows will be fed according to their individual recommendations and dry matter intake and milk production summarized for the entire herd. In group situations, one of the simulations will involve target feeding the group to the average recommended nutrient concentration. However, there will also be simulations that involve overfeeding or underfeeding the average recommendation to determine an optimal feeding level in different grouping environments. There will also be variations in herd productive capabilities, variation of productive ability of cows within a herd, and length of calving interval to determine the effect of these factors on a grouping or feeding strategy. Separate regressions will be run for what will be defined as herds with high, medium, and low producing capabilities. In summary, milk production and dry matter intake will be described as functions of number of groups, productive capabilites of the herd, variation in productive capabilities within the herd, and variation in calving interval.

Accomplishment of the second objective will lay the groundwork for the final objective, guidelines for grouping and feeding strategies based on milk prices and feeding and grouping costs. These guidelines can be derived from expected response to a change in number of groups, from grouping to individual feeding, or a change in feeding level. They can also be tailored to the individual dairy producer. If response is projected on a per cow basis, expected benefits can be extrapolated to the farm and a decision can be made based on size of the herd, cost of feed and price of milk, which should be known, and cost of grouping, which should be estimable with some accuracy. Several price and cost situations will be evaluated to demonstrate profit maximizing decisions under the stated economic conditions. However, one of the purposes of the final objective is also to advance a procedure to enable the dairy producer to more easily make a breakeven analysis on grouping and feeding policies based on the producers' own costs and prices and milk production and dry matter intake assumptions from the second objective.

A detailed description of the procedures follows in the chapter concerning modeling. However, a brief summary of the objectives will help to maintain the focus of the research. These are first to recommend energy and protein concentrations for lactating dairy cows. Second, to predict response to a change in feeding or grouping policy. And last, to determine the most profitable feeding and grouping strategy based on the prediction.

Chapter II

REVIEW OF LITERATURE

The purpose of this research is to determine a group feeding policy to maximize profits under any particular set of conditions that may exist on a dairy. The solution to this problem lies not only in analysis of the actual costs of the physical setup of the different feeding or grouping systems, but an analysis of conditions that are not so obvious or predictable. The latter part of the statement pertains particularly to estimating the response of cows to different feeding regimes and diets. The data to be used in this research are to be simulated based on other researchers' work. Therefore the search through the literature is not merely to establish a groundwork for different feeding and grouping systems, but also identify factors affecting dry matter intake and milk production in lactating dairy cows, as well as to establish the relationship between dry matter intake and milk production.

Dry Matter Intake

Prediction of dry matter intake for lactating cows is an area of nutritional management that is critical to issuing guidelines for balancing rations. The purpose of a balanced ration is to meet the nutrient requirements of body functions - specifically maintenance, growth, reproduction, and lactation (37). Because of scientific work in nutritional physiology, an estimate of the nutrients required to perform these functions is available in absolute terms (41). For example, the amount of energy required for a cow to produce a certain amount of milk can be estimated with a fair degree of accuracy. However, for the nutritionist to formulate a ration that will provide the amount of nutrients that the cow requires to perform her functions, an estimate of the cow's dry matter intake needs to be available as well.

Factors Affecting Dry Matter Intake

Control of feed intake and regulation of energy balance are influenced by a number of factors. A dry matter intake range between 2% and 4% of bodyweight may be observed within a herd (41). The most important factors affecting this range include milk yield of the cow, stage of lactation, body weight, and digestibility of the ration (1).

Days in lactation have been shown to have a quadratic effect on dry matter intake. At the beginning of lactation, dry matter intake increases until it reaches a maximum and then gradually declines. While milk yields peak between 1 and 2 months, intake will typically peak between 3 and 5 months (1).

Body weight is a major factor influencing dry matter intake. Larger animals tend to eat more than smaller animals. It has been established that there is some form of a linear relationship between body weight and dry matter intake. There is a consensus that this linear relationship exists between dry matter intake and metabolic body weight, metabolic body weight defined as live body weight raised to the power of .75 (1,3).

Several measurements can be used to estimate digestibility, including crude fiber (CF), acid detergent fiber (ADF), and neutral detergent fiber (NDF). Generally speaking, as fiber content increases, digestibility decreases. Chandler (10) found dry matter intake to decrease .026 kg per 100 kg of body weight for each one percent increase in the crude fiber content of a ration. An increase in forage quality (1) or concentrate percent (1, 3, 16, 24, 34) increased dry matter intake in lactating cows that had been fed rations of low metabolizability. Somewhat to the contrary, Vadiveloo and Holmes (56) did not find forage quality to affect dry matter intake.

Probably the most important factor affecting dry matter intake in lactating cows is the amount of milk produced (1,27). Different researchers have discovered varying linear relationships between dry matter intake and milk production. McCullough (34) and Vadiveloo and Holmes (56) found regression parameter estimates of the linear relationships between milk production and dry matter intake between .14 and .36, while Neal et al. (42) discussed several dry matter intake equations with parameter estimates between .1 and .2. The Agricultural Research Council of Britain (1) selected a value of .2 kg dry matter per kilogram of 4% fat-corrected milk as representative of the increase in dry matter intake due to increased milk production.

Several researchers have discussed relationships between milk production and dry matter intake that are not simple linear relationships. McCullough (34) used a quadratic equation to explain dry matter intake as a function of milk production. Change in predicted dry matter intake as a result of a one kilogram change in milk production varied from .463 to .319 kg of dry matter intake as milk production increased from 10 to 40 kg of 4% fat corrected milk per day. Brown (3) used a log linear relationship that varied between approximately .1 and .05 as milk production increased over the same range. The same conclusion can be derived from either of these results; dry matter intake is affected by milk production of the animal, but less so at high levels of production.

These are not the only factors that can affect dry matter intake in cattle. An increase in the frequency of feeding can increase dry matter intake, particularly during periods of high intake levels (27). Temperature has also been shown to inversely affect dry matter intake, although response to temperature depended largely on stage of lactation (33). Cows in lactation from 100 to 180 days were most affected by increases in temperature. However, when feed was continuously available, lactating cows increased their intake at night to such an extent that total daily dry matter intake was not seriously affected.

Internal metabolic functions of the animal such as hormones, metabolites, and gastrointestinal factors can also influence dry matter intake (41, 59). Combined with previously mentioned external factors, prediction of dry matter intake can be something less than an exact science.

Prediction of Dry Matter Intake in Lactating Animals

Most attempts to predict dry matter intake have involved regressing on factors that are known to affect intake. Chandler and Walker (10) determined daily intake of dry matter to be a function of type of forage, season, body weight, crude fiber content of ration, and total weight of butterfat produced daily. These variables explained 80% of the variation in the dry matter intake for the cows in their data base. Brown (3) found days in milk, milk, butterfat, body weight, crude fiber, and time of year to explain 76% of the variation in dry matter intake in the cows in his study.

Mertens (37) deviated from this approach of predicting dry matter intake by solving a system of equations. One equation set intake (I) equal to an assumed constant capacity (C) of the cow divided by a fill characteristic (F) of the diet; the other set intake equal to energy required (R) divided by the energy content (E) of the diet. The first equation is mathematically $I = C/F$, the second $I = R/E$. These equations imply that intake is a linear function of the cow's characteristics (capacity of the cow and energy required), but is a curvilinear function of dietary characteristics (fill characteristic and energy content) due to its reciprocal nature.[1] By defining fill characteristic and energy characteristic as functions of neutral detergent fiber, solving for energy required, and determining capacity to be about 1.1% of body weight, Mertens derived a prediction equation for dry matter intake. This system of predicting dry matter intake suggested that below 35 kg of daily milk production a cow will eat more of a ration based on average grasses than a ration based on average legumes. However, due to lower levels of NDF and higher levels of energy in the legumes compared to the grasses and a stipulation that 75% of the neutral detergent fiber in the diet be supplied by forages, dry matter intake will be higher for higher producing cows.

Erdman (17) approached the problem of predicting dry matter intake with the hypothesis that a cow will attempt to eat a ration that will achieve a prescribed energy balance.

[1] For example, if $f(n) = n$, $f(n)$ increases linearly as n increases. However, if $f(n) = 1/n$, $f(n)$ approaches zero asymptotically as n increases.

This does not completely agree with Coppock (14), who found this to be not true for cows in later stages of lactation. Under Erdman's reasoning, if energy balance could be predicted and dietary energy content estimated, dry matter intake could be predicted. He then proceeded under the assumption that maintenance requirements of lactating cows are relatively constant and the efficiency of use of metabolizable energy intake for milk production is also relatively constant.

Adjustments in digestibility were made by Erdman for the level of intake and the season. The decline in digestibility was described as:

$$DECLINE = .177 \times MTDN - 10.33$$

where MTDN was the percent of total digestible nutrients at maintenance levels of feeding. This relationship was used to describe the adjusted total digestible nutrients at maintenance level of intake (ATDN) by the formula:

$$ATDN = MTDN - FR \times DECLINE$$

where FR is the feeding rate in multiples of intake above maintenance. Erdman further adjusted the digestibility of the ration with the formula:

$$SDA = .18(T - 15)$$

where SDA is the seasonal digestibility adjustment to ATDN and T is the Celsius temperature. By assigning seasonal temperatures of 8, 18, 25, and 12 to winter, spring, summer, and fall, respectively, further TDN adjustments varying between -1.26 and 1.80 were made. These adjustments recognized that while the efficiency of use of metabolizable energy was constant, metabolizable energy available to the cow from the ration would decrease as rate of feeding increased and temperature decreased.

If a zero tissue energy balance was assumed, dry matter intake could be predicted by summing maintenance and production needs. This method only accounted for 44% of the variation in predicted versus actual dry matter intakes in Brown's data set, and not surprisingly tended to overpredict dry matter intake in early lactation and underpredict in late lactation. Erdman therefore attempted to account for positive and negative energy balances by assuming energy balance was the difference between calculated energy intake and maintenance and production energy requirements. This energy balance was then regressed on milk production per day, fat corrected milk per unit of metabolic weight and its square, lactation day, lacation day squared and cubed, fat percent and its square, diet crude protein percent, maintenance TDN and its square, maintenance net energy lactation and its square, and season of the year. A nine component model selected through stepwise regression only accounted for 48% of the variation in the dependent variable, with the square of fat-corrected milk per unit of metabolic weight the most important variable. However, by including predicted dry matter intake, the predicted tissue energy balance derived from the nine component model the R^2 improved to 68% from the 44% obtained when a zero tissue energy balance was assumed.

Milk Production

There has been much research devoted to the study of achieving higher milk production per cow. To attain these goals, scientists have devoted time and energy to studying and quantifying factors that affect milk production. The search through the literature will first identify variables that experimenters have found to affect milk production and then will emphasize quantifying the major factors that influence milk production in dairy cattle.

Factors Affecting Milk Production in Dairy Cows

There are two major areas affecting milk production in dairy cows - phenotypic effects and genotypic effects. The genetic makeup of the cow cannot be altered once she has been conceived, yet the genetic makeup has a great deal of influence on the level of milk production in the cow. Since there are so many factors affecting milk production and genetic influences that cannot be accurately measured, it is difficult to completely separate genetic aspects from phenotypic aspects. It is, however, recognized that cows do have inherent differences in their ability to produce milk (25, 50).

There is no more influential factor affecting milk production than nutrition, and its effects have been studied extensively. A cow's diet consists of two main sources of nutrients - forages (hay, silages, and other bulky feeds) and concentrates (chiefly grains). As dry matter intake increases, milk production increases (4). Although voluntary intake of forages is negatively related to concentrate intake, an increase in concentrates is associated with an increase in milk production due to an increase in total dry matter intake (50). An increase in the rate of grain feeding will not only increase milk production (32, 23), but body weight (3) and the protein and solids-not-fat content of the milk (30). The extent of this response will depend on amount of protein fed, stage of lactation, amount of forage fed, and genetic abilities of the cow (41).

Response to extra grain feeding can be attributed to extra energy in the ration. Several methods of measurement have been used to define the amount of energy in a feedstuff.

Energy in feed is used not only for maintenance, milk production, reproduction, and growth, but also appears in the form of feces, methane, and urine. Total heat production in kcal can be measured by the formula

$$Kcal = 3.886O_2 + 1.200CO_2 - .518CH_4 - 1.431N$$

where O_2, CO_2 , and CH_4 are liters of oxygen consumed, carbon dioxide and methane produced, and N is grams of urinary nitrogen (39). Subtracting fecal energy from total energy defines apparently digested energy, and subtracting methane energy and urine energy from this leaves metabolizable energy. In summary, a list of energy definitions is as follows:

GE = gross energy of total feedstuff consumed

DE = apparently digestible energy (GE - fecal energy)

ME = metabolizable energy (DE - methane energy - urine energy)

NE_{milk} = ME - heat increment

NE_{milk} , or NE_L, the net energy for milk production, is not a direct measurement of the heat value of a feedstuff, but is a measurement of the approximate contribution of that feedstuff to maintenance, reproduction, lactation, and weight gain of a lactating cow. Table 1 contains a list of estimated relationships between NE_{milk} and other measures of feed. It should be noted that NE_{milk} was less than the other forms of energy, as energy lost through heat transfer, fecal and urinary production was taken into account before figuring net energy available for maintenance, milk production, fetal growth, and weight gain.

Table 1. Comparison of Feed Energy Values

$$NE_{milk}(Mcal/kgDM) = .677DE(Mcal/kg) - .36$$

$$NE_{milk}(Mcal/kgDM) = .703ME(Mcal/kg) - .19$$

$$NE_{milk}(Mcal/kgDM) = .0305\ DE - .41$$

$$NE_{milk}(Mcal/kgDM) = .0309\ DE - .19$$

$$NE_{milk}(Mcal/kgDM) = .0266\ TDN - .12$$

$$NE_{milk}(Mcal/kgDM) = .809\ ENE + .54$$

Protein has been shown to have a positive effect on milk production. Protein effect is similar to the response of milk to energy in that milk production will increase at a decreasing rate (46). With diets based on corn and soybean meal, large increases in milk yield are obtained when crude protein is raised from 9-10% to 13-14%. Increasing crude protein above 14% results in smaller and declining rates of increase. Possible explanations for the increase in milk production due to increases in protein include increased dry matter intake, improved digestibility, and more optimal proportions of degradable and undegradable protein (9).

As the importance of dietary protein escaping the rumen becomes more important with increased milk production of lactating animals, researchers have established a system of describing the protein or amino acids that are absorbed from the small intestine. Intake crude protein is categorized as either undigestible intake protein, rumen degradable intake protein, or rumen undegradable intake protein. In this system, extra protein degraded by rumen fermentation and absorbed as ammonia is included in a definition of digestible protein, but is not included in a definition of absorbed protein. This system is also different in that absorbed protein differentiates in proportions of dietary protein that may escape rumen fermentation, but total crude protein does not. Therefore, nutrient requirements in terms of total crude protein will always be greater than or equal to the nutrient requirements in terms of absorbed protein.

Digestibility of the ration has a major influence on milk production. Crude fiber and acid detergent fiber are two measurements inversely related to digestibility of a ration. As digestibility decreases, milk production decreases. Therefore, as crude fiber and acid detergent fiber of a ration increase, milk production will tend to decrease. In a study by Rock et al. (45), milk production increased by .39 and .36 kg for each one percent decrease in crude and acid detergent fiber.

Crude fiber is the fiber fraction that is resistant to degradation in acid and alkali. Acid detergent fiber consists of cellulose, lignin, acid detergent-insoluble N, and acid insoluble ash. Values for NDF and ADF are more accurate measures of the fiber components of feeds than are values for crude fiber (41). Crude fiber underestimates forage fiber since some lignin is soluble in acid. Since both chemical and physical properties of feeds determine fiber quality and energy values of feeds, neither of these fiber analyses accurately predicts fiber qualities and energy values for all feeds. Both NDF and ADF are negatively correlated with digestibility, although ADF is apparently more so (41).

Lofgren and Warner (31) suggested that ADF and crude fiber were more accurate indicators of the ability of a diet to prevent depressed milk fat percentage. Minimum concentrations of 19% ADF and 17% crude fiber were found to maintain milk levels at essentially normal levels. ADF minimum during the first three weeks of lactation should be somewhat higher, around 21%, to minimize butterfat depression and health problems.

With the ultimate goal of increasing feed efficiency, it is important to consider changes in milk production with respect to changes in dry matter intake (the measure of efficiency) when considering the benefits of increased milk production. For example, Cassel et al. (8) found energy efficiency to be higher for cows fed concentrate individually through use of transponders. Although Guthrie (20) found high temperatures to have an adverse effect on milk production, there was no adverse effect on the efficiency of converting feed to milk. Miller (38) found forage consumption to be negatively related to milk production as well as gross feed efficiency. Milk production functions generally indicate decreasing feed efficiency at higher rates of dry matter intake (3, 21). While dry matter intake and milk production functions may at times be evaluated separately, it is consideration of the efficiency factor (the relationship between dry matter intake and milk production) that ultimately affects the final grouping analysis. In addition, it is not sufficient for this research to realize only that protein, energy, and digestibility affect milk production. The extent of these effects must be estimated and modeled for a solution to the grouping dilemma.

Modeling Milk Production

There are two basic approaches to modeling milk production. Record keeping systems such as DHIA are designed to estimate total milk production of individual cows based on a few sample observations. If a daily milk production curve can be accurately plotted against time, total milk production can be calculated by measuring the area under the curve. The first approach to modeling is to estimate the daily milk production curve using limited observations. There must be estimates of milk produced during the other 29 days of the month to compute total milk produced. If incomplete lactations are to be extended to estimate milk that will be produced over 305 days, there must be methods to predict milk that has not yet but will be produced.

The other approach to modeling assumes that daily milk production is dependent on various inputs. Feed is thought of as an *input* that is transformed by a *production function* (the cow) into *outputs*, in this case milk. Daily milk production will vary as the inputs and external factors affecting it vary.

The Lactation Curve

Wood (62) first proposed the incomplete gamma function to describe the expected milk production of a lactating animal. This lactation curve takes the exponential form $Y_n = an^b e^{-cn}$, where Y_n is the average daily yield in the *nth* day from the start of lactation, and e is the base of the natural logarithm. Parameters a,b, and c are to be estimated. A graph of the cow's daily milk production would show a curve increasing until 45 to 60 days into lactation and then slowly leveling off (28). The first coefficient, a, will not change the shape of the curve, but will increase the total production of the cow. The second coefficient, b is an index of the cow's capacity to utilize energy for milk production, and the c is the rate of decline in production over time. The ratio of b to c identifies the day of peak lactation, while persistency can be defined as $c^{-(b+1)}$ (49). Grossman (19) found the a to be the only parameter that was affected by additive genetic variance. This implies that selection would increase milk production without changing other characteristics of the milk curve.

Factors that could influence milk production can be discovered by testing for differences among parameter estimates for unlike groups of animals. Cows in first lactation had lower total production, lower peak yield, greater persistency, and later peak production than did cows in later lactation (49, 28). The breed of cow as well as the year fresh and month fresh also affected the lactation curve (19). Locational differences between regions and farms are other factors that can change the lactation curve (12).

The factors in the previous paragraph refer to the mean production for a group of cows. Production of individual cows will vary. Keown (29) believed variation in daily milk yield to be higher among high producing cows than low producing cows. There also has been indication that variation in milk production among cows is higher during early and late lactation (26). In a 1981 study in Virginia of 463 DHI herds, Swisher (55) found average test day standard deviation of milk production within a herd to vary between 2.77 and 10.89 kg. When grouped by herd size, average test day standard deviation ranged from a low of 6.22 kg for small herds (40-59 cows) to a high of 6.42 for the largest herds (greater than 150 cows). Seasonal differences were likewise small, ranging from 6.13 kg in the summer to a high of 6.46 kg in the spring.

Many of the factors that affect the lactation curve of a cow were factors that DHIA accounts for in extending test day averages to a standardized 305 day lactation period. Since it is not practical to measure a cow's production daily, the lactation curve based on sampling points has proved useful in estimating total production of the lactating animal. For this research, a model that predicts output based on input is necessary to analyze various feeding regimes. While the incomplete gamma function is good to test for the appropriateness of the final milk prediction model, a multiple regression model will be used to predict output based on inputs.

Input-Output Models

Heady (21) published some of the earliest work attempting to define milk production responses. A complex quadratic regression equation explained 83% of the variation in milk production between cows in his experimental data. Variables in his regression accounted for grain and hay intake, stage of lactation, genetic ability, inbreeding, body weight, age of the cow, and outside temperature. A simpler regression equation predicting weekly milk production (M) based only on weekly hay (H) and grain (G) intake was as follows:

$$M = -25.9304 + 2.5536G + 1.0465H - 0.005047G^2 - 0.001088H^2 - 0.003521GH$$

This expression was used in economic evaluation of milk response to feed. These evaluations included marginal rates of substitution, least cost rations, and profit maximizing levels of feeding for various grain-hay-milk price combinations.

Dean et al. (15) used regression equations to estimate milk response to estimated net energy. Several different analyses were evaluated, but in all cases, as with Heady's function, equations showed a diminishing marginal productivity to higher energy levels as demonstrated by negative quadratic components. In addition, all equations showed genetic ability and days in milk to change the slope of the response curve. Aggregate data for the cows in their experiments indicated an average decline in milk per month to be 6.93%.

Brown (3) developed a model to predict milk yield using independent variables accounting for days in lactation, butterfat, bodyweight, crude protein, percent of ration as concentrate, and dry matter intake. Brown's work indicated a diminishing marginal response of milk production based on weight of the cow, percent of ration as concentrate, and crude protein percent of the ration. According to his results, yields begin to decline at a bodyweight of 613 kilograms and a ration consisting of 16% crude protein and 76% concentrate. Although his results indicated milk production decreased at a decreasing rate with respect to days in milk, this must be tempered with the time of peak dry matter intake and the effect of dry matter intake on production.

Doyle (16) approached prediction of milk production not directly but through a partitioning of energy. By assuming that a cow would seek energy for milk only after satisfying maintenance and pregnancy needs, he calculated a pool of energy that would be available for milk production. Energy in the pool could then be partitioned between milk production and live-weight gain. His dependent variable, percent of total energy utilized for milk production (Um), was expressed as a function of energy in the production pool (ESMP), week of lactation (WL), and potential milk yield (PMY), which was linearly related to week in lactation. This function was described as:

$$Um = 1.50897 - .03430WL + .00113WL^2 - .01788ESMP + .00009ESMP^2 + .06549PMY - .00038(PMY \times ESMP)$$

In general, the signs of the equation are as expected, with an increased proportion of surplus energy partitioned to live weight gain as energy available in the production pool increases and potential milk yield decreases.

The previous literature reflects work related to "rules" regarding dry matter intake and milk production that will be established when simulating grouping situations. Once the "rules" have been determined, analysis of grouping systems can be undertaken.

Grouping cows

Just as a three-group feeding system would suggest a more efficient allocation of nutrients than a two-group system, the two-group system would seem to be a better method of allocation of nutrients than a one group system. If the one group ration is meeting the needs of the high performance cows, the lower producers may be overfed. In this situation, income over feed cost may be improved more through a reduction in the concentrate cost than an increase in milk produced (51). Profitability may also be increased by a reduction in health problems caused by fat cow syndrome from overfeeding low producers (40). If the one group ration is not overfeeding the lower producers, higher producers may not be having their nutritional requirements met, resulting in lower peak milk yields. Spahr (53) found that cows producing greater than 35 kg of milk per day to do well in group situations if net energy was greater than 1.91 Mcal/kg dry matter. A ration that took into account the lower producing cows in the herd would probably not achieve this level of energy concentration. A two group feeding system would be more likely to increase total milk in this case.

Expected benefit of the two group feeding system over the one group feeding system is not consistent among researchers. Wilk et al. (61) detected no significant differences between milk production, fat percent, fat corrected milk, body weight change, health, or reproductive performance. Clark et al. (11) tested differences between a three group feeding system and a one group feeding system with the same general results. A three group subset of Guernseys in his study did, however, have higher milk production in first lactation.

Cassell et al. (8) was interested in comparing one-group and two-group feeding systems to individual feeding achieved through use of transponders. While neither the one-group or two-group system was as efficient at converting feed energy to milk energy as the transponder feeding system, the one-group system of cows produced more milk and gained more weight, particularly during late lactation, than the two group herd of cows. Although weight gained during late lactation could suggest a higher incidence of health problems during subsequent freshenings, their research did not indicate this.

A possible explanation for the lack of difference found by these researchers between the two-group system and one-group system is the loss in production directly attributable to a rapid switch in rations (52). This could decrease overall performance of cows fed in two groups. When severity of the switch is minimized, income over feed cost of the herd may be improved. It has been suggested that to attain this goal, the difference in the production for which the ration is balanced be no more than 15% between groups (43). This could form the basis for Coppock's conclusion that those feeding total mixed rations should have a minimum of three groups (14).

Everson et al. (18) devised a research project where cows were divided into two groups. The first group was fed a constant 60:40 forage to grain ratio, whereas the second group was fed a 50:50, 65:35 and 85:15 forage-grain ratio as the stage of lactation progressed. Cows in the second group had an earlier positive energy balance, produced more milk, consumed more dry matter, and showed earlier post calving estrus.

Everson's project deviated from some of the previous grouping studies where cows were grouped according to milk production. Though many of these experiments involved grouping cows on the basis of milk production, the ultimate goal of grouping should be to minimize the variation of nutritional requirements within a group. The National Research Council recognizes age, weight, milk production, and fat percent as factors influencing the nutritional requirements (crude protein and net energy lactation) required by a lactating animal (41). Grouping by milk production alone will not necessarily achieve the group homogeneity desired. McGilliard (36) has proposed a cluster method for grouping that takes into account some factors that influence nutritional requirements of lactating animals. Cows are stratified by nutritional requirements into the most similar groups possible. Intraclass correlation for TDN% required in their experiment was .59 for the cluster method of grouping versus .41 for a grouping method based strictly on milk production (48).

In conjunction with reducing group nutritional variation, lead factors have been proposed to ensure that nutritional requirements of the majority of the herd are met. The lead factor will balance a ration to supply the absolute energy requirements of a cow producing one standard deviation of daily milk above the average cow in the group (54). Nutritional requirements will therefore be theoretically met for all those cows in the group with nutrient requirements less than the lead cow. This could suggest a situation with a feeding system of two or more groups where the cluster method of grouping and application of different lead factors to the different groups could be combined to minimize variation in nutritional requirements within a group and nutrient concentration between groups. Cows could be grouped to minimize variation in nutrient requirements. Different lead factors can then be applied to the different groups with either a goal of minimizing variation in nutrient density between groups or a restriction on the amount of variation between groups.

Chapter III

MODELING

The purpose of this chapter is to describe the first two procedures in detail. Briefly, the first procedure involves analyzing data to predict dry matter intake and milk production for lactating dairy cows. These results are reported in this chapter and used to establish protein and energy concentration recommendations, which are reported in Chapter 4. These recommendations are used in the second procedure, the simulation of 100-cow dairies under different grouping and feeding scenarios, also described in detail in this chapter.

Prediction Equations

Just as a solid foundation is essential to ensure the sturdiness of any physical structure, dry matter intake and milk prediction equations are absolutely crucial to the validity of generated data. Data used in estimating both dry matter intake and milk prediction equations were collected by Holter at the University of New Hampshire. Table 2 summarizes some of Holter's data. There were a total of 4149 observations, most of which consisted of 28-day periods, in the original data that were collected from 1966 through 1983. Records for 377 lactations from 171 different cows were gathered. The majority of cows had records for more than one lactation. The number of previous lactations for individual cows ranged from none (first calf heifers) to eight. Data were collected for 28-day periods for each of the cows, although the final period was not always 28 days. Most of the records were terminated at the end of either ten or eleven 28-day periods (280 or 308 days of data), with the number of days in lactation ranging from a minimum of 190 to a maximum of 473 with an average of 300. Total milk produced by individual cows varied from 3,303 kg to 11,364 kg, with an average of 6,450 kg. First period body weights were taken from 7 to 21 days after freshening (Holter, personal conversation). Weight changes over the lactation ranged from a loss of 117 kg of body weight to a gain of 179 kg. Average weight change was plus 60 kg over this period.

Milk weights and dry matter intakes for individual cows were totalled at the end of each period. Fat percent and solids-not-fat percent of milk, crude protein percent, acid detergent fiber percent, and megacalories of net energy of the ration, as well as birthdate, calving date, dry date and lactation number of the cow were also recorded. Since data were totalled for 28-day periods, totals were divided by 28 days and the mid-point of each period was assumed to be the observation day. For example, total amount of milk produced in the first period by a certain cow was divided by 28 and assumed to be the milk produced on day 14. Observations were thus analyzed on days 14, 42, 70, 98, and so forth for each lactation.

Table 2. Holter Data by Lactation Number

Variable	Previous lactations	N	Mean (kg)	SD (kg)	min (kg)	max (kg)
Total milk	0	126	5,648	1,134	3,635	8,652
Days in milk	0	126	137	17.6	105	215
Beginning weight	0	126	501	50.0	386	651
Weight change	0	126	76	36.8	-24	165
Total milk	1	104	6,716	1,480	3,280	11,364
Days in milk	1	104	135	17.5	86	202
Beginning weight	1	104	566	52.6	432	689
Weight change	1	104	58	50.1	-121	147
Total milk	2	66	6,872	1,354	3,627	9,929
Days in milk	2	66	137	16.9	104	192
Beginning weight	2	66	604	53.2	476	732
Weight change	2	66	49	50.5	-117	177
Total milk	3	38	7,063	1,373	3,773	10,226
Days in milk	3	38	135	10.4	117	168
Beginning weight	3	38	606	63.0	513	772
Weight change	3	38	54	50.3	-36	179
Total milk	4	20	6,974	1,524	4,402	9,579
Days in milk	4	20	134	11.5	114	159
Beginning weight	4	20	597	57.8	472	720
Weight change	4	20	49	51.5	-45	142
Total milk	5	11	6,910	996	5,062	8,544
Days in milk	5	11	134	14.7	105	162
Beginning weight	5	11	626	68.7	470	773
Weight change	5	11	30	28.7	-17	70
Total milk	6	8	6,976	1,733	4,692	10,509
Days in milk	6	8	133	19.1	117	163
Beginning weight	6	8	617	63.5	544	745
Weight change	6	8	25	39.1	-36	86
Total milk	7	3	7,044	2,141	4,741	8,973
Days in milk	7	3	138	22.7	112	153
Beginning weight	7	3	598	48.8	549	646
Weight change	7	3	45	66.5	-7	120
Total milk	8	2	6,872	1,914	5,518	8,226
Days in milk	8	2	137	31.1	115	159
Beginning weight	8	2	567	22.5	551	583
Weight change	8	2	53	20.9	-39	68
Total milk	All	378	6,450	1,447	3,303	11,364
Days in milk	All	378	136	16.1	86	215
Beginning weight	All	378	560	70.5	386	773
Weight change	All	378	60	46.9	-117	179

In collecting data, Holter did not delete unusual observations, some of which may have been caused by events not considered unusual, such as sickness. There were several cases where an animal averaged very small amounts of dry matter intake, as little as 4 kg per day over a 28 day period. It was felt that these observations could cause bias in final parameter estimates. For this reason, the record for any cow with an average daily dry matter intake of less than 8 kg (selected as a cut-off from visual analysis of the data) was deleted for both that period and the following period. In addition, so that all daily occurrences would have an equal influence, periods with less than 28 days were discarded. This reduced the number of total observations by 231, leaving 3918 for data analysis.

Table 3 summarizes some of the more pertinent data used in parameter estimation. The aggregate of this data is included with separate summaries for heifers and multi-parous animals. Included in this summary are inputs in terms of crude protein, net energy, acid detergent fiber, and total dry matter intake and output in terms of four percent fat corrected milk (hereafter known as 4% FCM or FCM). Since a premium is paid for butterfat differential, it was decided to convert a kilogram of milk to a kilogram of four percent fat corrected milk by the formula

[1] $FCM = .4 + (.15x \text{ fat percent})$

and refer to milk production in these terms throughout the research. The fifteen represents the prevailing farm level value of a one percent increase in the butterfat test.

Table 3. Selected Averages from Holter Data

Variable	Mean	SD	Min	Max
Daily Dry Matter Intake (kg)				
All cows	16.259	3.097	8.016	27.943
Heifers	14.662	2.049	8.241	24.757
Older cows	17.067	3.221	8.016	27.943
Daily 4% Fat Corrected Milk (kg)				
All cows	21.201	7.484	5.004	53.882
Heifers	18.302	4.292	7.931	33.797
Older cows	22.667	8.283	5.004	53.882
Percent Acid Detergent Fiber				
All cows	22.262	5.322	7.19	39.23
Heifers	21.617	4.404	8.89	32.97
Older cows	22.588	5.703	7.19	39.23
Percent Crude Protein				
All cows	15.265	2.183	8.35	22.79
Heifers	15.352	1.845	9.70	22.04
Older cows	15.221	2.335	8.35	22.79
Mcal NEL/kg Dry Matter				
All cows	1.629	.1286	1.194	2.879
Heifers	1.649	.1203	1.279	2.879
Older cows	1.620	.1315	1.194	2.258

Deriving Equations for Predicting Dry Matter Intake

As reviewed in the previous chapter, there have been numerous attempts to predict dry matter intake of individual cows. A problem with many of these equations is that dry matter intake is a function of milk production and milk production is a function of dry matter intake. If these two variables are indeed functions of each other, then the proper solution may entail solving a system of simultaneous equations. However, it is also quite possible that dry matter intake is as much a function of inherent milk producing capabilites of the cow as the actual milk produced. This, of course, would not be the only factor influencing dry matter intake. As stated in the previous chapter, weight of the cow, days in milk, fiber content, and possibly crude protein percent of the ration as well as other variables not measured, such as palatability, are also believed to be strongly correlated with dry matter intake.

Hypothesizing that dry matter intake is a function of these variables, and inherent milk producing capacity of the cow, the challenge was to develop a model that could predict dry matter intake for an individual cow. This was approached in two steps. Previous dry matter intake modeling seems to indicate that there is unexplained variation in dry matter intake between individual cows. For the purposes of this research, however, it was not necessary to scientifically explain this variation, only account for it. It was felt that at least some variation in dry matter intake between cows could be explained or predicted by dry matter intake in the previous period. This would in itself account for some basic differences between cows, such as the weight of the cow, milk producing capability, and general differences in appetite that might not otherwise be explained. The first step in the model thus entailed predicting dry matter intake of a cow based on characteristics of the ration, days in milk, and previous dry matter intake.

Stepwise regression was used to select variables in a dry matter prediction equation. Table 4 describes two nearly identical dry matter intake prediction equations, differing only in lack of previous dry matter intake as an independent variable. The more complete model was selected using stepwise regression. Independent variables included days in milk, days in milk squared (to account for a possible maximum dry matter intake), natural log of days in milk (to account for a possible exponential effect of days in milk), calving date (to account for a trend that could be attributed to time through either genetics, management, or a combination of the two), acid-detergent fiber and acid detergent fiber squared (to account for a maximum or minimum effect of fiber), and crude protein percent and crude protein percent squared (to account for a maximum or minimum effect of protein) as well as dummy variables for heifers to shift both the slope and intercept. Protein variables were discarded as non-significant factors in predicting dry matter intake in both models. The R^2 in the model with lagged dry matter intake was 80%, but in the absence of this variable, R^2 was 50%. In addition, the Durbin-Watson test for serial correlation indicated strong positive correlation between the disturbance terms in the absence of lagged variables.[2] This could be explained by a series of positive (or negative) disturbance terms over the ten or eleven periods for an individual cow, followed by a series of positive (or negative) disturbance terms for a different cow. If this were the case, accounting for cows in the model could correct for serial correlation. This was done by adding the previous dry matter intake as an independent variable. With a lagged variable in this equation, one observation was lost for each lactation. However, the loss of 377 observations was more than offset by improvement in the model. There was a marked increase in the variation explained in dry matter intake by the independent variables. All variables remained significant at the .05 level, with the

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[2] Serial correlation, a series of positive or negative disturbance terms, indicates that there is an unexplained factor that causes the prediction equation to understate or overstate the actual data for a longer sequence than that which would be expected to occur strictly by chance.

R^2 increasing from 49.50 to 80.9. In addition, the Durbin-Watson test statistic of 2.036 in the lagged model rejected serial correlation at the .05 level.

Table 5 summarizes separate equations selected for prediction of dry matter intake in heifers and multiparous cows. Although neither of the separate models explained as much variation in dry matter intake as the model using the entire data, parameter estimates using separate equations would be more accurate in prediction because they allow different responses according to age of cow. R^2 fell to 70.71 and 78.94 for heifers and multiparous animals. The Durbin-Watson test continued to reject serial correlation with a test statistic of 2.081 and 2.085 for these two classes of animals. Slightly higher heifer parameter estimates for previous dry matter intake compared to older cows, .78035 versus .73876, indicated a difference in persistency between these animals, with a lower intercept for heifers, 16.655 compared to 24.813. Dry matter intake was maximized at 16.7% acid detergent fiber for heifers and 16.2% for older cows.

There remained the problem of predicting first dry matter intake for an animal. Part two of the two step solution for predicting dry matter intake involved estimating an equation for first period dry matter intake. Fiber content of the ration, body weight of the cow, and milk producing ability of the cow were all felt to have an influence on first period dry matter intake. It was also thought that lactation number could have an influence on dry matter intake, but there existed the possibility of body weight being correlated with the number of previous lactations. Separating the equations into multiparous and primiparous classes minimized this problem. In the aggregate data, this was accounted for with the use of a dummy variable to shift the intercept of predicted dry matter intake for heifers.

Table 4. Equations Predicting kg Daily Dry Matter Intake
All Cows - 3547 Observations

Variable	Parameter Estimate	T-test	Parameter Estimate	T-test
Intercept	6.23976086	3.343	23.11088676	19.351
Previous Dry Matter Intake			0.74218828	73.706
Lactation (heifer=1, else 0)	-4.70180966	-26.170	-1.18545395	-9.676
Lactation-days in Milk Interaction	0.01349420	13.265	0.00478990	7.372
Calving date (Jan 1, 1960=1)	0.00040239	15.628	0.00010847	6.513
Days in Milk	-0.06445265	-7.507	0.04413589	8.333
Natural Log of Days in Milk	3.32225192	5.757	-5.17107385	-13.597
Days in Milk Squared	0.00006810	4.984	-0.00005157	-5.904
Acid Detergent Fiber Percent	0.25453788	4.443	0.11803135	3.276
Acid Detergent Fiber Percent Squared	-0.00957302	-7.733	-0.00390569	-4.999
R-Squared	49.50		80.09	
Durbin-Watson	0.530		2.036	

Table 5. Equations Predicting kg Daily Dry Matter Intake by Class
3547 Observations

Group	HEIFERS		MULTIPAROUS	
Observations	1192		2355	
Variable	Parameter Estimate	T-test	Parameter Estimate	T-test
Intercept	16.65496270	10.373	24.81318516	14.840
Previous Dry Matter Intake	0.78035491	47.483	0.73876015	58.440
Calving date (Jan 1, 1960=1)	0.00012288	5.656	0.00008516	3.741
Days in Milk	0.04022692	6.014	0.04400996	5.394
Natural Log of Days in Milk	-4.00031612	-8.547	-5.58339565	-10.317
Days in Milk Squared	-0.00005092	-4.923	-0.00004294	-3.317
Acid Detergent Fiber Percent	0.12594025	1.994	0.13870866	3.041
Acid Detergent Fiber Percent Squared	-0.00376907	-2.580	-0.00428985	-4.443
R-Squared	70.71		78.94	
Durbin-Watson	2.081		2.085	

Table 6 describes equations to predict first period dry matter intake. Each of these equations was selected using stepwise regression. Once again, aggregate data with a dummy variable for heifers explained more variation in first period dry matter intake than either of the separate equations. Stepwise regression selected log of body weight rather than body weight for all three equations. Acid detergent fiber was significant for aggregate data and heifers.[3] However, acid detergent fiber squared was significant for animals with previous lactations while acid detergent fiber was not. These parameter estimates would in theory indicate that the effect of acid detergent fiber never reaches a maximum. In practice, though, the range of data for acid detergent fiber percent in the first period ration limits application of a maximum effect of fiber on dry matter intake in this period. Body weight parameter estimates were higher for the combined data relative to the separated data; the inverse was true for first period milk yield. The individual cow's milk yield and body weight had a slightly larger effect on first period dry matter intake for older cows compared to heifers. To more specifically describe differences between heifers and cows with previous lactations, separate models were selected to use in predicting dry matter intake.

Deriving Equations for Predicting Milk Production

The previous section detailed the methods in deriving equations to predict dry matter intake for simulation. A valid economic analysis of any grouping decision must be based on properly simulating the allocation of energy derived from dry matter intake between milk production and changes in body weight. To do this, a milk production function based on some form of dry matter intake was formulated.

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[3] As a rule of thumb, a T-test greater than 2 is significant at the .05 level.

Table 6. Equations Explaining First Period kg Daily Dry Matter Intake

Group	All		Heifers		Multiparous	
Observations	371		120		251	
Variable	Parameter Estimate	T-test	Parameter Estimate	T-test	Parameter Estimate	Pr>T
Intercept	-11.82298	-1.616	-15.78342	-1.665	-22.11155	-2.342
Calving date (Jan 1, 1960=1)	-0.00029	-3.620	-0.00077	-6.748		
First Period 4% Fat Corrected Milk	0.23600	12.436	0.21102	5.294	0.21628	11.112
Natural Log of Body Weight	3.27344	2.820	4.22208	2.667	4.85841	3.256
Acid Detergent Fiber Percent	0.13562	3.466	0.15414	2.905		
Acid Detergent Fiber Percent Squared					0.00505	3.814
Lactation Num; Heifer=1; else 0	-0.76707	-2.352				
R-Squared	52.60		40.73		42.54	

As reviewed in the literature, dry matter intake for a dairy cow is used to meet nutrient requirements for maintenance, lactation, growth, and reproduction. Therefore, deriving the milk production function entailed allocating dry matter intake between these four processes. It was assumed that a cow will allocate nutrient requirements first to maintenance and reproduction with the remainder of the nutrients being divided between milk production and weight change. The first step in estimating a milk production function required determination of nutrients used for maintenance and fetal growth. Fortunately these estimates are readily available in the 1988 edition of NRC Nutrient Requirements of Dairy Cattle (41). With most fetal (reproduction) energy required during the dry period, it was decided to ignore these energy requirements. To estimate nutrients available for milk production and body weight change, only calories and protein required to maintain a cow of a specific body weight were subtracted from input. As stated by the National Research Council, NEL Mcal per day required to support maintenance is:

[2] $$Maincal = .08 \times LW^{.75}$$

where LW is body weight in kilograms. The remaining energy was assumed to be divided between milk production and body weight change.

Although nutrient requirements are now available in terms of degraded and undegraded intake crude protein, information from data collected was only available in terms of total intake crude protein. Therefore, crude protein requirements for maintenance of mature and lactating cattle were used in determining the amount of protein left for milk production. Daily crude protein requirements of lactating and pregnant cows at 50 kg intervals of body weight were taken from Table 6-3 of the 1988 NRC Nutrient Requirements of Dairy Cattle. These requirements were regressed on body weight and an equation was derived so that daily crude protein requirements could be estimated on a continuous as well as discrete basis. The daily grams of crude protein required for maintenance of a lactating cow were estimated with an R^2 of 99.8 as

$$[3] \quad Maincp = 7.934 \times WTKG^{.616}$$

where WTKG is body weight in kilograms. Once again, protein not used for maintenance was assumed to be available for milk production and body weight change.

Knowledge of nutrients in the dry matter was necessary in estimating energy and protein left after maintenance considerations. This figure could be reached through either of two methods. The direct method would be to use the variable in the data that described total energy in the ration. Maintenance energy would be subtracted, and the remainder partitioned between weight change and milk production. From NRC, a one kilogram loss of body weight releases 4.92 Mcal of NEL, while 5.12 Mcal of NEL are used in adding one kilogram of body weight to the cow. In determining energy available in one Mcal NEL, nutritionists have accounted for energy that will be lost without being used. Therefore, if all energy measurements are accurate, the variable in the data that describes NEL in the ration should be the same as the total amount of energy used by the cow for maintenance, milk production, and body weight change. A simple method to check this was to subtract maintenance and milk energy from the figure provided in the data and determine if the calculated energy balance explained all, or at least most, of the variability in weight change of the cow. When energy balance was regressed on body weight change, only seven percent of variability in the dependent variable was explained. The difference between calculated energy and energy as stated in the data was further substantiated by making the latter variable a function of total calculated calories and forcing the intercept through the origin. Although the R^2 was 98.3, the parameter estimate of .976 showed that there was a slight difference between the two indicators of energy intake. For example, if total calculated calories for the daily ration was determined to be 30 Mcal, the energy variable in the data would state only 30 times .976 Mcal, if exactly as predicted.

Actual variability between these two measurements was taking place in maintenance calories, milk calories, and weight change calories. Attributing all this variability to weight change resulted in energy balance explaining a very small portion of the weight change. This emphasized the importance of using the calculated energy in obtaining parameter estimates for predicting milk production. Since calculated energy was less than stated energy (as indicated by a parameter estimate of less than one when calculated energy was regressed on the furnished estimate of energy consumed), using energy stated in the data and computing weight changes based on energy balance would lead to a simulation where cows were gaining much more weight than was reflected in the experimental data.

As discussed in the previous chapter, energy units describe actual energy used in production, or the amount of energy in a feed that can be expected to be used for maintenance, reproduction, lactation, and weight change. However, crude protein is a measure of the amount of protein in the feed, without regard to how it will be used. Much of the protein ingested is expected to be lost without being used. For this reason, using the data from the variable that described crude protein in the ration was a more accurate method of assessing intake protein than calculating protein used in maintenance, milk production, and weight change.

In selecting variables to be tested in a milk prediction equation, it was possible that once inherent differences between cows' dry matter intake had been taken into account, protein and energy available over maintenance could be converted to milk at the same rate for all cows. However, this might not have been the case, and previous period milk production may have been an important part of explaining milk production for the current period. Table 7 summarizes two identical equations except for the lack of previous period's milk production. The first equation was created by deleting the previous period's milk production from the second equation. The second equation was selected by stepwise regression procedure from a series of variables dealing with available nutrients, time, and slope and intercept shifters for heifers as well as interactions between many of the variables. Available calories (Mcal) and protein (kg) were each accompanied by squared terms to account for the possibility of decreasing effects. In addition, there were terms to account for interactions between calories and protein as well as between days in milk and calories. The basis for the former interaction was that a milk response to additional protein or energy would depend partly on the availability of the other nutrient. Producing milk requires a balance between protein and energy. The latter interaction was justified by hypothesizing that partition of energy between body fat and milk changes through lactation, with a decreasing amount of energy allocated to milk production in the later stages of lactation.

Although independent variables explained 84% of the variation in milk yield in the first equation, addition of the previous period's fat corrected milk production caused a significant improvement in the model ($R^2 = 93\%$). T-tests indicate that two functional forms of days in milk were significant after being insignificant without the lagged variable. The Durbin-Watson test of 1.248 accepted serial correlation without the lagged variable, but rejected it with the lagged variable (2.036).

Unlike dry matter intake, the aggregate data indicated that there was a difference between heifers and multiparous cows in the production of 4% FCM, but this relationship

Table 7. Equations Explaining Daily 4% FCM (kg)
All Cows - 3547 Observations

Variable	Parameter Estimate	T-test	Parameter Estimate	T-test
Intercept	3.44094233	1.424	22.02545284	13.745
Previous 4% Fat Corrected Milk			0.59130102	68.829
Lactation (heifer=1, else 0)	-0.88824659	-8.334	0.48048259	6.630
Calving date (Jan 1, 1960=1)	0.00048538	18.445	0.00007656	4.206
Days in Milk	-0.02341686	-2.109	0.06220447	8.446
Natural Log of Days in Milk	0.74790668	1.017	-5.74519963	-11.723
Days in Milk Squared	0.00001825	1.033	-0.00008244	-7.081
NEL Mcal Available After Maintenance	0.18417909	4.526	0.07272185	2.728
CP kg Available After Maintenance	3.99107097	9.018	1.44810144	4.964
Available kg CP-NEL Interaction	0.15413121	9.081	0.10276647	9.23
Available kg CP Squared	-0.56589234	-4.176	-0.43260100	-4.882
R-Squared	84.48		93.37	
Durbin-Watson	1.248		2.036	

did not change as lactation progressed. Available protein in kilograms and available energy in megacalories were deemed significant, as was the interaction between these two terms as well as the square of the available protein. Calories squared was not significant, indicating no decrease or maximum effect of energy on milk production. This, of course, must be tempered with dry matter intake limitations on energy that may not be experienced to the same degree with protein.

An interesting observation can be made from the parameter estimates relating to protein. The change in milk with respect to a change in available protein can be expressed as:

[4] $$\frac{\partial FCM}{\partial P} = 1.448 + .103C - .865P$$

where C is available NEL in Mcal/kg and P is available kg of CP, recalling available is defined as that left over after satisfying maintenance requirements. With an average available protein of 2.1 kilograms and available Mcal of 17.01 for all cows, maximum milk production will occur at 3.82 kilograms of available protein, ((1.448+.103*17.01)/.865), or an increase of 1.7 kilograms over the average. If dry matter intake is assumed to be 20 kilograms and the crude protein percent is assumed for the sake of argument to be 15%, then maximum milk production would occur at 23.5% crude protein (15 + (1.7/20)*100). Since protein has a positive price, this suggests that this much should not be fed.

Table 8 summarizes parameter estimates for milk prediction equations for heifers and for cows with at least one previous lactation. While variables in the separate equations remained basically the same as the aggregated data, available calories dropped out of the heifer equation, while available protein and available protein squared both dropped out of the older cow equation. R^2 remained high for both equations, 89.6 and 93.4 for heifers and multiparous animals, and the Durbin-Watson test statistics of 2.146 and 2.048, respectively, rejected serial correlation. Comparing input response between the two equations, the change in kg of 4% FCM with respect to an increase of 1 Mcal NEL for heifers was .1323P and for others .1648 + .0669P, with P defined as before. At average P for heifers of 1.88 and 2.21 for older cows, the equations become .248 and .312, respectively. An increase in 1 Mcal of Nel per day would increase daily 4% FCM for that period by .248 kg for heifers and .312 kg for multiparous cows.[4]

The change in milk with respect to a change in protein for heifers can be defined as:

[5] $$\frac{\partial fcm}{\partial P} = 2.1123 + .1323C - 1.528P$$

and for the older cows:

[6] $$\frac{\partial fcm}{\partial P} = .0669C$$

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[4] Due to the lagged variable in the milk prediction equation, this increase would also affect future milk production. An equation describing total increase in 4% FCM from 1 Mcal Nel could be stated as:

$$dfcm/dNel = a \times \sum_{i=1}^{n} x^{i-1}$$

or

$$dfcm/dNel = \frac{x(1 - a^{n+1})}{1 - a}$$

where x is the parameter estimate for the lagged 4% FCM, a is the immediate increase in 4% FCM, and n is the number of periods remaining in lactation. With average available protein, the increase in 4% FCM for the remainder of a lactation for heifers due to a 1 Mcal increase in daily NEL for one period would be:

$$dfcm/dnel = \frac{.248(1 - .63^{n+1})}{.37}$$

and for the older cows:

$$dfcm/dnel = \frac{.312(1 - .59^{n+1})}{.41}$$

Table 8. Equations Explaining Daily 4% FCM kg by Class
3547 Observations

Group Observations	Heifer 1192		Multiparous 2355	
Variable	Parameter Estimate	T-test	Parameter Estimate	T-test
Intercept	21.68326152	10.717	22.34091129	9.882
Previous 4% Fat Corrected Milk	0.63027103	5.013	0.58679513	56.792
Calving date (Jan 1, 1960=1)	0.00011543	18.445	0.00004621	1.850
Days in Milk	0.06229410	7.314	0.05996329	5.525
Natural Log of Days in Milk	-5.73095774	-9.775	-5.52799449	-7.877
Days in Milk Squared	-0.00008203	-6.234	-0.00008288	-4.698
NEL Mcal Available After Maintenance			0.16484559	8.602
CP kg Available After Maintenance	2.11234652	3.641		
Available NEL-CP Interaction	0.13226817	15.813	0.06692902	13.019
Available kg CP Squared	-0.76412898	-5.371		
R-Squared	89.63		93.41	
Durbin-Watson	2.146		2.048	

With average C's of 15.287 and 17.885, daily 4% FCM would be expected to increase for that period by 1.262 kg for heifers and 1.196 kg for multiparous cows with a one kg increase in available protein. The same rules regarding consequences of future milk production that applied to changes in energy also apply to changes in crude protein. However, it can be stated from these two sets of equations that heifers appear less responsive in milk production to increases in energy than older cows, but there is little difference in protein response.

From the models that were run in this section, it would appear to be difficult to predict exactly how much milk a cow would produce and how much dry matter she would eat based on her body characteristics and ration characteristics. However, once there is some knowledge of previous performance concerning dry matter intake within the same lactation, the ability to predict future performance is enhanced greatly. This statement is even more true concerning milk production. Based on dry matter intake and milk production for the previous period, very accurate predictions can be made for 4% FCM. In summary, dry matter intake and milk prediction equations used in this research are based on the theory that input produces output and future outputs and inputs can be predicted with some degree of accuracy based on several variables, not the least of which is previous performance. The premise, then, is that dry matter intake is based on previous dry matter intake, which is based on inherent characteristics of that particular animal. These variables include most prominently the weight of the cow and first period milk production. This is the time at which milk production is least affected by dry matter intake and most affected by genetics and assumed proper conditioning. Once dry matter intake has been predicted over the course of the lactation, milk production can be predicted based on previous milk production and characteristics of the ration, most notably protein and energy.

Predicting Dry Matter Intake and Milk Production

Equations from the previous section will be used to predict dry matter intake and milk production for an individual cow. If future dry matter intake and milk production can be predicted, energy and protein concentrations can be established that will provide nutrients required for a zero or positive energy balance.

In this procedure equations will be assumed to be accurate estimates of occurrences. The first step in using the prediction equations is to select a basic genetic potential for a particular cow and derive first period milk production, period again defined as 28 days. For instance, if a cow is generated that has the potential or characteristics of an 8,000 kg producer over 305 days, expected first period milk production can be estimated using acceptable lactation curves.

Once first period milk is estimated, first period dry matter intake can be generated as a function of milk produced, weight of the cow, and fiber content of the ration. Then, as explained earlier, future dry matter intakes will be predicted, followed by future milk production estimates. For a cow being fed a predetermined diet, this is an easy process. However, complications arise when attempts are made to balance a diet that is based on an estimate of the next period milk production, even if parameter estimates are known, because dry matter intake is affected by energy concentration and a circular function can arise. This problem was corrected by first assuming that first period energy concentration was 1.72 Mcal/kg with 18% crude protein. These numbers were selected from NRC and supported by an ADF-energy relationship derived from the NRC tables. Acid detergent fiber percent was regressed on megacalories of net energy lactation per kilogram for 124 different feeds. This relationship, with an R^2 of 82.6, was expressed as:

[7] $ADF = 85.043 - 37.431NEL$

where ADF is percent acid detergent fiber and NEL is megacalories of net energy per kilogram. With these parameter estimates, a net energy concentration of 1.72 megacalories per kilogram is associated with an ADF percent of 20.7, a fairly realistic minimum for a first period ration. Energy balance was calculated as the difference between input energy and maintenance and milk energy. The energy balance was all assumed to go to changes in weight and this change was added or subtracted from the beginning period weight to compute the end of period weight.

Second period energy and protein concentration for a balanced ration were calculated by using previous period's milk production and previous period's dry matter intake plus ten percent. This generally led to a situation where energy balance for the second period was near zero. Energy for the third period and beyond was balanced using computed beginning of period weight as the weight required for maintenance and previous period dry matter intake and milk production. Since protein concentration did not directly affect dry matter intake, required protein could be and indeed was, calculated after milk production for the period was actually known. This insured that the NRC recommended amount of crude protein for the amount of milk produced was actually in the ration. With a linear relationship assumed between ADF and NEL concentration, a limit of 1.80 Mcal/kg was placed on energy concentration. This was related to an ADF percentage of 17.7, which is close to the minimum recommended by NRC. Since protein content is not directly related to ADF content, no direct constraints were placed on protein. However, by constraining energy and feeding only protein required for maintenance, growth, and milk production, which are reflected in the energy intake, an indirect limit was put on protein requirements.

Most situations, particularly for heifers, require some increase in body weight over the course of lactation. Some of this gain should be planned. From conversation with Holter, it was decided that if proper conditioning was assumed, very little weight gain should be planned for the older cows. A 50 kg gain was decided upon for heifers, with a 5 kg gain planned for cows with previous lactations. This was assuming approximately a 30 kg weight gain over the 60 day dry period. Beginning with the third period, additional amounts of energy and protein (320 g/kg) were added to the ration so that these amounts of body weight gain would be achieved by the end of 308 days.

Tables 9 and 10 trace heifers and multiparous cows through a lactation with a balanced ration. Lower body weights and milk production were used for heifers to reflect the differences in size and milk production that were in the data.[5] Relative to the other set of animals, the recommended ration for heifers maintained a higher concentration of nutrients for a longer period of time, even at lower milk production levels. This can be attributed to the desired extra growth as well as lower dry matter intake, particularly in earlier lactation. Although planned weight gains were 5 and 50 kilograms, actual 308 day weight changes ranged from 14.1 to 16.9 kg for cows with previous lactations and 33.1 to 46.1 kg for heifers. Weight changes beyond 308 days were modest as energy content of the ration was reduced to achieve only a planned energy balance.

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[5] Parameter estimates for calving date were multiplied by 8401, the SAS date for January 1, 1983, the last year of data availability, and added to the intercept.

Table 9. Sample Lactation Data for First Calf Heifers
Three Levels of First Period 4% FCM

Input	Period 1	2	3	4	5	6	7	8	9	10	11
4%FCM	30.0	30.3	29.6	28.6	27.6	26.7	25.9	25.1	24.4	23.5	22.5
Bwt	500	459	450	453	461	472	484	497	509	521	533
CP %	18.0	20.2	19.0	18.5	18.1	17.8	17.4	17.1	16.8	16.5	16.2
NEL	1.72	1.80	1.80	1.80	1.80	1.80	1.80	1.78	1.77	1.75	1.72
ADF%	20.7	17.7	17.7	17.7	17.7	17.7	17.7	18.2	18.9	19.6	20.7
DIM	14	42	70	98	126	154	182	210	238	266	294
DMI	13.7	16.0	16.8	16.9	16.8	16.7	16.5	16.4	16.3	16.2	16.0

Totals	Weight Change (kg)	4% FCM (kg)	Dry Matter Intake (kg)
308 Day	33.1	8238	4995
392 Day	55.4	9831	6251

Input	Period 1	2	3	4	5	6	7	8	9	10	11
4%FCM	25.0	26.3	26.2	25.7	24.8	23.8	22.8	21.8	20.8	19.8	18.6
Bwt	500	470	469	478	491	502	512	521	529	536	543
CP %	18.0	18.7	17.4	17.1	16.8	16.4	16.0	15.6	15.2	14.9	14.6
NEL	1.72	1.80	1.80	1.80	1.75	1.71	1.68	1.65	1.62	1.60	1.57
ADF%	20.7	17.7	17.7	17.7	19.6	20.9	22.1	23.2	24.3	25.3	26.4
DIM	14	42	70	98	126	154	182	210	238	266	294
DMI	12.6	15.2	16.1	16.4	16.4	16.3	16.1	16.0	15.8	15.5	15.1

Totals	Weight Change (kg)	4% FCM (kg)	Dry Matter Intake (kg)
308 Day	42.8	7157	4804
392 Day	52.9	8452	5973

Input	Period 1	2	3	4	5	6	7	8	9	10	11
4%FCM	20.0	22.2	22.7	22.2	21.2	20.1	19.1	18.2	17.3	16.4	15.5
Bwt	500	481	488	503	513	521	528	534	538	543	546
CP %	18.0	16.9	15.7	15.6	15.3	14.9	14.5	14.2	13.9	13.6	13.4
NEL	1.72	1.80	1.80	1.69	1.63	1.59	1.56	1.54	1.52	1.51	1.49
ADF%	20.7	17.7	17.7	21.6	23.9	25.4	26.5	27.3	28.1	28.7	29.3
DIM	14	42	70	98	126	154	182	210	238	266	294
DMI	11.6	14.4	15.5	15.8	15.8	15.6	15.3	15.1	14.8	14.5	14.1

Totals	Weight Change (kg)	4% FCM (kg)	Dry Matter Intake (kg)
308 Day	46.1	6020	4548
392 Day	51.3	7101	5636

Rations balanced on NRC absolute requirements and used to determine
****relationship between 4% FCM and nutrient concentrations****

Table 10. Sample Lactation Data for Multiparous Cows
Three Levels of First Period 4% FCM

Input	Period 1	2	3	4	5	6	7	8	9	10	11
4%FCM	40.0	40.3	39.2	36.7	33.7	30.7	27.7	24.8	22.1	19.5	17.0
Bwt	600	570	572	580	584	588	593	599	604	609	614
CP %	18.0	18.4	18.4	18.6	18.5	18.2	17.6	16.8	15.9	15.0	14.1
NEL	1.72	1.79	1.80	1.76	1.75	1.74	1.71	1.67	1.62	1.57	1.52
ADF%	20.7	18.1	17.7	19.1	19.6	20.0	20.9	22.4	22.4	26.3	28.2
DIM	14	42	70	98	126	154	182	210	238	266	294
DMI	19.8	22.1	22.1	21.2	20.1	19.1	18.2	17.4	16.7	16.0	15.3

Totals	Weight Change (kg)	4% FCM (kg)	Dry Matter Intake (kg)
308 Day	14.1	9289	5824
392 Day	25.6	10322	6983

Input	Period 1	2	3	4	5	6	7	8	9	10	11
4%FCM	30.0	30.5	28.9	26.1	23.2	20.4	18.0	16.0	14.3	12.8	11.5
Bwt	600	591	597	606	608	610	611	612	613	615	616
CP %	18.0	16.0	15.5	15.5	15.2	14.8	14.2	13.6	13.0	12.4	11.9
NEL	1.72	1.64	1.59	1.53	1.50	1.49	1.47	1.46	1.45	1.43	1.42
ADF%	20.7	23.6	25.4	28.0	28.9	29.4	29.8	30.3	30.8	31.4	32.0
DIM	14	42	70	98	126	154	182	210	238	266	294
DMI	17.6	20.3	20.4	19.4	18.2	16.9	15.9	15.0	14.3	13.7	13.2

Totals	Weight Change (kg)	4% FCM (kg)	Dry Matter Intake (kg)
308 Day	15.9	6489	5174
392 Day	20.7	7216	6190

Input	Period 1	2	3	4	5	6	7	8	9	10	11
4%FCM	20.0	21.0	19.8	17.8	15.8	14.1	12.7	11.7	10.8	10.1	9.3
Bwt	600	611	616	620	620	619	617	617	616	616	617
CP %	18.0	13.0	12.8	13.0	12.9	12.6	12.3	11.9	11.5	11.2	10.9
NEL	1.72	1.45	1.41	1.37	1.37	1.38	1.40	1.41	1.41	1.41	1.40
ADF%	20.7	30.8	32.3	33.8	33.7	33.3	32.8	32.4	32.3	32.4	32.7
DIM	14	42	70	98	126	154	182	210	238	266	294
DMI	15.5	18.0	18.0	16.9	15.6	14.6	13.8	13.1	12.7	12.4	12.1

Totals	Weight Change (kg)	4% FCM (kg)	Dry Matter Intake (kg)
308 Day	16.9	4570	4556
392 Day	20.5	5191	5517

Rations balanced on NRC absolute requirements and used to determine
****relationship between 4% FCM and nutrient concentrations****

Comparison of Dry Matter Intake Prediction Equations

Tables 11 and 12 are included to compare dry matter intake under the assumption of a balanced ration with other dry matter intake prediction equations. Table 11 shows comparisons with the equation designed specifically for heifers. Predictions were derived by using a first period milk production of 30 kg and a first period milk production of 20 kg and examining predicted dry matter intake at 42, 98, and 210 days in milk. Relative to other prediction equations, persistency of the derived prediction equation was much higher. Predicted intake early in lactation was somewhat lower than the other equations, but generally increased through time relative to these other equations.

Dry matter intake in equation I in Table 12 was generated by assuming first period milk production to be 35 kilograms and 20 kilograms and again tracing milk production through lactation at 42, 98, and 210 days. The derived predicted dry matter intake from this equation is very comparable to other predictions throughout early lactation, but falls somewhat during later lactation. There are two reasons that contribute at least partially to this. With the exception of the University of New Hampshire equation, allowances are not made for previous lactations. Dry matter intake tends to be more persistent in heifers, which is not reflected in this particular derived equation.

The second contributing factor in this drop is the increase in recommended fiber content of the ration. For energy balance to be achieved, energy content of the ration must be decreased, with a subsequent increase in ADF percent. Because dry matter intake is maximized in these equations at approximately 17% ADF, the increase in the fiber content suppresses dry matter intake. In a ration with a constant fiber content, dry matter intake would not decrease to the same extent that it does in this example.

Table 11. Comparison of DMI Equations for Heifers

Predicted Dry Matter Intake (kg)

Equation Number	A	B	C	D	E	F	G	H	I	J
	Source Code									
1	16.20	17.10	17.75	18.05	14.53	17.51	17.51	16.27	16.03	15.99
2	18.04	16.42	17.11	17.37	14.20	17.73	16.85	15.65	16.93	16.90
3	19.32	16.65	17.09	17.24	15.01	17.38	16.87	16.45	16.68	17.16
4	12.51	14.47	15.01	15.02	14.02	15.39	14.69	14.49	14.38	14.08
5	16.13	15.62	16.07	16.13	14.79	16.80	15.83	15.72	15.84	16.03
6	16.79	14.97	15.42	15.34	15.16	15.74	15.19	15.60	15.07	15.61

Key

Equation Number	Days in Milk	Body Weight (kg)	4% Fat Corrected Milk (kg)
1	42	460	30.3
2	98	454	28.6
3	210	497	25.9
4	42	481	20.0
5	98	503	22.2
6	210	534	18.2

Source of Dry Matter Prediction Equation

A = TRUE NRC
B = MICHIGAN STATE (NEW)
C = CORNELL
D = PENN STATE
E = MINISTRY OF AGRICULTURE
F = UNIVERSITY OF NEW HAMPSHIRE
G = HALBERT
H = MICHIGAN STATE (OLD)
I = DERIVED EQUATIONS ASSUMING BALANCED RATIONS
J = BROWN

Table 12. Comparison of DMI Equations for Multiparous Cows

Predicted Daily Dry Matter Intake (kg)

Equation Number	Source Code A	B	C	D	E	F	G	H	I	J
1	19.41	21.88	21.53	21.83	18.04	21.96	21.54	21.01	21.26	18.27
2	20.51	20.76	20.51	20.69	17.97	21.59	20.51	21.28	20.46	19.13
3	18.07	16.89	17.21	17.09	17.14	17.98	17.12	18.18	16.17	16.82
4	14.25	17.48	17.71	17.63	17.38	17.07	17.65	18.74	18.04	15.63
5	17.09	17.78	17.98	17.91	17.52	18.28	17.92	19.04	18.22	17.14
6	15.83	14.82	15.50	15.52	16.74	15.55	15.37	16.52	13.98	14.90

Key

Equation Number	Days in Milk	Body Weight (kg)	4% Fat Corrected Milk (kg)
1	42	580	35.4
2	98	594	31.2
3	210	607	19.6
4	42	611	21.0
5	98	614	21.7
6	210	615	13.5

Source of Dry Matter Prediction Equation

A = TRUE NRC
B = MICHIGAN STATE (NEW)
C = CORNELL
D = PENN STATE
E = MINISTRY OF AGRICULTURE
F = UNIVERSITY OF NEW HAMPSHIRE
G = HALBERT
H = MICHIGAN STATE (OLD)
I = DERIVED EQUATIONS ASSUMING BALANCED RATIONS
J = BROWN

Further comparisions of dry matter intake equations are demonstrated in Figure 1. This figure mathematically states the equations that were compared in the previous table.

Derivation of dry matter intake equations from this research is explained in detail later, but basically it entails predicting dry matter intake and milk production based on different combinations of starting weights and milk productions and, since intake is dependent on ration content, an assumed balanced ration. Dry matter intake was then made a function of several forms of days in milk, body weight, previous period fat corrected milk, and an interaction between fat corrected milk and days in milk. Changes in dry matter intake associated with a change in milk ranged from approximately .1 to .35 kg of dry matter intake for each kg of milk change for the various equations. For the derived equations, the parameter estimate for heifers was about .21 and .27 at 100 and 300 days in milk, respectively, and .24 and .30 kg of dry matter intake for each kg of milk change for the older group of cows.

Recommended Feeding Concentrations

The intricacies of balancing a ration for one cow in this project were described earlier. While these difficulties were overcome with the introduction of some minor assumptions relating to energy concentration in early lactation, balancing a ration for a group of cows provided difficulties exceeding those of an individual cow. These problems arose from having dry matter intake and milk production based on ration characteristics, while at the same time having ration characteristics based on milk production and dry matter intake. To compound the problem, previous period milk production affected current period milk production, and previous milk production was affected by dry matter intake,

Figure 1. Comparison of Dry Matter Intake Prediction Equations

[1] $$DMI = -4.5236 + 0.06292xBWT^{.75} + 0.000675xBWT + 0.17871xMilk + 5.0535xfat + 0.0698x\,\dim - 0.00017309x\,\dim^2$$

[2] $$DMI = 0.11046xBWT^{.7} + 0.004069xFCMxBWT^{.7}$$

[3] $$DMI = 0.0185xBWT + 0.305xFCM$$

[4] $$DMI = 0.0175xBWT + 0.33xFCM$$

[5] $$DMI = 0.025xBWT + 0.1xMILK$$

[6] $$DMI = -36.361 + 4.6177x\ln(BWT) + 5.593x\ln(FCM) - 0.02166x\,\dim + 0.0000204x\,\dim^2 + 1.9678x\ln(\dim)$$

[7] $$DMI = -7.96 + 0.00379xBWT - 0.00002216xBWT^2 + 0.48086xFCM - 0.00205xFCM^2 + 0.02519x\,\dim - 0.00006427x\,\dim^2$$

[8] $$DMI = -1.339 + 0.02024xBWT + 0.3149xFCM$$

[9] $$DMI = 0.02xBWT + 0.000507xBWTxFCM$$

[10] $$DMI = -18.2822 + 0.1798xFCM - 0.0137x\,\dim + 1.1628x\ln(\dim) - 0.0000029x\,\dim^2 + 0.0000083xBWT^2 + 4.7586x\ln(BWT) - 0.0131xBWT + 0.0003x\,\dim\,xFCM$$

[11] $$DMI = -30.1798 + 0.2094xFCM - 0.0252x\,\dim - 0.7775x\ln(\dim) + 0.0000381x\,\dim^2 + 0.0000124xBWT^2 + 9.0694x\ln(BWT) - 0.0250xBWT + 0.0003x\,\dim\,xFCM$$

[12] $$\ln(DMI) = .519776 + .339220x\ln(MILK) + .099266xFAT - 0.000827x\,\dim + 0.148073x\ln(\dim) + 0.000675xBWT^2 + 0.018001xCF - 0.000557xCF^2$$

ln = natural log
DMI = Dry Matter Intake (kg)
DIM = Days in milk (kg)
BWT = Body Weight (kg)
FAT = Butterfat (kg)
FCM = 4% Fat Corrected Milk (kg)
Milk = Milk kg
CF = Crude Fiber % of Dry Matter

[1] NRC
[2] Michigan State
[3] Cornell
[4] Penn State
[5] Ministry of Ag
[6] University of New Hampshire (heifers)
[7] University of New Hampshire (others)
[8] Halbert
[9] Michigan State (old)
[10] Derived equations (heifers)
[11] Derived equations (others)
[12] Brown

which was a function of energy concentration, which was a function of nutrient requirements of the cow and the rest of the cows in the group. This circular function would eventually approach a limit, but the approach could be time consuming.

A solution to this problem could have entailed feeding a group ration that was not dependent on nutrient requirements of the group. However, since one of the goals of the research was to determine a factor with which to balance a ration for the group, with the factor based on a balanced ration for the group average, this idea was discarded. Another possible solution, and the one selected, was to determine a linear relationship between characteristics of the cow and nutrient requirements as determined with the described method. An even simpler solution from the dairy producers point of view would be to base recommended nutrient concentrations for the next period on FCM of the current period. While not as precise as including all the previously mentioned variables, this method enables a readily obtainable figure to be used in determining recommended nutrient concentrations for a single cow, with the average of recommended concentrations to be used in feeding a group of cows. Nutrient concentrations that were recommended based solely on FCM were also the ones that were used in determining optimal grouping strategies. While these results were used in the simulation discussed in the following section, they will not be presented until Chapter 4.

Simulation

The prediction equations and methods for dry matter intake and milk production introduced earlier in this section were used to predict these same variables in the simulated dairy herd. Different grouping and feeding strategies, based on combinations of recommendations obtained from the first objective, were used to feed the 100 cow herds. In this, the second procedure, variation about the predicted dry matter intake was also introduced. It needs to be emphasized that the purpose of the simulation was not to recreate an entire farm situation, but only dry matter intake and milk production in cows that were fed either individually or in group situations. This approach allowed for analysis of milk production response to different feeding regimes. As an example, survival rate of replacements was assumed to be independent of feeding practices and not considered in the simulation. There are, of course, specific herd characteristics that will affect total milk production. Some of these characteristics will be discussed with the overview of the simulation.

Estimating Herd Characteristics

Factors that could affect total herd milk production in this simulation include genetic potential of the herd, variation of genetic potential within the herd, calving intervals, percent of heifers in the herd, and body weight. Since the purpose of the simulation was to create data at both the endpoints and midpoint of a spectrum of possibilities, it was not essential that the assumed average, or midpoint, of data reflect the true average with complete accuracy. Not only would this be difficult, but conditions and averages are constantly changing. It is, however, important to estimate the midpoints, or averages, of pertinent herd characteristics with a certain amount of accuracy so that the simulation will include statistics that are reflective of prevailing conditions. Data on these characteristics were primarily obtained from the Virginia Dairy Herd Improvement Association (DHIA), although other sources were occasionally used.

Herd production level

The easiest form of measurement in speaking of the production or genetic potential of a herd is to assume that average potential of the herd is reflected by average milk production of the herd. The March 1989 DHIA summary was used to obtain records for average 305 day mature equivalents of herds on test in Virginia. Averages for heifers were 8149 kg of milk and 286 kg of fat, while for cows with previous lactations these numbers were 8541 kg and 300 kg, respectively. Overall, the averages read 8388 kg of milk and 295 kg of fat. Transformed into 4% FCM by multiplying milk kg by .4 and fat kg by 15, heifers averaged 7553 kg and older cows 7830 kg, for an overall average of 7740 kg. Therefore, one of the assumptions that was used in the simulation was that mean herd production average was 7740 kg of 4% FCM.

Since within herd variation of nutrient requirements could have an impact on a grouping decision, information on variation of milk production within a herd was collected. Van Vleck (57) found standard deviation of temporary herd effects, permanent cow effects, and temporary cow effects for milk production to be 489 kg, 471 kg, and 666 kg, respectively. By summing the variance of these effects and taking the square root, the standard deviation of within herd effects was taken to be 951 kg.[6] McGilliard (35) estimated these figures to be 528 kg, 528 kg, and 725 kg, respectively. By the same method, standard deviation of these effects was 1041 kg. Butcher (6) found the standard deviation of annual milk production within a herd in his study to be 1135 kg, while a regional study (60) found this number to be slightly higher at 1270 kg. Based on these studies, and a correspondence of 1134 kg to 2500 lbs, 1134 kg was selected as the average standard deviation for the simulation.

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[6] This assumes covariances of zero.

Lactation number, Calving intervals, and Body weight

In earlier sections, dry matter intake, milk production, and nutrient concentrations were separated into either heifer or multiparous categories. The percentage of heifers in a herd will affect these three variables, necessitating an estimate of this percentage. From the March 1989 DHIA sheet (58), 32.4% of the cows in the herd were reported to be in their first lactation. DHIA was also the source of an estimate of calving intervals. The average calving interval for cows on record in the state of Virginia is 13.46 months, with a standard deviation of .91 months. This translates in days to 391 and 28, respectively, and forms a basis for assumptions to be made later.

The final characteristic to be discussed is weight of the animals. This creates differences in individual cows in the simulation in two manners. Maintenance requirements are higher for larger animals, and second, larger animals tend to have higher dry matter intakes. Recalling that body weight changes and consequently body weights throughout lactation will be based on previous weights, it is necessary only to estimate beginning lactation weight. Holter's data provided this source. Average first period weight for heifers was 504.5 kg with a standard deviation of 53.1 kg, while average weight for older animals was 589.6 kg with a standard deviation of 58.1 kg.

The figures that have been reported all played a part in the simulation. Some were used as assumptions, while others were used as guidelines when the effect of a certain herd characteristic was varied. Explanation of the use of these numbers is contained in the following section.

Model Construction

The purpose of the simulation was to reconstruct the original lactation and body weight data under different conditions. The approach to the simulation was therefore similar to the approach taken in the data analysis. A cow was generated at calving (her time zero as opposed to time zero in the simulation). Based on first period milk production, as well as body weight and fiber content of the ration, first period dry matter intake was predicted. After the first period, the roles of milk and dry matter intake were switched in the prediction process and milk production was no longer a variable directly affecting dry matter intake. In each subsequent period, dry matter intake was based on previous dry matter intake, as well as days in milk and fiber content of the ration. Predicted milk production was derived from days in milk, previous milk production, and energy and protein remaining after maintenance allotments. Parameter estimates for milk production and dry matter intake have already been detailed. The process of the model construction and the numbers that were used in the building of the model will now be described.

Daily milk production and dry matter intake were generated and recorded in terms of 28 day periods. These predictions were assumed to occur on day 14 and remain constant throughout the period so 28 day total was the daily prediction times 28. All freshenings were assumed to occur on the first day of a period. No milk was discarded for any reason. Therefore, dry matter intake and milk production for the first period were totalled as if they occurred over the entire period.[7]

[7] The discarding of milk for any reason is another event that is presumed to be independent of the grouping mechanism. Although this may not be true, as a two group situation may have healthier animals than a one group situation, it certainly goes beyond the scope of the data to determine this relationship.

To start the simulation, a 100 cow herd was created at time zero. Initial generation of the herd consisted of creating a cow and repeating the process 99 times. With the use of the random number generator available in Turbo-Pascal, each time a cow was created there was a 32.4% chance that the cow was a heifer. If the random number was greater than .324 the created animal was considered to have had at least one previous lactation. If the random number was less than or equal to .324, a heifer was created. The type of animal affected the beginning weight of that animal since mean heifer weight was 85 kg less than the mean starting weight for older cows. Starting weights were randomly assigned so that mean heifer weight was 504.5 kg with a standard deviation of 53.1 kg, leaving 68% of the observations between 451.4 kg and 557.6 kg, 95% of the observations between 398.3 kg and 610.7 kg, and so on as would describe a normal distribution. Starting weights for older cows were similarly generated with a mean weight of 589.6 kg and a standard deviation of 58.1 kg.

Another assigned characteristic to the newly generated cow was a calving interval. As described earlier, average calving interval for cows on test in Virginia was 391 days with a standard deviation of 28 days. It was assumed that there would be no difference between primiparous and multiparous cows in the expected value of this figure. To test the effect that a larger or smaller herd calving interval might have on the grouping decision, three calving interval lengths were used in separate analyses. The figure for the intermediate calving interval was the state average, while the high level was assigned a mean 20 days above this number (411 days) and the low level 20 days below (371 days). Standard deviation was assumed 28 days for each of these levels. Calving intervals were randomly assigned with a normal distribution and then rounded to the nearest 28 days so that calving intervals could be referred to in periods rather than days. It could be argued that assignment of calving intervals at parturition does not reflect the event as it occurs on the farm. However, this method can be effectively used to model an actual situation. In this case, it matters not how many times the cow was inseminated, or with which bull's semen. It only matters that lactation will end two periods short of the number of periods in the calving interval and that another fresh cow will be generated after the last period in the calving interval has been completed.

Another number that was generated at time zero for the individual cow was 305 day FCM, which was used to determine first period milk production. This process involved multiple steps with the generated number being affected by several variables. These variables included age of cow (whether or not she has had previous lactations), herd average, and standard deviation of within herd 305 day FCM. By working backward with equations used to extend records to 305 days, an estimate of first period milk production can be based on generated 305 day FCM.

Dairy Guideline 404-355 was printed for the purpose of extending cow records to 305 days (7). A cow's projected record can be calculated by the formula:

[8] $$A + (B \times C)$$

where A is the milk produced to date, B is the days remaining to 305 days in milk, and C is estimated average daily production remaining. C can be calculated by the formula:

[9] $$C = \{[J + (K \times \text{Days in Milk})] \times \text{most recent test day yield}\}$$

$$+ \{[L + (M \times \text{Days in Milk})] \times (\text{herd average}/1000)\}$$

J, K, L, and M are values that can be found in a table specific for breed and region. From this table, numbers can be found that apply specifically to either heifers or older cows, and factored according to season of breeding and days in milk. Although the table was constructed in conjunction with formulas to extend records to 305 days, if 305 day production is known, milk production on day 14 can be computed. By disregarding heifer seasonal factors and taking the average of the four seasons for each of J, K, L, and M, from the original formula A is equal to 14X and $B \times C$ is equal to $133.7669X + 372.5178 \times$ herd average/1000, where X is milk production on day 14. Moving milk production on day 14 to the left hand side of the equation, for heifers the formula is:

[10] $X = (\text{Total 305 day milk} - 372.5718 \times \text{herd average}/1000)/147.7669$

Through the same line of reasoning, the formula for the older cows is:

[11] $X = (\text{Total 305 day milk} - 418.3969 \times \text{herd average}/1000)/132.3628$

To solve for first period milk production, numbers must be substituted for the two variables on the right hand side of the equations.

From the DHIA sheets, it was seen that the overall average 305 day mature equivalents were 7740 kg, with heifers being 187 kg below this figure and the remaining cows 90 kg above. These numbers imply that the average older cow will be 277 kg above the average heifer. Three levels of herd producton levels were used in the simulation. The medium level, 7711 kg, reflects the average herd production of those on test in the state of Virginia. To represent high and low herd averages, 1134 kg was added to or subtracted from this figure. Therefore the high producing herd was assumed to average 8845 kg per cow per 305 day lactation, and the low producing herd 6577 kg. For each of these herd averages, expected 305 day yield for a heifer was 187 kg below herd average and expected 305 day yield for the older cows 90 kg above. From the previously presented information on the variation of milk production within a herd, an average standard deviation of 1134 kg within the herd was assumed. To test how variation of milk production within the herd might affect the optimal grouping solution, a high and low level of variance was also applied to the simulation. These numbers were 1587 kg and 680 kg, respectively. Applying the herd average and within herd standard deviation, a 305 day total for the individual cow could be generated and the formula used to calculate first period average daily FCM.

The three levels of within herd standard deviations, three levels of calving intervals, and three levels of average herd milk production combined for a total of 27 runs at any given feeding level for each of the one group, two group, three group, four group, and individually fed situations.

Beginning the Simulation

A typical approach to a simulation problem such as the one that was being investigated would be to create a herd at time zero and predict dry matter intake and milk production for each of the grouping scenarios at progressive time intervals. However, with predicted milk production and dry matter intake based on previous dry matter intake and milk production, the starting point (time zero) must be based on previous data. Therefore, although data were not collected and summarized until the first period after time zero, there were events in the simulation occurring before time zero. For each of the 100 cows, days in milk was assigned a random number between zero and the cow's previously determined calving interval.[8] Once again, this number was divided by 28 and

[8] There has been research to indicate that the assumption of randomly spaced calving dates is not valid for all herds. Norman et al. (44) in a study of 3,386,876 freshening dates found 54% of the parturitions to occur in the months of August through December, the five busiest months of freshening. This was in part corroborated by the March 1989 Virginia DHIA summary which indicated a larger number of cows to

rounded to translate days into periods. The cow's milk production and dry matter intake were predicted and recorded for the number of periods that the cow had been in milk prior to time zero of the simulation. Since data for the entire herd was not available prior to time zero in the simulation, it was assumed that the cow was fed her individually recommended diet in this time frame.

Although the simulation was started one cow at a time, an understanding of the concept may be enhanced by an overview through time. At a point that represented the largest generated number of days in milk the first cow or cows joined the herd. For example, if at time zero, the highest days in milk was 420, or 15 periods, the first cow or cows would join the herd 15 periods prior to time zero. The time frame previous to time zero that the cow joined the herd was dependent on the randomly generated length of time since freshening for that particular cow. Once the cow entered the herd she was fed according to the individual recommendations that were established earlier. At each period previous to time zero, another cow or cows joined the herd, so that herd size increases over time. By time zero, all 100 cows have joined the herd, with some as dry cows. If there was more time since freshening than two periods less than the calving interval, the cow was considered dry and milk production and dry matter intake were set at zero.[9] All cows had records for calving interval periods and periods in milk, and all lactating cows had records for previous dry matter intake, previous milk production, and body weight.

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calve in July, August, and September than April, May, and June. This same data sheet indicated an even distribution of the days in milk, but the culling of cows in later lactation may influence this and underestimate the number of cows that freshened 200-305 days previous. Nevertheless, a random distribution of days in milk was assumed since seasonal effects of days in milk were ignored in both dry matter intake and using 305-day adjusted cow records to predict first period milk production. The possible effect of a violation of this assumption is discussed later.

[9] Dry matter intake was considered zero because dry cow feeding was assumed to be independent of the grouping process.

After the 100 cows were generated and records established at simulation time zero for them, recording of data in the simulation process began. Dry matter intake and milk production were predicted from equations described earlier. The process of predicting dry matter intake and then milk production for each period continued for an individual cow until she completed her designated number of calving interval periods minus two, which represented the dry period. Once the cow has completed the two periods that she was considered dry, a new cow was generated that was completely independent of the previous cow and had a 32.4% chance of being a heifer.

One of the major differences between the time frame in the simulation that data were being collected and the time frame prior to their collection was that in the latter case the simulation of one cow was completed before the next cow was generated. In the former situation, all cows in a time period were completed before the next time period was started. Another difference was that after time zero the cows were fed according to group recommendations rather than individual recommendations, except of course when data were collected on individual feeding. A final difference in these two techniques was that there was no deviation from predicted occurences prior to time zero. In the later portion of simulation, randomness was introduced to reflect unexplained variation in the prediction models.

Introducing Random Variation

Randomness was introduced into first period milk production by random variation from total 305 day milk yield. This does not describe daily or even monthly variation between cows, but reflects the difference in projected 305 day milk production between different cows in the same herd. All cows of the same class (primiparous or multiparous) that have the same 305 day projected milk yield will have the same first period milk yield. Future milk production can be expected to be different as other factors enter the model, but no randomness for future milk production was directly introduced into the simulation model. Recalling that variables in the milk prediction model explained approximately 95% of the variation in the dependent variable, it was felt that introduction of an error term would not add much realism and could create problems in that a direct correlation between one period of milk and the next period dry matter intake would need to be established.

Randomness was introduced into dry matter intakes by using the mean square error in each period of the prediction model as an estimate of the variance. The predicted observation in the absence of randomness served as the mean, while the standard deviation acted as a measure of variation about the mean. Table 13 lists the mean square error for dry matter intake for each of the periods. The predicted column in the table is the estimate of the variance that was actually used in the simulation. These predictions were established by regressing the variance on time periods 2 through 11. For heifers, variance was described as:

$$MSE = -.36280 \times Period + .02634 \times Period^2 + 2.0945$$

and for older cows:

$$MSE = .16265 \times Period + 12.03916/Period - 1.3383294$$

where Period is the 28 day period. For period one, variance was the constant 2.66174 for heifers and 4.98346 for older cows. For periods beyond 11, variances were obtained by dropping the first eleven periods and re-estimating the dry matter intake equation. These estimates were 1.90810 and 2.13528, respectively.[10]

Correlations between randomness in dry matter intake and milk production had been established by the nature of the entire model. First period dry matter intake was influenced by first period FCM. A higher than expected dry matter intake in the first period would be associated with higher than expected dry matter intakes in succeeding periods. Second period milk production was partially dependent on second period dry matter intake. If dry matter intake was higher than expected, expected milk production would be higher than that predicted from the models in the absence of randomness. Since future milk production is based on future dry matter intake as well as previous milk production, both these factors tend to increase future milk production of any particular cow. If dry matter intake in the first period was lower than expected, the entire situation is reversed.

Additional Constraints

Several final assumptions in the simulation needed to be added, primarily to ensure that there would be some bounds on the data. Recommended crude protein percentages from NRC range from 12% to 19%. These numbers were used as restrictions to the range of recommended protein concentrations. Under no circumstance would a ration be fed that contained protein concentrations outside of this range. Similarly, energy concentrations were established between 1.35 and 1.76 Mcal/kg. This is slightly wider

[10] Variances were different for the first period due to a different equation being used to predict first period dry matter intake. Variances were different in later lactation because if days in milk was higher than 308, dry matter intake equations were re-estimated for periods greater than 11 and these equations used to predict dry matter intake for the remaining time in lactation. This is explained in the section pertaining to additional constraints.

Table 13. Estimate of Daily DMI Variance by Period (kg squared)

Period	Heifers		Older Cows	
	Estimated	Predicted	Estimated	Predicted
1	2.66175		4.98346	
2	1.48247	1.47426	5.01822	5.00655
3	1.39082	1.24316	3.17354	3.16268
4	.91522	1.06474	2.20140	2.32206
5	.83683	.93900	2.02667	1.88275
6	.80498	.86594	1.71377	1.64410
7	.96587	.84556	1.32493	1.52010
8	.75664	.87786	1.23535	1.46777
9	1.27700	.96284	1.93696	1.46320
10	1.23810	1.10050	1.18008	1.49209
11	.81967	1.29084	1.97930	1.54529
12	1.70999	1.53386	1.33316	1.61673

Note: Estimated from Mean Square Error in dry matter prediction equation
Predicted from regressing MSE on time

than limits from NRC, 1.42 to 1.72 Mcal/kg. The upper limit was selected because of its correspondence to 19% ADF from the previously discussed relationship between fiber and energy concentration. Although this was less than that used in deriving milk production and dry matter intake predictions, it was felt that 1.80 Mcal/kg would be difficult to achieve continuously on a practical basis for the average farm without consistently high quality forages. The bottom figure, 1.35 Mcal/kg, was selected simply as a floor that corresponded approximately with recommendations of an older cow giving 10 kg of 4% FCM, the same figure that NRC uses. A heifer would have to give less than 6 kg of milk for this constraint to be activated.

All cows in their first period of milk production had recommended concentrations of 1.72 Mcal/kg of energy and 19% crude protein. Since cows in the final period of lactation would not be milking the next period, they did not have any influence on feeding recommendations for the upcoming period. By the same reasoning, cows that were not in lactation but due to freshen next period would affect group feeding recommendations.

A constraint on dry matter intake was added due to the lack of data in later lactation. While the model apparently predicted dry matter intake fairly well during the first 11 periods, there was reason to believe that the model underestimated persistency in later periods. For cows with extended lactations, it was quite common for predicted dry matter intake to be so low as to not support maintenance during late lactation. Rather than having a minimum dry matter intake, it was felt that the dry matter intake equation could be re-estimated beyond the 11th period. Due to lack of data and relatively small intake that was prevalent at that late time in lactation, dry matter intake was estimated only as a function of the previous dry matter intake. Excluding the first ten periods of data allowed for 360 observations for the older cows and 185 observations for the heifers. When the intercept term was dropped, the parameter estimate describing dry matter intake as a function of previous dry matter intake was .967 for heifers and .963 for the other class of animals. The R^2 for each of these two models was 99.2. Figure 2 summarizes assumptions and constraints that were used in the simulation and described in this chapter.

Optimal Group Sizes

One of the goals in the grouping process was to minimize variation in nutrient requirements within the group. This could come from either a policy of equal group sizes or unequal group sizes. It was felt that equal group sizes in the simulation would best reflect minimization of the variance of nutrient recommendations as well as be closest to procedures most frequently practiced on commercial farms. However, if there was overwhelming evidence to indicate that a policy of equal group sizes would not minimize this variance, a different policy regarding group sizes should be examined.

The standard deviation of energy requirements was analyzed at the beginning of the first time period for each of the three levels of calving intervals, production averages, and variation of production average, for a total pool of 27. Various grouping strategies were tested to see which minimized total variation of within group energy recommendations. For a two group system, groups were divided 20%-80%, 30%-70%, 40%-60%, 50%-50%, 60%-40%, 70%-30%, and 80%-20%. For a three group system, the high group was analyzed at 10%, 20%, 30%, and 40%. The middle group could be 20%, 30%, 40%, or 50%, with the low group the sum of the first two groups subtracted from

Figure 2. Summary of Assumptions Used in Simulation

Category	Assumption	Source
First heifer weight	Mean 504.51 kg, SD 53.05 kg	Holter data
First multiparous weight	Mean 589.61 kg, SD 58.06 kg	Holter data
Heifer dry matter intake after 308 d in milk	96.7% of previous dry matter intake	Holter data
Multiparous dry matter intake after 308 d in milk	96.3% of previous dry matter intake	Holter data
CP recommendations	Maximum 19% Minimum 12%	Adjusted from NRC
NEL recommendations	Maximum 1.76 Mcal/kg, Minimum 1.35 Mcal/kg	Adjusted from NRC
% heifers in herd	32.4%	Virginia DHIA
Heifer 305 ME 4% FCM	7,533 kg	Virginia DHIA
Other 305 ME 4% FCM	7,830 kg	Virginia DHIA
All 305 ME 4% FCM	7,740 kg	Virginia DHIA
Calving Intervals	Minimum 360 d	
High	Mean 430 d, SD 29 d	Adjusted from Virginia DHIA
Medium	Mean 410 d, SD 29 d	
Low	Mean 390 d, SD 29 d	
Standard deviations within herd-305 day		
High	1587 kg	Van Vleck, McGilliard, Butcher
Medium	1134 kg	
Low	680 kg	
Herd production level		
High	8845.2 kg	Adjusted from Virginia DHIA
Medium	7711.2 kg	
Low	6577.2 kg	

100%. For the four group system, only two grouping strategies were analyzed. The first of these placed equal numbers of cows in each group. The second placed 10% of the cows each in the high and low group, with the remaining 80% divided between the other two groups.

The total pooled variance of within group recommended energy concentrations could be described by the formula:

$$[12] \qquad \frac{[(n_1 - 1)MSE_1 + (n_2 - 1)MSE_2]}{(n_1 + n_2 - 2)}$$

where MSE_n is mean square error of group n, the estimate of within group variance. Although there were only two terms in this model, the number of terms correspond to the number of groups of cows that were fed in any particular situation.

With a two group strategy, a total of 189 variances were examined from 27 herds and 7 grouping combinations. In the three group system, 432 variances were examined from the 27 herds and 16 grouping combinations. After selecting the grouping strategy in the two group system that minimized the total variance, on the average the high group had 50% of the cows and the low group had 50% of the cows. Using the same analytical technique for the three group system, the average portion of the herd in the high group was 31.4%, with the lower groups averaging 38.9% and 29.7%, respectively. With a four group system, a total of 54 variances were examined, two for each of the 27 herds. With only two grouping combinations possible, rather than averaging the number of cows in each group, a tally was kept regarding grouping strategy that would minimize total variance. In 14 of the 27 herds, groups with equal size minimized total variance of within group nutrient recommendations.

Since there has been some research to indicate that time of calving may have some seasonal trends, it was decided to determine grouping strategies that minimized total variance in recommended energy concentrations when calving did not occur equally spaced throughout the year. From Norman (44), 54% of calvings occurred in five months of the year. Days in milk in the simulation was therefore set so that 54% of cows were fresh less than 140 days, or five periods. Strategies to minimize total variance of recommended energy concentratons were then examined as before. In a two group system, the average percentage of cows placed in the high group was 54%, with 46% being placed in the lower group. The three groups system was divided with an average of 34.4% of the cows in the high group, 38.1% in the middle group, and 27.5% in the low group. With the four group feeding plan, equal sized groups minimized variance 16 times, while the 10-40-40-10 system minimized the variance 11 times.

These results were fairly similar to those obtained with equal calving throughout the year. While they certainly did not prove that equal sized groups would minimize total variance of nutrient recommendations, they did give support to the premise. The results seemed to suggest that equal size groups might be best for planning purposes, but actual grouping should be based on production with a constrained range of group sizes as possibilities.

Grouping and Feeding

The system of generating cows and predicting milk production and feed intake was described in the previous section. The system of grouping and feeding cows will now be detailed.

After cows were generated and brought to time zero, simulation and recording of data began. Analyses were run for individual feeding, one group, two groups, three groups, and four groups of cows. For individual feeding, each cow was fed the protein and energy concentration that was recommended from the previous period, unless of course the cow was in her first period of milk production when energy and protein concentrations were set to 1.72 Mcal/kg and 19%, respectively. Data were collected for energy and protein concentrations, dry matter intake, weight change, and milk production for each cow. This process was repeated for 50 time periods, at which time the simulation ended. To collect data on lactations, information was stored on each cow as she completed her lactation. This included data on total dry matter intake, total 4% FCM, and total weight change over the course of lactation.

In a one-group situation, all cows were fed the same diet. Therefore, protein and energy concentration, body weight change, and dry matter intake were collected only for each period, not each cow in each period. Records were also kept on the number of cows gaining and losing weight. At the end of a period, recommendations for nutrient concentrations for individual cows were totalled and divided by the number of cows that were included in the recommendations. Excluded cows were those in their last period of lactation or first dry period. The average recommendation was used as a basis for feeding the group in the next time period.

Standard deviation of recommended diets was also calculated. Rules regarding numbers that were used to compute the standard deviation were not completely the same as the rules used to compute the average. In calculating the standard deviation, figures used were those recommended with constraints of upper and lower limits. In averaging, figures were used without these constraints. An example may best present the logic behind this apparent inconsistency. If there were only two cows in the group and one was recommended an energy concentration of 1.90 Mcal/kg and the other 1.50 Mcal/kg, the average of these two, with constraints, would be (1.76 + 1.50)/2 , or 1.63 Mcal/kg. The higher producing cow would be underfed by .27 Mcal/kg, while the lower producer would be overfed by only .13 Mcal/kg. The lower producing cow exerted more influence on the final recommendation than the higher producing cow. However, to use unconstrained recommendations to calculate the standard deviation would paint a false picture of variation in actual recommended dietary concentrations. In a multiple group situation, unconstrained recommendations may vary from 1.76 Mcal/kg to 1.91 Mcal/kg, but actual recommendation would be 1.76 Mcal/kg for each cow. To compute standard deviation using figures without the constraint would imply that there was variation in the recommended group concentrations and that this number varied about the mean of 1.76. In actuality, there was no variation below the recommendation, only above it, and it did not influence the final recommendation.

Two, three, and four group strategies followed similar patterns. The main difference between these and the one group system is that the cows had to be grouped at the end of each period for the next period. Cows were sorted by recommended energy concentration, which was based solely on milk production and class of cow, with a secondary sort using protein concentration. Once a cow moved to a lower group, she was not allowed to move back to a higher group. This was to prevent borderline cows from bouncing back and forth between groups. With this as the only restriction, cows were divided into groups of equal size. Recommendation averages and standard deviations were computed for each group in the same manner as the one group system. Cows were fed the next period according to group recommendations.

To test the importance of following feeding recommendations, different group feeding levels were also tested based on standard deviations. Besides following group recommendations exactly, runs were made overfeeding average group protein recommendations by one-half the group standard deviation, underfeeding energy by one-half standard deviation, and finally underfeeding both energy and protein by one-half standard deviation. Since planned weight gains were used in derivation of recommended energy and protein concentrations, it was decided to forego any testing of increased feeding beyond that already mentioned. The additional four feeding levels, with the previous 27, made for a total of 108 runs for each of the one, two, three, and four group scenarios. With no group standard deviations with individual feeding, there were only 27 simulation runs. What remained at this point was to analyze the 479 herds and determine the extent of the factors affecting the relationship between dry matter intake and milk production. Once this relationship has been established, economic analysis of grouping and feeding strategies could be achieved.

Chapter IV

RESULTS

This chapter not only reports results regarding the economics of grouping, but results of several required intermediate steps that would have practical applications to a dairy. These intermediate steps pertain to recommended feeding concentrations to achieve a slightly positive energy balance as well as predicting response to changes in grouping and feeding policies. The final results deal with economic implications of different feeding levels and group numbers for dairy herds of various characteristics.

Recommended Feeding Concentrations

Chapter 3 described techniques for balancing a ration for an individual cow by predicting dry matter intake and milk production for a 28 day period. To review briefly, this involved generating first period milk production and estimating dry matter intake for that period from the appropriate prediction equation. First period nutrient concentrations were assumed to be 1.72 Mcal NEL/kg and 19% crude protein. A ration was balanced for absolute nutrients in the second period by assuming a 10% increase in dry matter intake and using the previous period milk production. The ration was balanced in the third period and beyond by using both the previous period milk production and dry matter intake. Additional energy and protein were added to the diet so heifers could gain a planned total of 50 kg of body weight and multiparous cows 5 kg of body weight by the end of 308 days, or 11 periods. To place some restrictions on energy content of the ration, a maximum of 1.80 Mcal/kg of NEL was allowed after the first period. Since body weight was generally lost in the first period, the usual situation was for more than planned body weight changes to be gained from when energy balance was achieved until the end of the eleventh period. The larger weight gain for heifers, combined with lower dry matter intake, resulted in a ration with higher nutrient concentrations at the same level of milk production than a ration balanced for an older animal.

Establishing a correlation between body characteristics and required nutrient concentrations could have practical farm applications if the relationship could be estimated accurately and applied with relative simplicity. The purpose of this section is to determine the relationship between the characteristics of a lactating animal and nutrient concentrations that would satisfy nutrient requirements of that particular animal. This was done by balancing rations using the previously described technique for various types of cows and then estimating the correlation between characteristics of the cow and nutrient concentrations that would fulfill maintenance, growth, and lactation requirements. Turbo-Pascal was used to generate different initial body weights and FCM to trace a cow's lactation. For heifers, starting weights of 400 to 700 kilograms were assumed with initial 4% FCM varying from 9 kg to 39 kg. For older cows, starting body weights ranged from 400 to 800 kg and milk weights from 10 to 50 kg. For each of these groups, initial body weights were incremented by 10 kg and initial milk weights by 2 kg. This generated 3328 observations for the heifer group and 5733 for the other group.

Stepwise regression was used to select a model to predict recommended protein and energy concentrations for an individual animal from characteristics of the cow and time in lactation. Three functional forms of days in milk were tested (linear, log, and squared) with two forms of body weight (linear and log) and 4% FCM from the previous period. This last variable was selected instead of 4% FCM for the current period because it is the one which is generally used to balance a ration. This would be reflected with a time delay of two weeks between test day milk yield and application of information, i.e. regrouping of cows or adjusting individual feeding. The final variable examined was an interaction between days in milk and previous period FCM.

Table 14 summarizes results of the regression procedure for predicting required protein concentration for a balanced ration. All selected variables were significant at the .01 level with models explaining 94.8% and 97.8% of the variation in recommended protein concentration.[11] Table 15 summarizes parameter estimates for recommended energy concentrations in Mcal/kg. With an upper limit of 1.80 Mcal/kg placed on recommended energy concentrations in the simulated ration, it was felt that deletion of these observations would allow a more accurate description of a linear relationship between characteristics of the cow and recommended energy concentrations. This constraint eliminated approximately 1000 observations from each of the models. The selected model accounted for 94.3% of the variation in energy concentraton for heifers and

[11] A factor contributing to the high R^2 was lack of unexplained variation in dry matter intake and milk prediction equations that were used to generate data.

93.7% of the variation in recommended energy concentration for cows with previous lactations.

The previous models account for a great deal of variation in the dependent variables and could be used to estimate balanced rations for lactating animals. However, equations with fewer variables could well make up in simplicity what hopefully would be little lost in accuracy. Under this premise, equations were solved with only previous FCM as an independent variable. Parameter estimates for these equations appear in Table 16. R-Square for protein recommendation equations fell from 94.9 to 92.08 and 97.8 to 90.6 for heifers and older cows, respectively, and 94.3 to 79.2 and 93.7 to 72.8 in the energy category. Parameter estimates for all categories of previous FCM were higher for heifers compared to the multiparous lactating animals. For protein, these numbers were .416 compared to .292, and for energy, .019 compared to .013.

In considering selection of an appropriate model, it was important to consider consistency with other findings. Recommended concentrations of energy increase .019 Mcal/kg for heifers and .013 Mcal/kg for older cows with a 1 kg increase in milk production. This is a greater adjustment than NRC recommendations, which suggest an increase of only .01 Mcal/kg. However, in justifying higher concentrations, an extra kilogram of FCM requires .74 Mcal NEL. If an older cow eats 17 kg of dry matter, the additional concentration of energy adds 17x.013 Mcal, or .221 Mcal to the diet. If it is assumed that the other .52 Mcal comes from additional dry matter intake and energy concentration is 1.6 Mcal/kg, dry matter intake must increase .325 Mcal (.52/1.6). For a heifer, this would be .013/.019 x .325, or .222 Mcal. These calculations are crude, but they indicate that the higher energy concentrations put forth in this research maintain consistency

Table 14. Equations Recommending CP% of Dry Matter Derived from Rations Balanced with Simulated Data

Group	HEIFERS		MULTIPAROUS	
Observations	3328		5733	
Variable	Parameter Estimate	SE	Parameter Estimate	SE
Intercept	108.56383		20.22160544	
Avg Daily 4% FCM in Previous Period (kg)	0.33733871	.00364	0.24576422	.00149
Days in Milk	0.03184076	.00246	0.02710867	.00139
Natural log of Days in Milk	-4.07803803	.17119	-1.72418151	.09811
Days in Milk Squared	-0.00003906	.0000334	-0.00004618	.0000019
Days in Milk-Milk Interaction	0.00038106	.0000181	0.00053551	.0000084
Natural Log of Body Weight	-17.37095220	4.3268	-1.16041730	.03222
Body Weight (kg)	0.05766154	.01649		
Body Weight Squared	-0.00002475	.0000077		
R-Squared	94.87		97.80	

Table 15. Equations Recommending Mcal/kg Dry Matter Derived from Rations Balanced with Simulated Data

Group	HEIFERS		MULTIPAROUS	
Observations	2193		4779	
Variable	Parameter Estimate	SE	Parameter Estimate	SE
Intercept	14.17533679		2.15814731	
Avg Daily 4% FCM from Previous Period (kg)	0.02930971	.000363	0.01989730	.000136
Days in Milk	0.00412063	.000142	0.00658054	.0000967
Natural Log of Days in Milk	-0.42249430	.01046	-0.38689413	.00689
Days in Milk Squared	-0.00000391	.0000002	-0.00000851	.0000001
Days in Milk-Milk Interaction	-0.00002323	.0000014	-0.00001349	.0000007
Body Weight (kg)	0.00843436	.00140		
Natural Log of Body Weight	-2.39703000	.39033		
Body Weight Squared	-0.00000337	.0000006	0.00000021	.00000001
R-Squared	94.33		93.74	

Table 16. Equations Recommending Nutrient Concentrations Average Daily 4% FCM from Previous 28 day Period Sole Regressor

Recommended CP% of Dry Matter

Group	HEIFERS		MULTIPAROUS	
Observations	3328		5733	
Variable	Parameter Estimate	SE	Parameter Estimate	SE
Intercept	6.55630	.04738	8.06409	.02930
Avg Daily 4% FCM from Previous Period (kg)	0.41597	.00213	0.29161	.00124
R-Square	92.0		90.6	

Recommended Mcal/kg Dry Matter

Group	HEIFERS		MULTIPAROUS	
Observations	2193		4799	
Variable	Parameter Estimate	SE	Parameter Estimate	SE
Intercept	1.23918	.00376	1.23298	.02212
Avg Daily 4% FCM from Previous Period (kg)	0.01907	.00017	0.01292	.00011
R-Square	79.2		72.8	

with relationships shown in dry matter intake equations presented in the review of literature.

Table 17 displays a comparison of NRC recommendations and recommendations in multiple and simple regression. The top half of the table shows a situation where milk production is declining at a rate of 6% per month. Each of the two classes of cows are assumed to start at the average weight for that class. The change in weight from a surplus or deficit of energy is considered in computing recommended energy concentration from the multiple regression equation. Recommended nutrient concentrations are higher for both simple regression and multiple regression models as compared to NRC recommendations. As milk production decreases over time, this difference lessens. The difference between multiple regression models and the simple regression models is much smaller. Recommended energy for heifers is lower with the single variable model until later in lactation, with the situation reversed for protein. For older cows, the entire sequence is reversed. Recommended energy is higher with the single variable model until later in lactation, while recommended protein concentration is lower with the single variable model until later in lactation.

The bottom half of Table 17 demonstrates more clearly the effect of days in milk on recommendations described by the multiple regression model. Milk production is constant, therefore NRC and the single variable regression recommendations are constant. Energy recommendations for heifers decrease gradually, while protein recommendations decrease gradually and then begin to increase. However, both types of nutrient recommendations increase over time, holding milk production constant, for the older class of lactating cow. For energy, this increase is from 1.48 Mcal/kg to 1.63 Mcal/kg from 70 to 322 days, and for protein 14.3% to 17.3% over the same time period. The multiple

Table 17. Recommended Nutrient Concentration Examples

Days in Milk Previous Period	70	98	126	154	182	210	238	266	294	322
Avg Daily 4% FCM (kg)	35.3	33.2	31.2	29.4	27.6	25.9	24.4	22.9	21.5	20.2
Recommended Energy (Mcal/kg DM)										
Multiple Regression										
Heifers	2.14*	2.01*	1.92*	1.85*	1.80	1.75	1.71	1.68	1.64	1.61
Multiparous	1.68	1.64	1.63	1.62	1.62	1.61	1.61	1.60	1.58	1.55
Single Regression										
Heifers	1.91*	1.87*	1.83*	1.80	1.76	1.73	1.70	1.68	1.65	1.62
Multiparous	1.69	1.66	1.64	1.61	1.59	1.57	1.55	1.53	1.51	1.49
From NRC Table 6-5										
Heifers	1.76	1.74	1.72	1.70	1.69	1.67	1.65	1.64	1.62	1.61
Multiparous	1.67	1.65	1.63	1.61	1.60	1.58	1.56	1.55	1.53	1.52
Recommended Protein (CP% of DM)										
Multiple Regression										
Heifers	20.7	19.6	18.8	18.2	17.6	17.1	16.6	16.1	15.6	15.1
Multiparous	17.1	17.0	16.9	16.8	16.7	16.5	16.3	16.0	15.6	15.2
Single Regression										
Heifers	21.2	20.4	19.5	18.8	18.0	17.3	16.7	16.1	15.5	14.9
Multiparous	18.3	17.7	17.11	16.6	16.1	15.6	15.1	14.7	14.3	13.9
From NRC Table 6-5										
Heifers	16.9	16.7	16.5	16.3	16.2	16.0	15.8	15.7	15.5	15.4
Multiparous	16.5	16.3	16.1	15.9	15.8	15.6	15.4	15.3	15.1	15.0

Days in Milk Previous Period	70	98	126	154	182	210	238	266	294	322
Avg Daily 4% FCM (kg)	25	25	25	25	25	25	25	25	25	25
Recommended Energy (Mcal/kg DM)										
Multiple Regression										
Heifers	1.85*	1.79	1.76	1.74	1.74	1.73	1.73	1.72	1.72	1.71
Multiparous	1.48	1.49	1.51	1.54	1.57	1.60	1.62	1.63	1.63	1.63
Single Regression										
Heifers	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72
Multiparous	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56
From NRC Table 6-5										
Heifers	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67
Multiparous	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
Recommended Protein (CP% of DM)										
Multiple Regression										
Heifers	16.9	16.5	16.4	16.5	16.6	16.7	16.9	17.0	17.2	17.3
Multiparous	14.3	14.6	15.1	15.5	15.9	16.3	16.6	16.9	17.1	17.3
Single Regression										
Heifers	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9
Multiparous	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
From NRC Table 6-5										
Heifers	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9
Multiparous	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5

*Actual recommended maximum concentration is 1.80 Mcal/kg.

regression recommendations increase later in lactation as predicted dry matter intake decreases. The higher increase in recommendations for older cows reflects larger predicted decrease in dry matter intake for these cows.

Due to the similarity in recommendations between the simple and multiple regression models, it was decided to use the simple regression model in simulation because of its simplicity. Not only does it require only one independent variable, but information for previous FCM is generally readily available. The selected equation for recommended energy concentrations for heifers is stated:

[13] $NEL = 1.239 + .019FCM$

where NEL is Mcal NEL/kg and FCM is 4% FCM from the previous period. For the older cows:

[14] $NEL = 1.233 + .013FCM$

For heifers, the final equation for the recommended crude protein as a percent of dry matter intake is stated:

[15] $CPPCT = 6.556 + .416FCM$

where FCM is the previous period's 4% FCM. For the older cows, this is stated as:

[16] $CPPCT = 8.064 + .291FCM$

Use of the parameter estimates described in the preceding paragraphs greatly simplified the procedure of ration recommendation. At the beginning of any period, the previous period 4% FCM was used to estimate energy and protein concentrations required to meet nutrient needs for that cow. A group average was calculated by summing individual concentration recommendations and dividing by the number of cows in the group. Nutrient recommendations could then be targeted to the average cow in the group or the cow one-half standard deviation above or below average.

The recommendations derived in this section could also have farm applications. With individual feeding, rations can be balanced based on the recommended concentrations for heifers or multiparous cows. In a practical sense, higher concentrations could be used for underconditioned older cows, as well as heifers. In the same sense, lower concentrations could be used for overconditioned heifers as well as older cows. A group feeding recommendation could be derived by summing individual requirements and dividing by the number of cows in the group. A shortcut method would be to take the group average 4% FCM and use the recommendations derived from a weighted average of the two classes of animals.[12] As will be discussed more fully, approximately one-third of cows on test in Virginia are in first lactation. Weighting the intercepts and parameter estimates for [13] and [14] by one-third and two-thirds, recommended Mcal/kg could be based on group average FCM and the equation:

[17] $NEL = 1.24 + .015FCM$

For protein recommendations, the weighted equation from [15] and [16] could be stated:

[18] $CPPCT = 7.56 + .333FCM$

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[12] As with all the equations that recommend nutrient requirements, milk production must be adjusted to a fat corrected basis. For each .1% deviation from 4% butterfat, .015 times the amount of uncorrected milk produced must be added or subtracted to the uncorrected figure to arrive at 4% FCM.

The Results of Individual and Group Feeding

The following three sections discuss results of data collected from individual and group feeding. The first section discusses results of feeding recommended nutrient concentrations that were derived in the preceding section to cows in one group, two groups, and individually. The second part contrasts results of simulated data collected from one, two, three, and four group feeding plans and the expected response from adding one or more groups. The third section details expected consequences of reducing energy feeding, reducing protein feeding, reducing both, or increasing protein. Results can be used in conjuction with a fixed number of groups to determine the most profitable feeding policy under this constraint.

Comparing Individual to Group Feeding

Data on milk production, body weight changes, and ration and herd characteristics were collected for the 27 herds (3 levels of 3 previously discussed categories) over 50 time periods in the simulation for cows in individual and group feeding situations. Average 28 d 4% FCM and dry matter intake per cow were obtained by multiplying daily dry matter intake and FCM for each cow by 28, summing, and then dividing by number of cows in lactation. Total energy and protein were computed by multiplying dry matter intakes by the appropriate energy concentrations and summing. These numbers were then divided by total dry matter intake to determine protein and energy concentrations of the ration for that period. If it is assumed that protein and energy concentrations for a ration are determined by altering forage and concentrate ratios within a herd for that time period, two rations of identical protein and energy concentrations across different grouping strategies will have exactly the same components. If total concentrations were not weighted according to dry matter intake, two rations with identical protein and energy concentrations may not have identical components across different grouping strategies. For example, a herd fed in one group may average 16% CP. The same herd fed in two groups may have the high group with a 17% CP ration and the low group with 15% CP. However, the high group would in all likelihood eat more than the low group, and the overall ration concentration for that time period would be higher than 16%.

Table 18 summarizes data for cows fed individually and in one and two group systems. These data represent recommended feeding levels only since the individual feeding system did not test underfeeding and overfeeding and it was not desired to compare differences between individual feeding of recommended concentrations and group feeding of higher than or lower than recommended nutrient concentrations. Each of the low, medium, and high producing herds represented 450 observations, one for each of the time periods in the nine herds within each level of production. The nine herds represented three levels of calving intervals (CI) and three levels of within herd variation of 305 d 4% FCM (SD). In low herds, cows in one group ate the most feed, 482.37 kg per cow over 28 days, and produced the least milk, 605.22 kg. Although the ration energy and protein concentrations were lowest of the three feeding types, these cows still had the highest percentage of cows gaining weight, 77.5% compared to 67.3% and 63.3% for two group and individually fed cows. They also gained the most weight, .2634 kg per cow per day, versus .1589 kg for two group animals and .1260 kg for individually fed animals.

Table 18. Individual and One and Two Group Means for All Cows
Recommended Feeding Levels Only
450 Observations from 9 Herds, 50 Time Periods Each

Low producing Herds	One Group	Two Groups	Individual
Avg daily 4% FCM (kg)	21.61	22.24	22.21
Avg daily dry matter intake (kg)	17.23	16.80	16.78
% Cows gaining weight	77.5	67.3	63.3
Avg daily wt change (kg)	.2634	.1589	.1260
Avg NEL Mcal/kg dry matter	1.580	1.609	1.600
Average CP % of dry matter	15.286	15.918	15.796
FCM kg/Mcal NEL	.7934	.8215	.8267
FCM kg/CP kg	8.201	8.306	8.371
Avg 28 day 4% FCM (kg)	605.22	622.84	621.89
Avg 28 day dry matter intake (kg)	482.37	470.82	469.93

Medium Producing Herds	One Group	Two Groups	Individual
Avg daily 4% FCM (kg)	24.39	24.78	24.57
Avg daily dry matter intake (kg)	17.75	17.29	17.29
% Cows gaining weight	75.1	63.6	60.8
Avg daily wt change (kg)	.1405	.0920	.0691
Avg NEL Mcal/kg dry matter	1.622	1.641	1.622
Avg CP % of dry matter	16.187	16.795	16.302
FCM kg/NEL Mcal	.8465	.8743	.8755
FCM kg/CP kg	8.481	8.542	8.713
Avg 28 day 4% FCM (kg)	682.98	695.10	687.91
Avg 28 day dry matter intake (kg)	497.10	484.32	483.99

High Producing Herds	One Group	Two Groups	Individual
Avg daily 4% FCM (kg)	27.27	26.98	27.28
Avg daily dry matter intake (kg)	18.26	17.76	17.87
% Cows gaining weight	71.0	59.3	57.5
Avg daily wt change (kg)	.1427	.0229	.0069
Avg NEL Mcal/kg dry matter	1.659	1.654	1.651
Avg CP % of dry matter	17.054	17.496	16.862
FCM kg/NEL Mcal	.8993	.9194	.9241
FCM kg/CP kg	8.750	8.692	9.047
Avg 28 day 4% FCM (kg)	763.69	756.96	763.79
Avg 28 day dry matter intake (kg)	511.39	497.58	500.31

Cows in two group and individual feeding plans had very similar intakes and milk production. Over a 28 day period, cows fed in two groups produced on average .95 kg more FCM and ate .89 kg more dry matter than cows that were fed individually. However, individually fed cows ate a ration that was slightly lower in protein and energy concentration, 15.796 compared to 15.918 and 1.600 compared to 1.609. These differences were best reflected in the two ratios that express kg FCM relative to Mcal Nel and kg CP. Individually fed cows produced .8267 kg FCM for each Mcal NEL consumed and 8.371 kg FCM for each kg CP. For the two group cows these figures were .8215 and 8.306 and the one group cows .7934 and 8.201.

A similar pattern was seen with the medium producing cows. Cows fed in one group produced the least FCM over 28 days, 682.98 kg versus 695.10 for two groups and 687.91 for individual feeding, ate the most feed, 497.10 kg compared to 484.32 kg for two groups and 483.99 kg for individually fed cows, had the highest percentage of cows gaining weight, 75.1% compared to 63.6% for cows fed in two groups and 60.8% for cows fed individually, and largest average daily weight gain per cow, .1405, .0920, and .0691 kg for the three respective grouping practices. Two group cows had the highest concentration of nutrients, 1.641 Mcal/kg energy and 16.795% CP compared to 1.622 Mcal/kg energy for the other two systems and 16.187% CP for one group cows and 16.302% CP for individually fed cows.

It is interesting to observe that with identical energy concentrations and very similar protein concentrations between one group and individually fed cows, the individually fed cows produced on average 4.93 kg more FCM while consuming 13.11 kg less dry matter over 28 days. This is apparent in the ratios for kg FCM produced for each Mcal NEL and kg CP ingested. For one group cows these are .8465 and 8.481, for cows in two groups, .8743 and 8.542, and for individually fed cows, .8755 and 8.713 for the respective ratios.

Results garnered with the high producers deviated somewhat from the previous pattern. Individually fed cows produced the most FCM, 763.79 kg compared to 763.69 kg for one group cows and 756.96 kg for two group cows, while two group cows ate the least dry matter, 497.58 kg versus 500.31 kg for individually fed cows and 511.39 kg for one group cows. The one group continued to gain the most weight, .1427 kg per cow per day contrasted with .0229 kg per cow per day for the two group feeding system and .0069 kg per cow per day for the individual feeding system, and had the highest percentage of cows gaining weight, 71%, while the other respective groups had 59.3% and 57.5%. FCM produced per Mcal NEL continued to be lowest for one group cows, .8993, and highest for individual cows, .9241, with two group cows falling in the middle at .9194. However, unlike the other two production classes, the two group system had the lowest amount of FCM produced per kg CP. This figure was 8.692, balanced against 8.750 for the one group system and 9.047 for individually fed cows.

Individual feeding had higher FCM and lower dry matter intake compared to cows in the one group feeding plan for all three herd classes. In low herds, dry matter intake was 2.6% lower contrasting individual feeding with one group feeding, and FCM was 2.75% higher. For the middle herds, dry matter intake was 2.6% lower but FCM increased by .7%. For high herds, milk production was very close, but dry matter intake was 2.2% lower for individually fed cows.

The distinction between two group and individual feeding was not as obvious in dry matter intake and FCM categories. With low herds, dry matter intake decreased .2% and FCM decreased .1% when changing from two group to individual feeding. In the middle production herds, FCM decreased 1% and dry matter intake decreased .1% when switching from two group to individual feeding. In the high category, the increase in dry matter intake was .5%, but FCM also increased by .9%.

To draw conclusions on grouping based on dry matter intake and FCM would not be entirely fair since the rations that were fed were not alike. The ratios between milk produced and energy and protein consumption alleviate this discrepancy, but they fall short in providing information on costs and benefits of grouping. However, an equation to predict 28 d 4% FCM per lactating cow could isolate the effect of a change from group to individual feeding. It was felt that 28 d 4% FCM per cow in milk could be predicted on the basis of 28 d dry matter intake, energy level fed (Mcal/kg), herd characteristics, and whether cows were fed individually or in groups. The amount of dry matter intake consumed (DMI) and energy concentration of the ration (NEL) were included because both influence the amount of energy available for milk production. However, crude protein was excluded since both energy and protein are linearly related to previous period FCM. With this linear relationship to a common variable, there would be a strong possibility of multi-collinearity in the model. Dummy variables for high calving intervals (Hci), low calving intervals (Lci), high standard deviation of 305 d milk production within the herd (Hsd), and low standard deviation of 305 d milk production within the herd (Lsd) were all included to test effects of herd characteristics on 4% FCM. Interactions between herd characteristics and feeding systems were also tested for relative advantages between feeding systems (Hcig, Lcig, Hsdg, Lsdg). The final variable in the model was added to account for any difference between 4% FCM between grouping and individual feeding (Totgrp). This variable was set to 1 if cows were grouped, 0 if they were individually fed.

Table 19 summarizes results of the models tested with data pooled from one group and individually fed herds. Independent variables explained 92.2%, 91.1%, and 91.5% of the variation in 28 d 4% FCM per lactating cow in the low, medium, and high producing herds. Moving from low producing herds to medium producing herds to high herds, parameter estimates for dry matter intake (DMI) and energy level (NEL) both increase. This would make sense as it implies that dry matter intake and energy are being used at higher efficiencies for higher producing herds. In addition, parameter estimates greater than one for dry matter intake at all herd levels show that more than one kg of FCM would be produced for a one kg increase in dry matter intake. Since one kg of FCM is worth significantly more than one kg of dry matter, these estimates would imply that there is no reason to limit the amount of dry matter that a cow would eat. This is not to say that nutrient concentration should be unlimited or that excess feed should be placed in the bunk.

For herds with average characteristics, parameter estimates indicate individual feeding improved 28 d 4% FCM by 15.629 kg, 22.919 kg, and 22.873 kg per lactating cow relative to one group feeding.[13] Herd characteristics affected milk production in some form in all the herds. In low producing herds, high calving intervals decreased FCM, but less in one group feeding than with individual feeding. Low calving intervals increased production in both feeding systems. High standard deviations increased production relative to the average with individual feeding, but decreased it with group feeding. In medium producing herds, low calving intervals had a positive effect on 4% FCM, moreso with individual feeding. High calving intervals decreased milk production relative to average intervals, but only in grouped herds. Low standard deviations had a negative effect with

[13] The increase in 4% FCM was assumed holding dry matter intake and ration contents constant. With no increase in cost, an increase in production would also imply an increase in profitability.

Table 19. Prediction Equations for Individual and One Group Feeding
28 day 4% FCM per Lactating Cow (kg)

	Low herds		Medium herds		High herds	
Variable	Parameter Estimate	SE	Parameter Estimate	SE	Parameter Estimate	SE
Intercept	-1419.277		-1817.456		-1985.509	
DMI	1.467	.040	1.490	.046	1.569	.047
NEL	843.499	25.543	1097.750	37.375	1189.333	32.267
Totgrp	-15.629	1.215	-22.919	1.378	-22.873	1.072
Hci	-6.502	1.107				
Lci	3.965	.847	8.564	1.155	5.274	.901
Hcig	4.918	1.467	-5.160	1.284		
Lcig			-4.552	1.691		
Hsd	10.485	1.012	4.174	.912	6.213	1.305
Lsd			-3.841	1.203	-8.831	1.044
Hsdg	-12.738	1.431			-13.578	1.817
Lsdg			7.677	1.582		
R-Square	92.2		91.1		91.5	

DMI = Dry matter intake (kg)
NEL = Mcal NEL/kg dry matter
Totgrp = 0 if individually fed, 1 if grouped
Hsd = High standard deviation of 305 day 4% FCM
Lsd = Low standard deviation of 305 day 4% FCM
Hsdg = Hsd interaction with Totgrp
Lsdg = Lsd interaction with Totgrp
Hci = High calving interval
Lci = Low calving interval
Hcig = High calving interval interaction with Totgrp
Lcig = Low calving interval interaction with Totgrp

individual feeding, but a positive effect with one group feeding. High standard deviations had a positive effect for all feeding systems. Finally, in high producing herds, low calving intervals increased FCM relative to average and high calving intervals. Low standard deviations diminished 4% FCM, as did high standard deviations in grouped herds, while individual feeding increased FCM for herds with high standard deviations.

For herds with average characteristics, changing from one group to individual feeding increased 28 d 4% FCM per lactating cow from a range of 15 to 22 kg, depending on level of herd production. Higher calving intervals had the expected negative effect on milk production. There was no consistent advantage to individual feeding due to high calving intervals. However, the advantage of individual feeding relative to group feeding increased consistently in herds with high variation of 305 d milk production within the herd.

Table 20 summarizes results of the three models tested using data pooled from the two group and individually fed herds. The difference between two group and individual feeding was not as large as the difference between individual and one group feeding. The parameter estimate for the variable representing grouping systems was -5.131 for the low herds, -16.290 for the medium herds, and -5.031 for the high herds.

In low producing herds, high calving intervals depressed milk production, but less in the two group feeding system than with individual feeding. Low calving intervals increased FCM relative to the average for both two group and individual feeding systems. High and low standard deviations of within herd 305 d 4% FCM had a negative effect on milk production in the two group scheme.

Table 20. Prediction Equations for Individual and Two Group Feeding
28 day 4% FCM per Lactating Cow (kg)

	Low herds		Medium herds		High herds	
Variable	Parameter Estimate	SE	Parameter Estimate	SE	Parameter Estimate	SE
Intercept	-1502.532		-2319.165		-2442.849	
DMI	1.573	.039	1.516	.046	1.569	.051
NEL	864.104	26.887	1399.060	47.078	1466.450	54.669
Totgrp	-5.131	1.165	-16.290	1.569	-5.031	1.477
Hci	-5.301	1.085	3.276	1.242		
Lci	4.004	.824	8.281	1.246	3.277	.966
Hcig	2.759	1.417	-9.342	1.738	-3.816	1.307
Lcig			-5.044	1.714		
Hsd			5.136	.865	9.160	1.461
Lsd			-6.146	1.168	-11.017	1.493
Hsdg	-11.190	1.512			-6.578	2.036
Lsdg	-2.627	1.153	6.827	1.525	4.011	1.993
R-Square	91.2		90.5		88.7	

DMI = Dry matter intake (kg)
NEL = Mcal NEL / kg dry matter
Totgrp = 0 if individually fed, 1 if grouped
Hsd = High standard deviation of 305 day 4% FCM
Lsd = Low standard deviation of 305 day 4% FCM
Hsdg = Hsd interaction with Totgrp
Lsdg = Lsd interaction with Totgrp
Hci = High calving interval
Lci = Low calving interval
Hcig = High calving interval interaction with Totgrp
Lcig = Low calving interval interaction with Totgrp

In medium producing herds, an individually fed herd with a high calving interval had higher than average production, but the same herd fed in two groups had lower than average production. Low calving intervals increased 4% FCM, more in individually fed herds than grouped ones. High standard deviations had a positive effect on milk production, while low standard deviations had a negative effect on milk production in individually fed herds.

In high producing herds, the established pattern was generally maintained. Low calving intervals increased production in both systems. High calving intervals depressed production relative to average calving intervals in grouped feeding schemes. High standard deviations increased FCM, more with individual feeding than with group feeding, while low standard deviations had the completely opposite effect. Except for low producing herds, the advantage of individual feeding compared to two group feeding was higher in herds with high calving intervals. A stronger relative advantage also seemed to lie with individual feeding when herds had a high variation of total milk production.

A summary of comparisons between one group and individual feeding and two group and individual feeding is presented in Table 21. In low producing herds, a change from one group to individual feeding increased FCM from 1.9 to 3.2%. With no change in feed cost, this would mean an expected yearly increase in profit of 1.9 to 3.2% of milk revenue before cost of the feeding system was subtracted. For medium herds, the range was 2.2 to 4.1%, and high herds 2.3 to 4.0%. Changing from two groups to individual feeding, expected annual increase in milk revenue over feed cost ranged from .2 to 1.6% for low herds, 1.1 to 3.2% for medium producing herds, and 0.0 to 2.0% for high producing herds. Although advantages were less than a change from one group, an additional benefit would be the extra money saved from having to feed two less groups rather than one.

Comparing Grouping Policy

This section reports results of the simulation regarding feeding with different numbers of groups. Unlike the previous section, groups were not always fed strictly according to recommendations. In addition to the series of feedings that fed strictly recommended nutrient concentrations, there was a set that fed recommended protein and underfed average energy by one-half of the group standard deviation, one that fed recommended energy and underfed average protein by one-half of the group standard deviation, one that underfed each average by one-half standard deviation, and one that fed recommended energy and overfed group average protein by one-half standard deviation. With four sets of feedings, there were 1800 observations rather than the previous 450 in each of the low, medium, or high producing herds.

Tables 22, 23, and 24 summarize one, two, three, and four group means for each of the low, medium, or high producing herds. These tables were included to show for each group average daily 4% FCM, average daily dry matter intake, average daily weight change, standard deviations of nutrient requirements within the group, average days in milk, and number of cows within the group that gained weight. This section will deal with some of the highlights of these tables.

Table 22 describes grouping data for low producing herds. Milk production and dry matter intake decreased and days in milk increased moving from high to low groups. Changes were distinct. For example, in a two group feeding system, average days in

Table 21. Change in 4% FCM with Change from Group to Individual Feeding
KG per Milking Cow per 28 Day Period

LOW PRODUCING HERDS

SD	Calving Interval	one group to individual (kg)	two groups to individual (kg)
-1	-1	11.66	3.75
-1	0	15.63	7.76
-1	1	17.21	10.31
0	-1	11.66	1.12
0	0	15.63	5.13
0	1	17.21	7.68
1	-1	13.92	1.66
1	0	17.88	5.66
1	1	19.47	8.21

MEDIUM PRODUCING HERDS

SD	Calving Interval	one group to individual (kg)	two groups to individual (kg)
-1	-1	15.07	12.37
-1	0	19.08	15.61
-1	1	24.24	21.68
0	-1	18.91	13.05
0	0	22.92	16.26
0	1	28.08	22.36
1	-1	14.73	7.92
1	0	18.75	11.15
1	1	23.91	17.22

HIGH PRODUCING HERDS

SD	Calving Interval	one group to individual (kg)	two groups to individual (kg)
-1	-1	26.43	8.76
-1	0	31.70	12.04
-1	1	31.70	15.85
0	-1	17.60	1.75
0	0	22.87	5.03
0	1	22.87	8.85
1	-1	24.96	-.83
1	0	30.24	2.45
1	1	30.24	6.27

SD= 1 if high standard deviation 305 day 4% FCM, 0 if average, -1 if low
CI= 1 if high calving interval, 0 if average, -1 if low

milk nearly doubled from 126.5 to 230.9 from high group to low group. In a four group feeding system, average days in milk increased from 91.4 to 288 when comparing highest group to lowest group. In a two group feeding system, there was a fairly sharp decrease in recommended nutrients as energy fell from 1.705 Mcal/kg to 1.44 Mcal/kg and CP concentration decreased from 18.03% to 12.93%. This 15.5% drop in energy concentrations slightly exceeded the 15% limit suggested by Nocek (43) and may not be practical. Declines were more moderate with three groups, changing from 1.750 Mcal/kg to 1.550 Mcal/kg to 1.409 Mcal/kg and 18.77% to 15.03% to 12.38%.

Four groups was the minimum number in low producing herds where the high group reached maximum allowable energy, 1.76 Mcal/kg. On average, none of the groups received the lowest recommended nutrient concentrations, 12% CP or 1.35 Mcal Nel/kg dry matter, and the standard deviation of within group recommended nutrient concentrations was always lowest for the highest group for both energy and protein. It is interesting to observe that in low groups with three or four group feeding systems, dry matter intake exceeded FCM, yet cows in these groups lost weight on average. With two groups, average daily weight gain was small, .037 kg per cow per day, and FCM was slightly higher than dry matter intake, 14.69 kg compared to 14.49 kg.

Group averages for medium producing herds can be found in Table 23. In a two group system, high producing cows were fed, on average, rations that contained 1.75 Mcal/kg of dry matter and crude protein that was 18.78% of dry matter. Low groups received 1.46 Mcal/kg and 13.48% CP, meaning drop-off in nutrient concentrations was similar to that of low producing herds. The high group in both the three and four group feeding systems received maximum energy allotment, 1.76 Mcal/kg, while being allocated 18.98% and 19% CP for these respective groups. The only groups to lose weight on

Table 22. Low Herd Means by Group

One Group Means	
Daily 4% FCM (kg)	20.89
Within group SD daily 4% FCM (kg)	7.56
Daily avg dry matter intake (kg)	16.98
Cows in group	86.38
Cows in group gaining weight	61.86
Avg daily weight change/cow (kg)	.1888
Avg days in milk	178.4
Recommended Mcal NEL/kg dry matter	1.541
Within group SD of Mcal/kg	.1165
Recommended CP% of dry matter	15.05
Within group SD of recommended CP%	2.46
FCM kg/NEL Mcal	.7968
FCM kg/CP kg	8.19

Two Group Means	GROUP One	Two
Daily 4% FCM (kg)	29.02	14.69
Within group SD of daily 4% FCM (kg)	6.93	4.40
Daily average dry matter intake (kg)	18.86	14.49
Cows in group	43.43	42.95
Cows in group gaining weight	31.48	23.43
Avg daily weight change per cow (kg)	.1976	.0370
Avg days in milk	126.5	230.9
Recommended Mcal NEL/kg	1.705	1.44
Within group SD Mcal/kg dry matter	.0575	.0755
Recommended CP% of dry matter	18.03	12.93
Within group SD of recommended CP%	1.38	1.54
FCM kg/NEL Mcal	.9020	.7027
FCM kg/CP kg	8.54	7.83

Three Group Means	One	GROUP Two	Three
Daily 4% FCM (kg)	31.03	21.61	12.36
Within group SD of daily 4% FCM (kg)	7.22	4.62	3.14
Daily average dry matter intake (kg)	19.01	17.32	13.36
Cows in group	28.80	29.10	28.48
Cows in group gaining weight	19.40	20.73	13.42
Avg daily weight change per cow (kg)	.1328	.2124	-.0284
Avg days in milk	108.3	160.4	267.8
Recommended Mcal energy (NEL/kg)	1.750	1.550	1.409
Within group SD of NEL Mcal/kg	.0321	.0596	.0639
Recommended CP% of dry matter	18.77	15.03	12.38
Within group SD of recommended CP%	.8726	1.38	1.21
FCM kg/NEL Mcal	.9327	.8032	.6551
FCM kg/CP kg	8.69	8.29	7.46

Four Group Means	One	GROUP Two	Three	Four
Daily 4% FCM (kg)	31.86	25.26	17.95	11.39
Within group SD daily 4% FCM	7.47	5.32	3.34	2.76
Daily avg dry matter intake (kg)	19.06	18.43	15.89	12.90
Cows in group	21.73	21.46	21.89	21.30
Cows in group gaining weight	13.60	15.96	14.33	9.58
Avg daily weight change/cow (kg)	.0688	.2653	.1379	-.0479
Avg days in milk	91.4	140.8	195.8	288.0
Recommended Mcal NEL/kg dry matter	1.76	1.62	1.50	1.40
Within group SD recommended Mcal/kg	.025	.065	.042	.063
Recommended CP% of dry matter	18.94	16.28	13.92	12.21
Within group SD of recommended CP%	.55	1.47	1.06	1.11
FCM kg/NEL Mcal	.9508	.8466	.7516	.6305
FCM kg/CP kg	8.82	8.41	8.09	7.21

average were the high groups in three and four group systems, although low groups in these systems gained on average relatively small amounts of weight, .0094 kg and .0030 kg. These two groups, as with low producing herds, averaged higher dry matter intake than FCM. The standard deviations of the within group nutrient requirements were once again smallest for the highest producing groups.

Table 24 contains the summary of high producing herds. High group cows in two, three, and four group feeding systems all lost weight on average, although more than half gained weight in the two group plan (23.62 out of 43.45) and nearly half gained weight in the high group of the four group plan (8.47 out of 21.72). Maximum nutrients were recommended for each of these groups. In the four group system, drop-off in the second group was relatively small, only to 1.72 Mcal/kg and 18.42% CP. Within group standard deviation of recommended concentrations was noticeably smaller in high groups for each of the situations where more than one group was fed. For two groups, these figures were .029 for energy and .69 for protein, compared to low group standard deviations of .091 and 1.89. With three groups, standard deviation of recommended energy was .019 Mcal/kg versus .060 and .072 for the other groups, and .229% compared to 1.38% and 1.42% for the others. In the four group situation, energy was .020 Mcal/kg, contrasted with .044, .053, and .071 Mcal/kg, while the numbers for CP% were .06%, 1.02%, 1.27%, and 1.31%.

To summarize a visual analysis of events occurring within the groups, it would appear that when more than two groups were fed, the high and low groups were at a slightly positive or slightly negative energy balance. Weight that was replaced on the cows in these situations was done so in the middle group or groups. Cows generally moved to lower groups as days in milk increased, where the variation in nutrient requirements was

Table 23. Medium Herd Means by Group

One Group Means	
Daily 4% FCM (kg)	23.59
Within group SD of daily 4% FCM (kg)	8.49
Daily average dry matter intake (kg)	17.54
Cows in group	86.31
Cows in group gaining weight	60.33
Avg daily weight change per cow (kg)	.1426
Avg days in milk	178.3
Recommended Mcal NEL/kg	1.58
Within group SD of Mcal NEL/kg	.1148
Recommended CP% of dry matter	15.88
Within group SD of recommended CP%	2.42
FCM kg/NEL Mcal	.8497
FCM kg/CP kg	8.47

Two Group Means	GROUP One	Two
Daily 4% FCM (kg)	32.57	16.25
Within group SD of daily 4% FCM (kg)	7.47	4.89
Daily average dry matter intake (kg)	19.42	14.86
Cows in group	43.39	42.92
Cows in group gaining weight	27.81	23.97
Avg daily weight change per cow (kg)	.0648	.0428
Avg days in milk	122.3	234.9
Recommended Mcal NEL/kg dry matter	1.75	1.46
Within group SD of recommended Mcal/kg	.0412	.0847
Recommended CP% of dry matter	18.78	13.48
Within group SD of recommended CP%	1.00	1.75
FCM kg/NEL Mcal	.9605	.7447
FCM kg/CP kg	8.93	8.10

Three Group Means	One	GROUP Two	Three
Daily 4% FCM (kg)	34.38	24.36	13.66
Within group SD of daily 4% FCM (kg)	7.59	5.18	3.43
Daily average dry matter intake (kg)	19.68	17.87	13.80
Cows in group	28.76	29.09	28.46
Cows in group gaining weight	16.36	20.20	14.49
Avg daily weight change per cow (kg)	-.0450	.1842	.0094
Avg days in milk	101.9	163.2	271.1
Recommended Mcal NEL/kg dry matter	1.76	1.59	1.43
Within group SD of recommended Mcal/kg	.0226	.0609	.0683
Recommended CP% of dry matter	18.98	15.99	12.76
Within group SD of recommended CP%	.51	1.42	1.32
FCM kg/NEL Mcal	.9925	.8533	.6904
FCM kg/CP kg	9.20	8.51	7.74

Four Group Means	One	GROUP Two	Three	Four
Daily 4% FCM (kg)	35.30	28.73	20.35	12.60
Within group SD daily 4% FCM (kg)	7.62	6.00	3.77	2.97
Daily avg dry matter intake (kg)	19.80	19.08	16.44	13.37
Cows in group	21.71	21.44	21.87	21.30
Cows in group gaining weight	11.06	15.27	14.10	10.76
Avg daily weight change/cow (kg)B	-.1380	.2172	.1275	.0030
Avg days in milk	85.9	140.6	197.8	290.5
Recommended Mcal energy (NEL/kg)	1.76	1.67	1.54	1.42
Within group SD recommended Mcal/kg	.021	.057	.048	.067
Recommended CP% of dry matter	19.00	17.44	14.79	12.51
Within group SD of recommended CP%	.237	1.34	1.16	1.20
FCM kg/NEL Mcal	1.013	.8999	.8034	.6638
FCM kg/CP kg	9.39	8.62	8.35	7.51

Table 24. High Herd Means by Group

One Group Means	
Daily 4% FCM (kg)	26.50
Within group SD of daily 4% FCM (kg)	9.49
Daily average dry matter intake (kg)	18.09
Cows in group	86.39
Cows in group gaining weight	57.61
Avg daily weight change per cow (kg)	.0848
Avg days in milk	178.3
Recommended Mcal NEL/kg dry matter	1.62
Within group SD of recommended Mcal/kg	.111
Recommended CP% of dry matter	16.78
Within group SD of recommended CP%	2.301
FCM kg/NEL Mcal	.9023
FCM kg/CP kg	8.74

Two Group Means	GROUP One	Two
Daily 4% FCM (kg)	35.76	17.64
Within group SD of daily 4% FCM (kg)	8.12	5.25
Daily average dry matter intake (kg)	20.05	15.19
Cows in group	43.45	42.94
Cows in group gaining weight	23.62	24.89
Avg daily weight change per cow (kg)	-.0884	.0603
Avg days in milk	117.1	240.3
Recommended Mcal NEL/kg dry matter	1.76	1.49
Within group SD of recommended Mcal/kg	.029	.091
Recommended CP% of dry matter	18.99	13.98
Within group SD of recommended CP%	.69	1.89
FCM kg/NEL Mcal	1.014	.7798
FCM kg/CP kg	9.39	8.30

Three Group Means	One	GROUP Two	Three
Daily 4% FCM (kg)	37.86	26.85	15.02
Within group SD of daily 4% FCM (kg)	8.05	5.67	3.72
Daily average dry matter intake (kg)	20.45	18.29	14.21
Cows in group	28.79	29.11	28.49
Cows in group gaining weight	13.01	19.65	15.55
Avg daily weight change per cow (kg)	-.2429	.1549	.0454
Avg days in milk	95.1	167.6	273.4
Recommended Mcal energy (NEL/kg)	1.76	1.63	1.45
Within group SD of recommended Mcal/kg	.019	.060	.072
Recommended CP% of dry matter	19.00	16.88	13.20
Within group SD of recommended CP%	.229	1.38	1.42
FCM kg/NEL Mcal	1.051	.8967	.7264
FCM kg/CP kg	9.74	8.69	7.99

Four Group Means	One	GROUP Two	Three	Four
Daily 4% FCM (kg)	38.99	32.02	22.58	13.93
Within group SD of daily 4% FCM (kg)	7.97	6.62	4.18	3.22
Daily avg dry matter intake (kg)	20.60	19.60	16.88	13.82
Cows in group	21.72	21.48	21.91	21.28
Cows in group gaining weight	8.47	14.22	13.89	11.74
Avg daily weight change/cow (kg)	-.3620	.1528	.1160	.0483
Avg days in milk	79.5	142.3	202.1	291.1
Recommended Mcal NEL/kg dry matter	1.76	1.72	1.57	1.44
Within group SD recommended Mcal/kg	.020	.044	.053	.071
Recommended CP% of dry matter	19.00	18.42	15.60	12.89
Within group SD of recommended CP%	.06	1.02	1.27	1.31
FCM kg/NEL Mcal	1.075	.9486	.8492	.6993
FCM kg/CP kg	9.96	8.86	8.56	7.80

always higher than the highest producing group. Even with maximum nutrient concentration, cows in the high group of high producing herds for all multiple group situations lost weight. In medium producing herds this occurred only in three and four group settings.

Comparing Group Means

The previously discussed tables were presented strictly as visual aids in understanding what is happening with the grouping of the cows. Tables 25, 26, and 27 display means of the data that were used in evaluation of the effects of grouping or feeding more or less than average group recommendations. Table 25 summarizes results of low producing herds fed in one group, two groups, three groups, and four groups. Each of the four grouping scenarios had on the average 86.38 of the 100 cows in the herd in lactation during any one time period. The one group set of cows had the highest number of weight gainers, 61.86, with this number decreasing to 54.92, 53.54, and 53.47, as the number of groups increased to two, three, and four. This was reflected in average daily weight gain decreasing from .1888 kg to .1177 kg to .1065 kg to .1064 kg as the numbers of groups increased from one to four. The average cow fed in one group ate the most feed over the 28 day period, 475.5 kg compared to 467.1 kg, 464.1 kg, and 464.3 kg, for two, three, and four groups. The average cow in this group also produced the least 4% FCM, 584.9 kg, contrasted with 613.1 kg, 607.7 kg, and 606.1 kg for the two, three, and four group sets of cows. On a percentage basis, changing from one group to two groups increased milk production by 4.8% and decreased dry matter intake by 1.8%. Further increases in the number of groups did little to change the data on dry matter intake and 4% FCM. At three groups, FCM decreased by .9% and dry matter intake by .6%.

Moving to four groups, milk decreased by .3% and dry matter intake increased by less than .1%.

Part of the lower milk production in the one group set of cows can be explained by lower concentrations of nutrients fed. These cows were fed on the average 1.541 Mcal Nel per kg of dry matter and 15.05% CP, compared with two group nutrient concentrations of 1.591 and 15.84, three group nutrient concentrations of 1.589 and 15.75, and four group nutrient concentrations of 1.586 and 15.70.

At least a portion of the reason for lower nutrient concentration was the higher standard deviations within one group of cows relative to any of the other grouping policies. As group numbers increased, within group standard deviation of daily FCM decreased from 7.56 kg to 5.67 kg to 4.99 kg and finally to 4.72 kg. This decrease was reflected in the change in the within group standard deviation of protein and energy. For protein, this number fell from 2.464 kg to 1.464 kg by moving from one group to two groups. This decline continued modestly to 1.157 kg and 1.046 kg in the three and four group systems.

The standard deviation of energy recommendations followed the same pattern. For one group of cows, this figure was .1165 Mcal/kg. For two groups, this number fell to .0665 Mcal/kg. With three groups, it was .0519 Mcal/kg, decreasing to .0487 Mcal/kg in a four group setting.

Changing from one group to two groups increased kg FCM per Mcal Nel from .7968 to .8244 and increased kg FCM per kg CP from 8.188 to 8.289. Beyond two groups, increase in the milk-protein ratio was modest. At three groups and four groups it increased to 8.304 kg and 8.308 kg FCM per kg CP. In the energy category, there were

Table 25. Low Herd Means by Number of Groups
All Feeding Levels

1800 Observations	Number of groups			
	One	Two	Three	Four
Daily 4% FCM (kg)	20.89	21.86	21.67	21.61
Within group SD of daily 4% FCM (kg)	7.56	5.67	4.99	4.72
Daily average dry matter intake (kg)	16.98	16.67	16.56	16.57
28 day FCM per lactating cow (kg)	584.9	613.1	607.7	606.1
28 day DMI per lactating cow (kg)	475.5	467.1	464.1	464.3
Lactating cows	86.38	86.38	86.38	86.38
Lactating cows gaining weight	61.86	54.92	53.54	53.47
Avg daily weight change per cow (kg)	.1888	.1177	.1065	.1064
Avg days in milk	178.4	178.7	178.8	178.8
Recommended energy (Mcal/kg)	1.571	1.607	1.600	1.597
Energy level fed (Mcal/kg)	1.541	1.591	1.589	1.586
Within group SD recommended energy	.1165	.0665	.0519	.0487
Recommended CP% of dry matter	15.07	15.84	15.75	15.70
CP% of dry matter fed	15.05	15.83	15.76	15.70
Within group SD recommended CP%	2.464	1.464	1.157	1.046
FCM kg/NEL Mcal	.7968	.8244	.8234	.8223
FCM kg/CP kg	8.188	8.289	8.304	8.308

Recommended Feeding Level for Group Average Only

450 Observations	Number of groups			
	One	Two	Three	Four
Daily 4% FCM (kg)	21.61	22.24	21.96	21.90
Within group SD of daily 4% FCM (kg)	7.44	5.67	5.00	4.73
Daily average dry matter intake (kg)	17.23	16.80	16.69	16.70
28 day FCM per lactating cow (kg)	605.2	622.8	615.9	614.1
28 day DMI per lactating cow (kg)	482.4	470.8	467.8	467.8
Lactating cows	86.40	86.40	86.40	86.40
Lactating cows gaining weight	66.92	58.13	56.21	55.96
Avg daily weight change per cow (kg)	.2634	.1589	.1398	.1378
Avg days in milk	178.7	178.9	179.1	179.1
Energy level fed (Mcal NEL/kg)	1.580	1.609	1.603	1.599
Within group SD recommended Mcal/kg	.1136	.0654	.0514	.0484
CP% of dry matter fed	15.29	15.91	15.80	15.74
Within group SD recommended CP%	2.338	1.442	1.143	1.041
FCM kg/NEL Mcal	.7934	.8215	.8211	.8204
FCM kg/CP kg	8.201	8.312	8.327	8.333

actually modest declines as the figures for these two classes of groups were .8234 and .8223.

The bottom half of Table 25 was included to summarize results of only feeding recommended concentrations. Changes in dry matter intake and FCM when changing the numbers of groups are very similar to changes observed when feeding higher or lower than average recommended nutrients. From one group to two groups, FCM increased from 605.2 kg to 622.8 kg, or 2.9%, and dry matter intake decreased from 482.4 kg to 470.8 kg, or 2.4%. Three group FCM was 615.9 and four group FCM 614.1, percentage decreases of 1.1% and .3%, while both the three and four group dry matter intake were 467.8 kg, representing a decline of .6% and no change.

Energy concentrations increased from 1.580 Mcal/kg NEL to 1.609 Mcal/kg NEL at two groups, and then declined to 1.603 Mcal/kg and 1.599 Mcal/kg at three and four groups. Protein concentrations increased from 15.29% to 15.91% before falling to 15.80% and 15.74%. The proportion of cows gaining weight decreased with an increase in number of groups, declining from 66.92 to 58.13 to 56.21, and finally to 55.96 with four groups. Average daily weight gain followed this pattern, decreasing from .2634 kg to .1589 kg to .1398 kg and then to .1378 kg with the largest number of groups.

The most interesting part of this data may be in comparing results of feeding to the average cow to results with all types of feeding. In all four grouping classes, average daily weight gain, number of cows gaining weight, and FCM produced per kg CP was highest when feeding was targeted to the average cow. The only exception to this was the ratio of 4% FCM to Mcal energy, which was slightly higher in all group classes for the entire data.

Data for medium producing herds summarized in the top half of Table 26 followed generally the same pattern as low producing herds. Each category of grouping systems had on average 86.31 lactating cows. The one group system averaged 60.33 cows gaining weight, while the two, three and four group systems had 51.78, 51.00, and 51.17, with average daily weight gains of .1426 kg, .0539 kg, .0502 kg, and .0524 kg for the respective grouping systems.

Milk production increased from 660.5 kg to 684.7 kg, or 3.7%, and dry matter intake decreased by 2.2%, from 491.2 kg to 480.3 kg, when the number of groups was increased from one to two. At three groups, 28 d FCM was 676.7 kg and dry matter intake 479.7 kg, representing decreases of 1.2% and .1%. With four groups, these numbers were 679.9 kg FCM and 481.2 kg dry matter intake. These figures meant rather modest increases of .5% and .3% for the respective categories. Nutrient concentrations of rations increased from 1.579 Mcal/kg and 15.88% CP to 1.624 Mcal/kg and 16.49% CP as the total number of groups changed from one to two. At three and four groups, energy in the ration was 1.614 Mcal/kg and 1.615 Mcal/kg, and crude protein 16.29% and 16.31%. The ratios measuring milk to energy and protein increased from .8496 kg FCM/Mcal Nel to .8770 and 8.474 kg 4% FCM/kg CP to 8.634. These figures for three and four groups were .8736 and .8742 for energy, and 8.656 and 8.657 for protein.

Standard deviation for within group requirements followed the previously established pattern. For energy, standard deviations of .1147, .0629, .0506, and .0480 corresponded to one, two, three, and four group systems. For protein, these numbers were 2.419, 1.374, 1.083, and .9779. The significance of these quantities will be discussed more fully in the section dealing with levels of feeding.

Table 26. Medium Herd Means by Number of Groups
All Feeding Levels

1800 Observations	Number of groups			
	One	Two	Three	Four
Daily 4% FCM (kg)	23.59	24.41	24.13	24.25
Within group SD of daily 4% FCM (kg)	8.49	6.18	5.40	5.08
Daily average dry matter intake (kg)	17.54	17.14	17.11	17.17
28 day FCM per lactating cow (kg)	660.5	684.7	676.7	679.9
28 day DMI per lactating cow (kg)	491.2	480.3	479.7	481.2
Lactating cows	86.31	86.31	86.31	86.31
Lactating cows gaining weight	60.33	51.78	51.00	51.17
Avg daily weight change per cow (kg)	.1426	.0539	.0502	.0524
Avg days in milk	178.3	178.6	178.7	178.7
Recommended energy (Mcal NEL/kg)	1.609	1.637	1.624	1.625
Energy level fed (Mcal NEL/kg)	1.579	1.624	1.614	1.615
Within group SD recommended Mcal/kg	.1147	.0629	.0506	.0480
Recommended CP% of dry matter	15.93	16.49	16.27	16.31
CP% of dry matter fed	15.88	16.50	16.29	16.31
Within group SD of recommended CP%	2.419	1.374	1.083	.9779
FCM kg/NEL Mcal	.8496	.8770	.8736	.8742
FCM kg/CP kg	8.474	8.634	8.656	8.657

Recommended Feeding Level for Group Average Only

450 Observations	Number of groups			
	One	Two	Three	Four
Daily 4% FCM (kg)	24.39	24.78	24.39	24.56
Within group SD of daily 4% FCM (kg)	8.34	6.23	5.43	5.14
Daily average dry matter intake (kg)	17.75	17.29	17.22	17.29
28 day FCM per lactating cow (kg)	683.0	695.1	684.0	688.7
28 day DMI per lactating cow (kg)	497.1	484.3	482.7	484.3
Lactating cows	86.27	86.27	86.27	86.27
Lactating cows gaining weight	64.81	54.91	53.84	53.63
Avg daily weight change per cow (kg)	.2140	.0920	.0834	.0839
Avg days in milk	178.1	178.3	178.5	178.4
Energy level fed (Mcal NEL/kg)	1.622	1.641	1.627	1.629
Within group SD of recommended Mcal/kg	.1118	.0614	.0505	.0482
CP% of dry matter fed	16.18	16.59	16.32	16.37
Within group SD recommended CP%	2.334	1.350	1.075	.977
FCM kg/NEL Mcal	.8465	.8743	.8706	.8721
FCM kg/CP kg	8.481	8.642	8.677	8.682

As with the lower producing cows, when recommended energy and protein levels were fed, milk production, dry matter intake, the number of cows gaining weight, average daily weight gain, and milk produced per unit of protein ingested were all higher than the data for the multiple levels of feeding. This was reversed once again with the lower ratio for milk to energy when only considering recommended feeding results.

Table 27 describes the final class of herds, the high producers. In the top half of the table, which details the averages for all levels of feeding, 28 d FCM per cow increased only a modest .9% from 742.2 kg to 749.2 kg when shifting from one group feeding to two group feeding. However, dry matter intake decreased from 506.6 kg to 493.7 kg, or 2.5%, under the same circumstances. Moving to three and four groups, FCM first decreased 3.9 kg, or .5%, and then increased 8.5 kg, or 1.1%, with dry matter intake increasing by .9 kg (.2 %) and 2.2 kg (.4%). Energy concentration fed was 1.621 Mcal/kg, 1.642 Mcal/kg, 1.634 Mcal/kg, and 1.641 Mcal/kg, with corresponding protein concentrations of 16.78%, 16.86%, 16.73%, and 16.86%. The numbers describing the standard deviation of within group nutrient requirements for energy decreased from .1105 to .0596 to .0504 and then to .0467 as the number of groups increased from one to four. For protein these figures were 2.298, 1.290, 1.010, and .911.

Of the 86.39 lactating cows in each grouping scenario, 57.61 gained weight in one group systems, 48.51 in two groups, 48.21 in three groups, and 48.32 in four groups. The average daily weight change was .0848 kg per cow in the one group system, but moved to a slightly negative figure for two, three, and four group systems at -.0145 kg per cow per day, -.0137 kg per cow per day, and -.0117 kg per cow per day. The ratios concerning milk produced per unit of energy or protein ingested followed the same pattern as that with the low and medium producers. For one, two, three, and four groups, these ratios

Table 27. High Herd Means by Number of Groups
All Feeding Levels

1800 Observations	Number of groups			
	One	Two	Three	Four
Daily 4% FCM (kg)	26.50	26.70	26.57	26.88
Within group SD of daily 4% FCM (kg)	9.49	6.69	5.81	5.50
Daily average dry matter intake (kg)	18.09	17.62	17.65	17.73
28 day FCM per lactating cow (kg)	742.2	749.2	745.3	753.8
28 day DMI per lactating cow (kg)	506.6	493.7	494.6	496.8
Lactating cows	86.39	86.39	86.39	86.39
Lactating cows gaining weight	57.61	48.51	48.21	48.32
Avg daily weight change per cow (kg)	.0848	-.0145	-.0137	-.0117
Avg days in milk	178.3	178.7	178.7	178.7
Recommended energy (Mcal NEL/kg)	1.650	1.652	1.644	1.651
Energy level fed (Mcal NEL/kg)	1.621	1.642	1.634	1.641
Within group SD recommended Mcal/kg	.1105	.0596	.0504	.0467
Recommended CP% of dry matter	16.83	16.82	16.72	16.85
CP% of dry matter fed	16.78	16.86	16.73	16.86
Within group SD recommended CP%	2.298	1.290	1.010	.911
FCM kg/Mcal NEL	.9023	.9238	.9214	.9240
FCM kg/CP kg	8.740	9.002	9.004	8.999

Recommended Feeding Level for Group Average Only

450 Observations	Number of groups			
	One	Two	Three	Four
Daily 4% FCM (kg)	27.27	26.98	26.87	27.12
Within group SD of daily 4% FCM (kg)	9.31	6.67	5.83	5.52
Daily average dry matter intake (kg)	18.26	17.76	17.78	17.82
28 day FCM per lactating cow (kg)	763.7	757.0	753.7	760.6
28 day DMI per lactating cow (kg)	511.4	497.6	498.2	499.4
Lactating cows	86.42	86.42	86.42	86.42
Lactating cows gaining weight	61.34	51.32	50.71	50.71
Avg daily weight change per cow (kg)	.1427	.0229	.0186	.0162
Avg days in milk	178.2	178.6	178.6	178.6
Energy level fed (Mcal NEL/kg)	1.659	1.654	1.647	1.652
Within group SD of recommended Mcal/kg	.1068	.0584	.0494	.0461
CP% of dry matter fed	17.05	16.90	16.78	16.89
Within group SD of recommended CP%	2.199	1.266	.999	.901
FCM kg/Mcal NEL	.8993	.9194	.9180	.9211
FCM kg/CP kg	8.750	8.999	9.011	9.009

were .9023, .9238, .9214, and .9240 for energy, and for protein 8.740, 9.002, 9.004, and 8.999.

In observing data from recommended feeding, the numbers were very similar to data from all feedings. With higher nutrient concentrations, milk production and dry matter intake were slightly higher for every grouping scenario when examining recommended feeding only. Feeding the recommended diet also resulted in slightly positive weight gains for each grouping system. Average daily weight gain per cow ranged from a high of .1427 kg with one group to a low of .0162 kg with a four group system. Milk produced per unit of ingested energy and protein repeated the pattern established with low and medium producing herds. More milk was produced per unit of energy with all feedings, but more milk per unit of protein was produced when only feeding recommended concentrations.

Separating Group Effects

From the means, it can be observed that increasing the number of groups from one to two, dry matter intake decreased and FCM increased. However, the concentration of nutrients also increased. Therefore, it would be useful to know how much of the changes were due to increased nutrient concentrations and how much were due to change in the number of groups. It would also be helpful to know how any herd characteristics, such as calving interval or within herd standard deviation of 305 d 4% FCM, would affect milk production. For these reasons, a model was constructed to explain 28 d 4% FCM in a lactating cow for the low, medium, and high producing herds. Three variations of the number of groups were included in the model. These forms were the number itself (Totgrp), the square of the number (Tgsq), and a log transformation of the number of groups (Lg). Average 28 d dry matter intake (Admi) and the energy (Avgnel) and protein (Avgcp) concentrations fed were also in the model. High and low calving intervals (Hci and Lci) and their interaction with the number of groups (Hcig and Lcig) and the number of groups squared (Hcigsq and Lcigsq), as well as high and low standard deviations of 305 d mature equivalent 4% FCM (Hsd and Lsd) were part of the model. Their interaction with the number of groups (Hsdg and Lsdg) and the number of groups squared (Hsdgsq and Lsdgsq) were also included.

There are several terms to describe the amount energy or protein was increased or decreased relative to the average cow. Energy was either fed at the recommended level or one-half standard deviation of the within group nutrient requirements below it. This variable was designated as Stnel, and although it could only be 0 or -.5, it represented a range of absolute numbers, depending on the standard deviation of the recommended energy within a group. If energy was reduced, protein could be either reduced by one-half standard deviation or fed to recommendations. This variable, Stcp, could also represent a continuum of absolute numbers, depending on the standard deviation of the recommended protein within a group. If energy was not reduced, protein was either overfed by one-half standard deviation or fed to recommendations. There was an interaction between these two terms in the model (Stnelcp), and these two terms and the number of groups (Stnelcpg), as well as interactions between the level of energy fed and the number of groups (Stnelg) and the number of groups squared (Stnelgsq) and the same interactions between the level of protein fed and the number of groups (Stcpg and Stcpgsq).

Parameter estimates and standard errors for the three models are displayed in Table 28. All included variables were significant at the .05 level. R-Squared for low, medium, and high producing herds was 94.5%, 94.8%, and 92.4%, respectively.

To determine the consequences of a change in the number of groups on 28 d 4% FCM per lactating cow, first derivatives of 4% FCM with respect to group were taken based on parameter estimates in Table 28. The equation for each of the models is listed in Figure 3. The equations explain expected change in FCM holding all other factors constant. This would of course include dry matter intake and nutrient concentrations. Since the energy content of the ration is known to affect fiber content, which affects dry matter intake, the dry matter intake within a group would most likely change. However, if overall energy concentration remained the same, overall fiber concentration would remain the same, and the assumption of holding dry matter intake constant for the entire herd could be considered valid. The advantage of this technique is that it allows separation of the effect of changing the number of groups from the effect of changing contents of the ration.[14]

Under the constraint of feeding only recommended concentrations, Table 29 was constructed based on Table 28 to display the grouping effect on FCM. The results do not necessarily reflect the expected answers based on a visual analysis of the means. For example, when changing from a one group system to a two group system in low producing herds, actual milk production increased on the average by 28.2 kg, dry matter intake decreased by 8.4 kg, protein concentration increased .7% and energy concentration increased by .05 Mcal/kg (Table 25). Holding dry matter intake and protein and

[14] While this assumption was valid for testing the grouping effect, it was not valid for testing the effect of underfeeding energy. A reduction in energy concentrations (and increase in fiber content) should affect dry matter intake as well as 4% FCM. This is addressed in a subsequent section.

Table 28. Equations Predicting kg 28 d 4% FCM per Grouped Cow

Variable	Low herds Parameter Estimate	SE	Medium herds Parameter Estimate	SE	High herds Parameter Estimate	SE
Intercept	-905.311		-1085.345		-1016.729	
Totgrp	26.843	6.208	32.760	7.413	-58.533	7.761
Log grp	-28.573	6.464	-23.639	7.771	94.279	8.179
Tgsq	-2.440	.676	-3.387	0.798	4.549	0.829
Admi	1.215	.014	1.442	0.015	1.566	0.017
Avgnel	155.804	18.967	201.236	22.524	170.115	18.683
Avgcp	42.756	.994	43.080	1.170	44.036	1.102
Stannel	-20.716	5.049	-34.470	6.075	-6.245	1.349
Stannelg	12.280	3.638	19.377	4.282		
Stannelgsq	-1.921	.680	-3.052	0.789		
Stancp	-137.329	4.972	-134.847	5.821	-130.532	4.804
Stancpg	66.832	3.036	73.488	3.706	69.278	8.179
Stancpgsq	-10.077	.534	-11.985	0.656	-11.194	0.541
Stannelcp	34.300	4.410	59.899	4.865	51.827	5.624
Stannelcpg	-12.598	1.610	-18.193	1.779	-15.897	2.043
Hsd	-4.676	1.028	-4.835	1.121		
Lsd						
Hsdg	3.657	.689	4.123	.751	4.088	.331
Lsdg			-.967	.109	-1.689	.333
Hsdgsq	-.095	.032	.135	.034	-.137	.026
Lsdgsq	-.047	.008			.051	.026
Hci	7.713	1.056				
Lci			-5.976	1.140		
Hcig	-5.653	.693	-1.330	.109	-1.090	.132
Lcig	.796	.101	5.394	.755	2.239	.298
Hcigsq	.180	.031				
Lcigsq					-.094	.023
R-Square	94.5		94.8		92.5	

Totgrp	Number of groups
Log grp	Natural log of number of groups
Tgsq	Number of groups squared
Admi	Average 28 day dry matter intake per lactating cow
Avgnel	Avg Mcal/kg of Nel
Avgcp	Avg CP%
Stannel	SD of underfed energy (-.5 or 0)
Stannelg	Totgrp interaction with underfeeding energy
Stannelgsq	Tgsq interaction with underfeeding energy
Stancp	SD of underfed or overfed protein (-.5, 0, or .5)
Stancpg	Totgrp interaction with underfeeding protein
Stancpgsq	Tgsq interaction with underfeeding protein
Stannelcp	Protein-energy underfeeding interaction
Stannelcpg	Protein-energy underfeeding interaction with groups
Hsd	High standard deviation of within herd 308 day 4% FCM
Lsd	Low standard deviation of within herd 308 day 4% FCM
Hsdg	HSD interaction with Totgrp
Hsdgsq	HSD interaction with Tgsq
Lsdg	LSD interaction with Totgrp
Lsdgsq	LSD interaction with Tgsq
Hci	High calving interval
Lci	Low calving interval
Hcig	High calving interval interaction with Totgrp
Hcigsq	High calving interval interaction with Tgsq
Lcig	Low calving interval interaction with Totgrp
Lcigsq	Low calving interval interaction with Tgsq

Fig 3. Equations Predicting FCM Change with Change in Number of Groups
kg per Lactating Cow per 28 Day Period

Low production herds

dFCM/dgrp = 26.843 - 28.573/G - 4.488 G - 12.598 StannelStancp
+ 12.280 Stannel - 3.841 StannelG + 66.832 Stancp - 20.153 StancpG
- 5.653 Hci + .360 Hcig + .796 Lci
+ 3.657 Hsd - .189 Hsdg + .093 Lsd

Medium production herds

dFCM/dgrp = 32.760 - 23.639/G - 6.774 G - 18.193 StannelStancp
+ 19.377 Stannel - 6.102 StannelG + 73.488 Stancp - 23.968 StancpG
- 1.330 Hci + 5.394 Lci -.414 Lcig
+ 4.123 Hsd - .271 Hsdg - .967 Lsd

High production herds

dFCM/dgrp = - 58.532 + 94.279/G + 9.096 G - 15.897 StannelStancp
+ 69.278 Stancp - 22.388 StancpG
- 1.090 Hci + 2.239 Lci - .187 Lcig
+ 4.088 Hsd - .273 Hsdg - 1.689 Lsd + .102 Lsdg

G	Total Number of groups
Stannel	SD of underfed energy (-.5 or 0)
Stancp	SD of underfed or overfed protein (-.5, 0, or .5)
Hsd	High standard deviation of within herd 308 day 4% FCM
Lsd	Low standard deviation of within herd 308 day 4% FCM
Hci	High calving interval
Lci	Low calving interval

*Increase in groups taken at midpoint

energy concentrations constant, the increase in FCM was only 1.06 kg (Table 29). Only examining the means as reported in Table 25, increasing the number of groups from two to three decreased FCM. However, as reported in Table 29, the effect of changing the number of groups while holding herd dry matter intake and nutrient concentrations constant was to increase average 28 d 4% FCM of lactating cows in the average low producing herd by 3.05 kg. Apparently the decline in mean 4% FCM as reported in the earlier table was attributable to the decrease in dry matter intake and concentration of nutrients.

The effect of group changes on FCM in low producing herds was not favorable to increasing the number of groups when feeding recommended nutrients. There were even situations where changing from one group to two groups had a negative effect on FCM. The most beneficial situation in changing from one group to two groups was when the herd had a low calving interval and a high variation of 305 d production among the cows. This resulted in an average increase of 5.23 kg per cow. To change this to three groups resulted in an additional 8.17 kg FCM. This was the highest figure for any of the low producing herds.

Improvement in 4% FCM production with an increase in the number of groups was more apparent with medium producing herds. Switching from one to two groups resulted in an increase of 6.84 kg per cow per 28 days in a herd with average calving interval and average variation of milk production within the herd. This increased to a maximum of 15.33 kg with a low calving interval and high variability. Further increases were attained by changing to three groups. For the average herd, this figure was 6.37 kg. To continue to a four group system resulted in a very modest gain per cow of 2.3 kg.

Table 29. Change in 4% FCM with Change in Number of Groups
KG per Lactating Cow per 28 Day Period

LOW PRODUCING HERDS

Standard deviation 305 d FCM	Calving Interval	one group to two groups (kg)	two groups to three groups (kg)	three groups to four groups (kg)
-1	-1	1.95	5.08	3.86
-1	0	1.16	4.29	3.06
-1	1	-3.96	-.47	-1.33
0	-1	1.86	4.99	3.77
0	0	1.06	4.19	2.97
0	1	-4.05	-0.56	-1.42
1	-1	5.23	8.17	6.76
1	0	4.44	7.38	5.97
1	1	-.68	2.63	1.57

MEDIUM PRODUCING HERDS

Standard deviation 305 d FCM	Calving Interval	one group to two groups (kg)	two groups to three groups (kg)	three groups to four groups (kg)
-1	-1	10.65	9.76	5.28
-1	0	5.87	5.40	1.33
-1	1	4.54	4.07	0.00
0	-1	11.61	10.73	6.24
0	0	6.84	6.37	2.30
0	1	5.51	5.04	.97
1	-1	15.33	14.17	9.42
1	0	10.56	9.81	5.47
1	1	9.23	8.48	4.14

HIGH PRODUCING HERDS

Standard deviation 305 d FCM	Calving Interval	one group to two groups (kg)	two groups to three groups (kg)	three groups to four groups (kg)
-1	-1	18.39	2.26	.49
-1	0	16.43	.49	-1.09
-1	1	15.34	-.60	-2.18
0	-1	19.92	3.69	1.83
0	0	17.96	1.92	.24
0	1	16.87	.83	-.85
1	-1	23.60	7.10	4.96
1	0	21.64	5.33	3.37
1	1	20.55	4.24	2.28

NOTE: 0 is average, 1 is higher than average, -1 lower than average

Relatively sharp increases were observed in high producing herds when a change was made from one group to two groups. For the average herd within the high producers, this change resulted in an increase of 17.96 kg per cow per period. However, further changes to three and four groups resulted in only modest increases of 1.92 kg and .24 kg. Having a low calving interval and high variability of 305 d milk production altered these results only modestly. The increases were 23.60 kg, 7.10 kg, and 4.96 kg, moving from one group to two groups to three groups to four groups.

This section reported on expected results of a change in grouping policy. These results were used to establishing assumptions concerning an economic analysis of grouping policy. However, to summarize this section, it can be stated that changing from one to two groups, with no change in feed cost, increased milk revenues from -.7 to .9% in low producing herds, .7 to 2.3% in medium producing herds, and 2.1 to 3.2% in high herds From two groups to three groups, the changes ranged from -.1 to 1.3% in low herds, .6 to 2.1% in medium herds, and -.1 to 1.0% in high herds. With high producing herds, the ranges were -.2 to 1.1%, -.2 to 1.0%, and -.3 to .7%, respectively. These changes, of course, do not consider change in cost in the physical process of feeding. More specific information concerning economics is detailed in later sections.

Effects of Underfeeding

Figure 4 lists equations describing change in 4% FCM with respect to change in nutrients due to reduced feeding of energy or protein. These equations were obtained by taking the first derivative of 28 d 4% FCM with respect to the variables relating to reduced feeding of energy or protein from the regressions detailed in Table 28. They were then used to construct Tables 30, 31, and 32 which list by groups the expected changes in FCM if a change in feeding policy is implemented.

The first section of Table 30 details expected change in FCM if feeding policy is changed to reduce energy concentrations by one-half the within group standard deviation of energy requirements. The second part of the table lists expected change in milk production if protein concentrations are reduced by one-half the within group standard deviation of recommended CP concentrations. Since there was an interaction between reduced feeding of energy and protein, the third portion of the table lists the total expected reduction in 4% FCM if both energy and protein are reduced from the average by one-half standard deviation. This figure could be calculated by summing either the expected decrease in 4% FCM if protein is reduced (Stnel=0) and then energy is reduced (Stcp=-.5), or energy is first decreased (Stcp=0) and then protein reduced (Stnel=-.5).

The final section of Table 30 furnishes the average value of one-half standard deviation of within group nutrient requirements for each of the groups. These numbers were obtained by multiplying within group standard deviations of recommended energy and protein from Tables 25, 26, and 27 by one-half.

Examining the first row of figures in Table 30 allows the reader to see how much decrease could be expected in FCM if energy concentrations are reduced and protein fed according to group average. Moving from one group to two groups, there was a rather sharp reduction from 5.179 kg per one-half SD to 1.920 kg. However, part of this reduction can be attributed to decrease in standard deviation of nutrient requirements within the group. These figures were standardized by dividing the reduction by one half the standard deviation, listed in the bottom line of the table. Examining the standardized version, the minimum drop in milk with a reduction in energy concentration of .01

Fig 4. Equations Predicting Change in FCM with Change in Feeding Level
kg per Cow per 28 Day Period

Low production herds

$$\frac{\partial fcm}{\partial stannel} = 12.280G - 1.921G^2 - 20.716 + 34.300Stancp - 12.598StancpG$$

$$\frac{\partial fcm}{\partial stancp} = 66.832G - 10.077G^2 - 137.329 + 34.300Stannel - 12.598StannelG$$

Medium production herds

$$\frac{\partial fcm}{\partial stannel} = 19.377G - 3.052G^2 - 34.470 + 59.899Stancp - 18.193StancpG$$

$$\frac{\partial fcm}{\partial stancp} = 73.488G - 11.985G^2 - 134.847 + 59.899Stannel - 18.193StannelG$$

High production herds

$$\frac{\partial fcm}{\partial stannel} = -6.245 + 51.827Stancp - 15.897StancpG$$

$$\frac{\partial fcm}{\partial stancp} = 69.278G - 11.194G^2 - 130.532 + 51.827Stannel - 15.897StannelG$$

G = Number of groups

G^2 = Number of groups squared

Stannel = SD of underfed energy (-.5 or 0)
Stannelg = Totgrp interaction with underfeeding energy
Stancp = SD of underfed or overfed protein (-.5, 0, or .5)
Stancpg = Totgrp interaction with underfeeding protein

Table 30. Change in 4% FCM in Low Herds with Change in Feeding Level KG per Lactating Cow per 28 Day Period

Change in 4% FCM With .5 Standard Deviation Reduction in Energy Level

	Groups 1	2	3	4
(1) If Recommended CP Fed	-5.179	-1.920	-.583	-1.166
(2) Per .01 Mcal/kg	-.888	-.577	-.224	-.478
(3) If Reduced CP Fed	-10.604	-4.196	.291	2.857
(4) Per .01 Mcal/kg	-1.819	-1.260	.112	1.171

(4)=(3) divided by (10); (2)=(1) divided by (11)

Change in 4% FCM With .5 Standard Deviation Reduction in Protein Level

	Groups 1	2	3	4
(5) If Recommended Energy Fed	-40.287	-21.987	-13.763	-15.617
(6) Per 1% CP	-32.700	-30.036	-23.770	-29.859
(7) If Reduced Energy Fed	-45.713	-24.263	-12.890	-11.594
(8) Per 1% CP	-37.104	-33.145	-22.262	-22.167

(8)=(7) divided by (10); (6)=(5) divided by (11)

Change in FCM with .5 Standard Deviation Reduction in Protein & Energy

	Groups 1	2	3	4
(9) 28 day 4% FCM per cow	-50.892	-26.183	-14.473	-12.760

Change in Nutrient Concentration with .5 SD Change in Feeding Level

	Groups 1	2	3	4
(10) Energy (Mcal NEL/kg)	-.0583	-.0333	-.0260	-.0244
(11) CP% of dry matter	-1.232	-.732	-.579	-.523

Mcal/kg occurred in the three group situation, where a decrease in concentration of .01 Mcal/kg implied a decrease in milk production of .224 kg. However, if protein was being underfed, the minimum drop in milk production with a decrease in energy occurred in the four group feeding scenario, where FCM actually increased slightly with a decrease in energy concentration.

Reduced protein feeding to low producers produced the same general results as underfeeding energy. If energy was fed according to recommendations, the grouping strategy with the least adverse affect on 4% FCM was the three group system. A one-half standard deviation drop in feeding resulted in a decrease of 13.763 kg of milk, or 23.770 kg per one percent drop in protein. If energy was underfed and then protein reduced, the four group system had the smallest negative impact on 4% FCM. This decrease was 11.594 kg, or 22.167 kg for a one percent drop in protein concentration.

Although the third section of the table was not standardized, it can be seen that the smaller drops in milk production due to underfeeding both protein and energy occurred in the three and four group systems. In three groups, this drop was 14.473 kg, and in four, 12.760 kg. With the smaller standard deviations in the system with the most groups, the decreases in milk production with an absolute decrease in protein and energy concentration were probably slightly less in the three group feeding plan.

Table 31 describes the same data as Table 30, only for medium producing herds instead of low producers. Once again there was a sharp decrease in loss of milk if underfeeding energy in a two group rather than a one group setting, with a good deal of this decrease due to smaller variation in nutrient requirements within groups in the two group feeding system. Absolute decreases were 9.073 and 3.962 kg per cow per period, corresponding to 1.581 kg per .01 Mcal/kg and 1.258 Mcal per .01 Mcal/kg. The minimum decrease occurred at three groups if protein was fed to recommendations (1.904 kg FCM and .752 kg FCM per .01 Mcal/kg DMI) and at four groups if protein was underfed (actually an increase of .321 kg FCM and .134 kg FCM per .01 Mcal/kg DMI). If protein was fed to recommendations instead of being underfed by one-half standard deviation, expected increase in FCM per cow per period was 36.672, 17.906, 11.124, and 16.328 kg, corresponding to one, two, three, and four group feeding systems. For a 1% change in protein, these figures were 30.059, 26.063, 20.524, and 33.390 kg. If energy was underfed, decreases in FCM were 47.099, 23.784, 12.454, and 13.109 kg. Standardized to a 1% change in protein, these numbers were 38.605, 34.602, 22.978, and 26.808 kg. Total FCM lost per cow in a period if underfeeding both energy and protein was 56.171, 27.746, 14.358, and 16.006 kg. Once again, the grouping strategy least affected by underfeeding was the three group plan.

Information pertaining to high producing herds can be found in Table 32. Underfeeding energy resulted in a loss of 6.245 kg 4% FCM per cow per 28 day period regardless of number of groups. Since the standard deviation was smaller with the higher number of groups, the loss per .01 Mcal/kg was greater with more groups. If protein was already underfed, underfeeding energy resulted in losses of 12.105, 8.131, 4.157 and .182 kg for one, two, three, and four group feeding systems, or on a per .01 Mcal/kg basis, 2.189, 2.728, 1.649, and .078 kg.

The opportunity cost associated with underfeeding protein was very similar to that seen with medium producing herds. The loss in milk ranged from a high with the one group system of 36.226 kg 4% FCM to a low of 11.724 kg 4% FCM with the three group system. Standardized to a 1% CP basis, these changes were 31.528 kg, 28.492 kg, 21.315 kg, and 35.666 kg, moving from least to most groups. If energy was underfed, the op-

Table 31. Change in 4% FCM in Medium Herds with Change in Feeding Level
KG per Lactating Cow per 28 Day Period

Change in 4% FCM With .5 Standard Deviation Reduction in Energy Level

	Groups 1	2	3	4
(1) If Recommended CP Fed	-9.073	-3.962	-1.904	-2.897
(2) Per .01 Mcal/kg	-1.581	-1.258	-.752	-1.207
(3) If Reduced CP Fed	-19.499	-9.840	-3.234	.321
(4) Per .01 Mcal/kg	-3.397	-3.124	-1.278	.134

(4)=(3) divided by (10); (2)=(1) divided by (11)

Change in 4% FCM With .5 Standard Deviation Reduction in Protein Level

	Groups 1	2	3	4
(5) If Recommended Energy Fed	-36.672	-17.906	-11.124	-16.328
(6) Per 1% CP	-30.059	-26.063	-20.524	-33.390
(7) If Reduced Energy Fed	-47.099	-23.784	-12.454	-13.109
(8) Per 1% CP	-38.605	-34.602	-22.978	-26.808

(8)=(7) divided by (10); (6)=(5) divided by (11)

Change in FCM with .5 Standard Deviation Reduction in Protein & Energy

	Groups 1	2	3	4
(9) 28 day 4% FCM per cow	-56.171	-27.746	-14.358	-16.006

Change in Nutrient Concentration with .5 SD Change in Feeding Level

	Groups 1	2	3	4
(10) Energy (Mcal NEL/kg)	-.0574	-.0315	-.0253	-.0240
(11) CP% of dry matter	-1.220	-.687	-.542	-.489

Table 32. Change in 4% FCM in High Herds with Change in Feeding Level
KG per Lactating Cow per 28 Day Period

Change in 4% FCM With .5 Standard Deviation Reduction in Energy Level

	Groups 1	2	3	4
(1) If Recommended CP Fed	-6.245	-6.245	-6.245	-6.245
(2) Per .01 Mcal/kg	-1.129	-2.095	-2.478	-2.669
(3) If Reduced CP Fed	-12.105	-8.131	-4.157	-.182
(4) Per .01 Mcal/kg	-2.189	-2.728	-1.649	-.078

(4)=(3) divided by (10); (2)=(1) divided by (11)

Change in 4% FCM With .5 Standard Deviation Reduction in Protein Level

	Groups 1	2	3	4
(5) If Recommended Energy Fed	-36.226	-18.378	-11.724	-16.264
(6) Per 1% CP	-31.528	-28.492	-21.315	-35.666
(7) If Reduced Energy Fed	-45.208	-23.386	-12.758	-13.323
(8) Per 1% CP	-39.346	-36.257	-23.195	-29.218

(8)=(7) divided by (10); (6)=(5) divided by (11)

Change in FCM with .5 Standard Deviation Reduction in Protein & Energy

	Groups 1	2	3	4
(9) 28 day 4% FCM per cow	-48.462	-26.509	-15.881	-16.446

Change in Nutrient Concentration with .5 SD Change in Feeding Level

	Groups 1	2	3	4
(10) Energy (Mcal NEL/kg)	-.0553	-.0298	-.0252	-.0234
(11) CP% of dry matter	-1.149	-.645	-.550	-.456

portunity cost of underfeeding protein increased for three of the grouping plans, but decreased for the four group scenario. These costs were 45.208, 23.386, 12.758, and 13.323 kg, and standardized to 39.346, 36.257, 23.195, and 29.218 kg. Total losses in milk due to underfeeding both energy and protein were 48.462, 26.509, 15.881, and 16.446 kg.

In summarizing the three production classes of herds, the opportunity cost of underfeeding protein to all herds was quite similar, while underfeeding energy was more detrimental with higher producing herds. The within group standard deviations of all three classes of herds were also very similar, with high producing herds having a slightly smaller variation in nutrient requirements within the groups. This figure in the one, two, three, and four group feeding scenarios was .0553, .0298/kg, .0252, and .0234 Mcal/kg for energy and for protein 1.149, .645, .550, and .456%, with the other classes of herds a little larger.

Generally speaking, three and four group feeding strategies minimized loss in 4% FCM due to feeding to less than the average cow. With more than two groups, high producing cows in a herd will be fed close to recommended nutrients even if they are underfed because within group standard deviation of nutrients for the high groups was relatively small. Underfeeding of high producing cows was more detrimental to herd production than reduced feeding in later lactation.

Under certain conditions, some feeding decisions were quite apparent without knowing the price of milk or cost of the ration. For example, if a four group medium or high producing herd was underfeeding protein for whatever reason, an obvious strategy would be to underfeed energy as well since it would result in a negligible change in 4% FCM. It would seem in that situation that protein was the limiting factor in milk production and an increase in protein would be a more satisfactory solution than decreasing energy. However, if for some reason it was not possible to increase protein, energy should be reduced as well.

In a similar vein, if a low producing herd was underfed energy by .0244 Mcal/kg, reducing protein concentration of the overall ration by one-half percent in a four group feeding system would result in the loss of only 3.835 kg of 4% FCM per cow per 28 day period. A more precise analysis of the economic reasons behind the underfeeding of cows will be detailed in the following section.

The Economics of Feeding and Grouping Cows

Grouping and feeding policies are not necessarily two independent events. When the grouping policy was examined, the change in 4% FCM was looked at while holding dry matter intake and nutrient concentrations constant. The grouping policy that appeared most responsible for an increase in 4% FCM under these constraints was the two group feeding system. However, the three group system apparently was the least responsive to reduced feeding of recommended nutrients. The benefits to a small response are that targeting feeding to a lower than average cow in the group would lead to relatively smaller decreases in milk production. This would suggest that an increase in milk price would favor two group feeding and an increase in feed price three group feeding. Since the four group system did not appear more favorable under either of these conditions, economic evaluations will concentrate on comparing individual to one and two group recommended feeding, and contrasting one, two, and three group feeding plans.

The Economics of Individual vs. Group Feeding

The purpose of this section is to examine the decision making process in economically evaluating costs and benefits of switching from group to individual feeding. The first analysis pertains to evaluating a change from one group to individual feeding. With this type of change, benefits could be expected to be achieved from either an increase in milk production, a decrease in dry matter intake, or a decrease in nutrient concentrations of the ration. However, recalling that Table 19 described change in FCM holding dry matter intake and energy concentration (which was linearly related to protein concentration) constant, the benefits of changing to an individual feeding system could all be attributed to the increase in FCM. Profit can be defined as $\pi = pq - FC - VC$, where p is price of milk, q is quantity FCM produced, FC is fixed cost, and VC is variable cost. Converting to individual feeding from a one group system, change in profit would be price, p, times change in quantity per cow, q, times number of cows. Increased costs would be the change in fixed cost plus the change in variable cost per cow times the number of cows.

There are several unknowns in this equation. With some assumptions added, profitability can be evaluated from a change in feeding systems. From Table 19, expected change in FCM for the average medium producing herd was 22.919 kg/cow per 28 days when changing from one group to individual feeding. If a price of $.30/kg was assumed ($13.64/cwt), then expected increase in revenue would be $6.88 per cow per 28 day period. If on the average there were 100 cows milking, expected increase in four week revenues would be $688, which would need to exceed increases in total fixed and variable costs for the period.

A range of milk prices and variable costs can be tested to examine a maximum affordable investment. If milk price and individual system cost are known a minimum number of cows to finance a system can be determined. For a medium producing herd that has on average 100 cows milking, the top of Table 33 lists annual increase in profit at three different milk prices and three different increases in variable costs, all with no fixed costs.[15] These results were then used to determine the maximum investment that can be financed for ten years at 12% interest.[16] If there was no increase in variable cost per cow associated with individual feeding, which is not realistic but included to show increase in revenue, profit can be expected to increase between $7449 per year with a milk price of $.25/kg and $10,429 per year with a milk price of $.35/kg. These figures were obtained by multiplying milk price by expected increase in 28 d 4% FCM for one cow, in this case 8.64 kg from Table 29. The 28 day increase in profit per cow could then be multiplied by the number of cows in milk, 100, and the number of 28 day periods in a year, 13. At $30 per cow, or $3000 per year, variable cost of operating an individual feeding system, increase in annual profit assuming no fixed cost would range from $4449 to $7429 under the three pricing scenarios.

The middle of Table 33 presents the maximum investment that could be afforded with these price scenarios and the variable cost per cow. Range of prices were from $25,138 to $58,924. The final part of Table 33 shows the number of cows required to finance a $10,000 investment if a switch were to be made to individual feeding. As the price of milk went down or variable cost went up, number of cows required to cover fixed costs went up. With no variable cost, between 16.08 and 22.51 cows were required to finance

[15] In this context, increase in variable cost is increase in cost of the physical process of feeding the cow, not a change in cost of feed. This terminology will be used throughout the economic analysis.

[16] This represents a nominal, rather than real rate of interest. Since no allowance was made for inflation, a milk price reflecting average price over the next ten years should be used.

Table 33. Breakeven Analysis for Individual vs One Group Feeding
Medium Producing Herds, Average Characteristics

Annual Increase in Profit with 100 Cows in Milk and No Fixed Cost

Variable Cost per Cow	Price of Milk per kg		
	$.25	$.30	$.35
$ 0	7449	8939	10429
$15	5949	7439	8929
$30	4449	5939	7429

Maximum Breakeven Investment at 10 Years, 12% Interest, 100 Cows in Milk

Variable Cost per Cow	Price of Milk per kg		
	$.25	$.30	$.35
$ 0	42,088	50,506	58,924
$15	33,613	42,031	50,448
$30	25,138	33,555	41,973

Breakeven # of Cows in Milk/$10,000 Investment, 10 Years, 12% Interest

Variable Cost per Cow	Price of Milk per kg		
	$.25	$.30	$.35
$ 0	23.76	19.80	16.97
$15	29.75	23.79	19.82
$30	39.78	29.80	23.82

a $10,000 investment in an individual feeding system. If variable cost increased to $3000 per year, the range for the number of cows was between 22.10 and 36.39 as milk price varied from $.25/kg to $.35/kg. These results can be used to analyze a breakeven number of cows for any investment cost. This can be done by dividing the cost by 10,000 and multiplying the result by the number of cows in the appropriate row and column. If cost of the investment was $30,000, with a milk price of $.30/kg and variable cost of $15 per cow, the minimum number of cows for the investment to pay for itself in ten years at a 12% discount rate would be 22.29 times 3, or 66.87.

Tables 34 and 35 combine information concerning changes in 4% FCM with economics presented in the preceding paragraphs. Under assumption of $.30/kg for milk price, three different variable costs are presented for the three herd types. Within each herd type, average represents a herd with average calving interval and variation of milk production, low represents the lowest possible predicted change in 4% FCM, and high represents the highest possible change.

From examining only the highest variable cost in Table 34, it can be seen that the average low producing herd with 100 cows milking could afford to spend $17,491 on an individual feeding system if contemplating a switch from a one group system. A medium producing herd could afford $33,556 under the same circumstances, and $18,880 if changing from a two group system.[17] A high producing herd with average characteristics could afford to spend no more than $33,445 for the same herd characteristics. In a switch from two group to individual feeding, the herd would probably need a low SD and a high CI to justify such a change.

[17] In this situation, the change in variable cost would more than likely not be the same. Since there is probably a greater variable cost in feeding with two groups than one, the change in variable cost associated with a change from a two group system would be less than a one group system.

Table 34. Maximum Investment Cost for Individual Feeding
10 Years, 12% Interest, Milk Price = $.30/kg, 100 Milking Cows

LOW PRODUCING HERDS

	Change in Annual Variable Cost per Cow $0	$15	$30
One group to individual			
Low - low or avg SD	25,694	17,218	8,743
Average	34,442	25,967	17,491
High - high SD, high CI	42,904	34,429	25,953
Two groups to individual			
Low - low or avg SD, low CI	2,468	-----	-----
Average	11,304	2,829	-----
High - low SD, high CI	22,719	14,244	5,768

MEDIUM PRODUCING HERDS

	Change in Annual Variable Cost per Cow $0	$15	$30
One group to individual			
Low - high SD, low CI	32,459	23,984	15,508
Average	50,506	42,031	33,556
High - mid SD, high CI	61,877	53,401	44,926
Two groups to individual			
Low - high SD, low CI	17,452	8,977	502
Average	35,830	27,355	18,880
High - mid SD, high CI	49,272	40,797	32,321

HIGH PRODUCING HERDS

	Change in Annual Variable Cost per Cow $0	$15	$30
One group to individual			
Low - mid SD, low Ci	38,783	30,308	21,832
Average	50,396	41,921	33,445
High - low SD, mid or high CI	69,854	61,378	52,903
Two groups to individual			
Low - high SD, low CI	-----	------	------
Average	11,084	2,609	------
High - low SD, high CI	34,927	26,452	17,976

Table 35 reports information concerning minimum numbers of cows required to justify investment in individual feeding facilities. The figure corresponding to each row and column is the number of lactating cows (not total number of cows in the herd) that would be needed to justify each $10,000 investment. For example, if a $30,000 individual feeding system was to be installed, the cow numbers would each need to be multiplied by three. If the increase in variable cost per cow for changing from a one group to an individual feeding system with a medium producing herd of average characteristics was $30, the minimum number of cows to support the purchase of the $30,000 system would be 3 times 29.80, or approximately 89.

From Table 35, it can be seen that to justify changing from a one group system to a $20,000 individual feeding system with an annual increase in variable cost per lactating cow of $30, a low producing herd would need between 77 cows (with a high SD and low CI) and 229 cows in milk in the herd (low or mid SD and high CI). A medium producing herd would require between 45 (low or mid SD and high CI) and 129 cows (high SD and low CI), and a high producing herd, 35 (low SD) to 64 (high SD). To switch from two groups to individual feeding with an additional cost of $15 per cow annually, a low producing herd with average characteristics would require 707 cows milking. The average medium producing herd would need 73 cows, with a low of 49 (low or mid SD and high CI) and a high of 223 (high SD and low CI) while the average high producing herd would require 766 cows. Even under the situation most conducive to a switch from two groups to individual feeding, a high calving interval and high within herd standard deviation of milk production, a minimum of 75 cows would be required to pay for the system.

Table 35. Minimum No. Cows in Milk per $10,000 Feeding Investment
10 Years, 12% Interest, Milk Price = $.30/kg

LOW PRODUCING HERDS

	Change in Annual Feeding Cost per Cow $0	$15	$30
One group to individual			
Low - low or mid SD, low CI	38.92	58.08	114.38
Average	29.03	38.51	57.17
High - high SD, high CI	23.31	29.05	38.53
Two groups to individual			
Low - mid SD, low CI	405.18	-----	-----
Average	88.46	353.47	-----
High - low SD, high CI	44.02	70.21	173.36

MEDIUM PRODUCING HERDS

	Change in Annual Feeding Cost per Cow $0	$15	$30
One group to individual			
Low - high SD, low CI	30.81	41.70	64.48
Average	19.80	23.79	29.80
High - mid SD, high CI	16.16	18.73	22.26
Two groups to individual			
Low - high SD, low CI	57.30	111.39	1993.06
Average	27.91	36.56	52.97
High - mid SD, high CI	20.30	24.51	30.94

HIGH PRODUCING HERDS

	Change in Annual Feeding Cost per Cow $0	$15	$30
One group to individual			
Low - mid SD, low CI	25.78	32.99	45.80
Average	19.84	23.85	29.90
High - low SD, mid or high CI	14.32	16.29	18.90
Two groups to individual			
Low - high SD, low CI	------	------	------
Average	90.22	383.33	------
High - low SD, high CI	28.63	37.81	55.63

To generalize the results of comparing group feeding to individual feeding, it would appear that nearly all dairies with an average of 100 cows in milk over the year would support a switch from one-group feeding to an individual feeding system that cost $20,000 plus an increase in annual variable cost over the one group system of $3000 per year. In fact, the average low, medium, and high producing herds would need only 58, 40, and 40 cows in milk to support this move. With an increase in variable cost of $15 per cow per year, medium producing herds would need between 49 and 222 cows in milk to change to individual from two group feeding. However, average low and high producers would need over 700 cows milking to justify a change from two groups to individual feeding. This suggests that there are situations where two group feeding can be as profitable as individual feeding.

The Economics of Total Group Numbers

Dividing a herd of cows into more than one group should normally increase allocational efficiency of the feeding system. Higher producing cows would be fed rations with higher nutrient concentrations, while lower producing cows would receive lower concentrations. When the cows in the simulation were fed in different grouping systems, feed intake often decreased and milk production increased. A previous section of the research dealt with accounting for the increase in milk due to an increase in the number of groups, holding dry matter intake and overall nutrient concentrations constant. That section formed part of the basis for economic analysis of grouping. Since ration content and dry matter intake did not change, benefits to grouping can be attributed to increase in 4% FCM.[18]

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[18] This, of course, is not completely true. Ration contents do change within each group, under the as-

The profitability analysis for this section follows the same logic as that in the preceding section. For profit to increase, increase in milk times price of milk must exceed increase in fixed and variable cost. Increasing the number of groups would be more associated with an increase in variable costs than investment. A change to individual feeding would probably mean a higher increase in fixed than variable cost.

Table 36 demonstrates the effect of milk price and grouping cost on the ultimate grouping decision. The top part of the table shows expected increase in revenue from an increase in 28 d 4% FCM for a 100 cow dairy herd with three possible milk prices. Increases in revenue varied from a low of $1300 per year with a 4 kg increase per cow to a high of $9100 with a milk price of $.35/kg.

The second section of the table shows the maximum total cost that would support an increase in milk production at the given price level. Increases in total cost are those that are attributed to the extra group, such as additional operating expenses and labor costs due to an increase in time spent feeding. There could also be additional fixed costs involved, probably pertaining to an adjustment in the facilities due to a change in the feeding system. The annual cost of $1,000 of capital amortized over 10 years at an annual 12% interest rate would be $177. Over 365 days, this is approximately $.50 per day. Therefore, to account for any fixed costs, $.50 per day per $1,000 invested can be subtracted from the maximum variable cost that the increase in revenue would support. As an example, from Table 29, an average medium producing herd would have an expected increase in 28 d FCM of 6.84 kg if a change was made from one to two groups.

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sumption that this occurs due to a change in the forage-concentrate ratio. High producing cows receive a higher amount of concentrate and low producing cows receive a lower proportion of concentrate. Overall, total forage and concentrate consumed within the herd remain the same. Another possible benefit to increasing number of groups is a reduction in concentrate fed with a smaller corresponding loss in milk than would have occurred with fewer groups. The economic implications of this are discussed in a later section.

Table 36. Breakeven Analysis for Determining Number of Groups

Annual Increase in Revenue with 100 Cow Herd

Price of Milk per kg	Increase in 28 Day 4% FCM per Cow				
	4 kg	8 kg	12 kg	16 kg	20 kg
$.25	1300	2600	3900	5200	6500
.30	1560	3120	4680	6240	7800
.35	1820	3640	5460	7280	9100

Maximum Increase in Variable Cost per Day for 100 Milking Cows
Subtract $.50 per $1,000 Investment from Variable Cost

Price of Milk per kg	Increase in 28 Day 4% FCM per Cow				
	4 kg	8 kg	12 kg	16 kg	20 kg
$.25	$3.57	$7.14	$10.71	$14.28	$17.86
.30	4.29	8.57	12.85	17.14	21.43
.35	5.00	10.00	15.00	20.00	25.00

Minimum Number of Milking Cows per kg Improvement*
Add $.50 per $1,000 Investment When Determining Total Cost

Price of Milk per kg	Total Increase in Cost per Day ($)					
	2.50	5.00	7.50	10.00	12.50	15.00
$.25	280	560	840	1120	1400	1680
$.30	233	467	700	933	1167	1400
$.35	200	400	600	800	1000	1200

*Divide by Expected Improvement to Find Minimum Number of Cows

Interpolating the appropriate section of Table 36, it could be concluded that expected improvement in milk production would support an increase in total cost of feeding between $6.10 and $8.55 as price of milk ranged from $.25 to $.35 per kg.

The final section of the table was included to give a perspective on required group size. There were three levels of milk prices and six levels of variable costs examined. An estimate of expected increase in FCM from Table 29, combined with an estimate of variable cost, can be used to determine the minimum number of cows in the herd that would economically support an increase in the number of groups. Using the earlier expected increase of 6.84 kg and adding $6.00 per day variable cost and a $3,000 investment for a total increase of $7.50 in daily cost, the minimum number of cows required can be calculated. At a milk price of $.30/kg, 700 milking cows would be needed if estimated improvement was 1 kg per cow per 28 days. Since the improvement was 6.84 kg per cow, 700 must be divided by by 6.84, for a final estimate of 102 milking cows, 51 in each group, required to support the change from one group to two groups. If a move from two groups to three groups was considered, with the same increase in cost as the move from one to two groups, the expected improvement in milk production would only be 6.37 kg. The 700 must be divided by 6.37, for a total of 110 cows required to support the three group system, or about 37 in each group.

Examining low and high producing herds with average characteristics in Table 29, it can be seen that increasing low herds from one to two groups had virtually no effect on 4% FCM. However, increasing to three groups was associated with an increase in milk production of 4.19 kg. This would support an increase in operating cost of $4.49 per day for a herd with 100 milking cows at a milk price of $.30/kg. Under the assumption of a $7.50 per day increase in cost of feeding, 167 cows would be needed to finance the change to three groups (700/4.19). The average high producing herd increased 28 d 4% FCM by 17.96 kg per lactating cow. Using the same assumptions and methods as above, this would support an increase in operating cost of $19.24 per day and only 39 cows would be needed to finance the change from one to two groups.

Table 29, which described increases in FCM associated with increases in the number of groups, was used to construct Table 37. This table demonstrates the minimum number of cows per group necessary to justify a $10 increase per day per added group increase in fixed and variable feeding costs under three different milk price scenarios. Within each production class, average defines a herd that has average calving intervals and average variation of within herd milk production. Low describes the situation that was found to be least beneficial for adding a group, and high the opposite. This method of evaluation was selected so that the minimum number of cows would be presented along with a range of possible values.

The average medium producing herd, with an increase in costs of $10 per day and milk price at $.30/kg, would require 68 cows to be in each group. As herd characteristics varied from extreme situations, minimum number of cows per group in medium producing herds varied from 30 to 103, indicating the influence of herd characteristics on the grouping decision. If it was desired to increase the number of groups to three, the minimum group size in a herd with average characteristics would be 49 with a $10 cost per group per day. Therefore, while a herd size of 136 could justify two groups, a herd size of 147 would be needed to justify three groups.[19]

[19] It may seem odd that milk production is more responsive to an increase from one to two groups rather than two to three groups, yet smaller groups are required for the three group system. Although the increase in FCM per cow is smaller with a change from two groups to three groups, the increased production is felt over 105 cows rather than 82.

Table 37. Minimum Number of Cows per Group per $10.00 Increase in Cost per Day per Group

LOW PRODUCING HERDS

	Milk Price per kg		
	$.25	$.30	$.35
One to two groups			
Average	528.3	440.3	377.4
High - high SD, low CI	107.1	89.2	76.5
One to three groups			
Average	142.2	118.5	101.6
High - high SD, low CI	55.7	46.4	39.8
Two to three groups			
Average	89.1	74.3	63.6
High - high SD, low CI	45.7	38.1	32.6

MEDIUM PRODUCING HERDS

	Milk price per kg		
	$.25	$.30	$.35
One to two groups			
Low - low SD, high CI	123.3	102.8	88.1
Average	81.9	68.2	58.5
High - high SD, low CI	36.5	30.4	26.1
Two to three groups			
Low - low SD, high CI	91.7	76.4	65.5
Average	58.6	48.8	41.9
High - high SD, low CI	26.3	22.0	18.8

HIGH PRODUCING HERDS

	Milk price per kg		
	$.25	$.30	$.35
One to two groups			
Low - low SD, high CI	34.1	28.4	24.3
Average	31.2	26.0	22.3
High - high SD, low CI	23.7	19.8	16.9
Two to three groups			
Average	194.4	162.0	138.9
High - high SD, low CI	52.6	43.8	37.6

High producing herds required very few cows to justify changing from one to two groups. A high producing herd with average herd characteristics and an increase in variable cost of $10 per day needed only 26 cows per group with a milk price of $.30/kg and 31 cows per group with a milk price of $.25/kg. Even with extreme herd characteristics and the lowest milk price, these figures ranged from 24 to 36. Increasing to three groups required a minimum group size of 162 cows for the average high producing herd at a milk price of $.30/kg. Even the most favorable situation, a high SD and low CI, required 44 cows per group at this same milk price.

In low producing herds and a milk price of $.30/kg, an increase in operating cost of $10 per day required a minimum of 89 cows per group for the situation most conducive to adding a group, high SD and low CI. However, if it was desired to increase from one group to three groups, this figure was reduced to 46 cows per group.[20] In a herd with average characteristics, 102 cows per group would be required. For low producing herds, an economic analysis was made from one to three groups as well as one to two groups since a greater increase was seen with the addition of the third group than the second group, but the third group could not be added until after the second one.

Table 37 can be used to evaluate a minimum number of cows necessary to support a change in grouping policy even if estimated increase in cost is not $10 per day. If this is the case, the number of cows necessary to support the actual estimated increase can be determined by dividing that cost by ten and multiplying the result by the appropriate milk price column and herd category row.

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[20] The assumed increase in cost was $10 per day for each additional group. Therefore by adding two groups, total increase in fixed and variable cost was $20.

Results presented above indicated that under nearly all scenarios for high and medium producering herds, it was profitable to increase from one to two or three groups. With a grouping cost of $10 per day, a medium sized herd with average characteristics would require 55 cows in each of two groups, while an average herd in the high producing category would only need 26 cows per group. A medium producing herd in the same situation would require 48 cows per group to defend an increase to three groups, while high producers would be less inclined to justify a third group.

Economic reasoning for increasing the number of groups with low producing herds was not as obvious as with the other two classes. This is not totally consistent with the data regarding comparison of individual and one and two group feeding systems, which showed some benefits to increasing to two groups. There were some situations where increasing to two groups was beneficial and it could be that some of the herd characteristics that were correlated with higher grouping benefits were disguised in some of the other variables. Economic benefits of increasing low producing herds to three groups were less than but comparable to the other two production classes of herds.

The Economics of Grouping and Underfeeding Energy

Tables 30, 31, and 32 described expected losses in milk due to feeding less protein and energy than group average. When different grouping systems were analyzed, rations of equal nutrient contents were compared. Therefore, when groups were compared, parameter estimates for reduced feeding described expected loss in milk due to not feeding group average nutrient concentrations. If the value of dry matter intake saved was greater than the value of lost milk production, reduced feeding would be economically sound. This section concerns this economic evaluation of underfeeding.

Using Virginia Dairy Guideline 404-152 (5) and NRC (41) as sources, Table 38 was presented for nutrient analysis of selected feeds. Feeds were chosen because of common usage on dairies. Table 38 was used to construct sample feeds using corn silage, alfalfa silage, corn grain, and soybean meal to balance rations with different protein and energy concentrations. These rations are reported in Appendix A. As can be seen from Appendix A, with high quality forages, high energy concentrations are practical even with a constraint of no more than 50% of dry matter intake from concentrates.

Table 38, with slight modifications, was used as a basis for the analysis concerning reduced feeding of recommended nutrients. There were some assumptions that needed to be made concerning dry matter intake and nutrient concentrations. One of the more important assumptions was that ration energy content could be adjusted by altering the ratio of concentrate to forage. Some of the energy and protein values in Table 38 were changed slightly to simplify mathematical computations. A forage mix of one-half corn silage and one-half alfalfa silage, both of intermediate quality, would have an energy concentration of 1.41 Mcal/kg and protein concentration of 12%. For simplification, the first figure was modified to 1.40 Mcal/kg. No matter what the ratio of corn to soybean meal, it was also assumed that concentrate contained 2.00 Mcal/kg. Energy concentration would increase from 1.40 Mcal/kg to the maximum allowable 1.76 Mcal/kg as the proportion of concentrate in the ration increased from 0 to 60%. This would correspond with an ADF% between 17 and 18, depending on the amount of soybean meal in the concentrate.[21]

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[21] This figure is less than the minimum recommended by NRC, 19%, but could be attainable with a higher ADF% if high quality forages were used as displayed in Appendix A.

Table 38. Energy and Protein Contents of Selected Feeds

Forages	NEL (Mcal/kg)	CP %	ADF %
Corn Silage (Excellent)	1.60	8	26
Corn Silage (Average)	1.52	7	29
Corn Silage (Poor)	1.43	10	35
Alfalfa Silage (Excellent)	1.38	20	36
Alfalfa Silage (Average)	1.30	17	41
Alfalfa Silage (Poor)	1.23	14	45

Concentrates	NEL (Mcal/kg)	CP %	ADF %
Soybean Meal	1.90	50	10
Corn Grain	2.02	10	3

Source: Virginia Dairy Guideline 404-152 (Revised October 1985)

It was further assumed that protein content of the concentrate could be adjusted by varying the ratio of corn to soybean meal. Energy content of the concentrate remained at 2.00 Mcal/kg. Minimum protein in the concentrate was 12%, achieved with 95% corn at 10% CP and 5% soybean meal at 50% CP. The cost of energy was based on the cost of corn, while cost of protein was the premium paid for exchanging corn for soybean meal.[22] Finally, the price ratio of protein and energy was assumed to remain constant between forage and concentrate. If relative value of soybean meal increased, relative value of protein in the forage increased as well.

To economically analyze benefits and costs of underfeeding, terminology must first be defined. Cost was lost milk production, defined in terms of kg of 28 d 4% FCM per lactating cow. Benefits were accrued by reducing energy and protein concentrations while replacing more expensive feeds with cheaper feeds. In the case of energy, concentrate was replaced by forage. For protein, soybean meal was replaced by corn. Underfeeding in the simulation was described not in terms of Mcal/kg or CP%, but in terms of standard deviations of nutrient recommendations within a group. One-half standard deviation of within group nutrient recommendations differed according to the number of groups, but ranged from .0234 Mcal/kg to .0583 Mcal/kg for energy and from .456% to 1.232% for protein. Reduced feeding was analyzed not only in terms of 4% FCM lost, but 4% FCM lost per unit of energy or protein. By standardizing reduced feeding to a per unit basis, differences in absolute concentrations across different herds with different numbers of groups could be taken into account. To reflect limits of the data, reduced feeding was constrained to .03 Mcal/kg and 1% CP for the herd. Some

[22] When analyzing the concentrate cost, the small amount of soybean meal in the base concentrate mix would mean that the necessary minimum or maximum cost of a bushel of corn would be slightly less than the figures presented as representing a bushel of corn. Corn cost and concentrate cost will be used interchangably since the base concentrate cost is assumed to be the 95% corn mix. Protein costs will be analyzed separately.

groups within the herd would, of course, exceed this limit, while others were underfed to a smaller extent, depending on the standard deviation of nutrient requirements within the group.

To begin the analysis of underfeeding energy, there need be only two inputs considered, concentrate (C), and forage (F). Since forage has been established as having 1.40 Mcal/kg NEL and concentrate 2.00 Mcal/kg, percent concentrate in the ration can be stated as:

[19] $CPCT = (NEL - 1.40) \times 5/3$

where CPCT is the proportion concentrate in the dry matter and NEL is recommended energy in Mcal/kg. Total concentrate is

[20] $C = DMI \times CPCT$

and a change in concentrate with a change in energy content of the ration is:

[21] $\Delta C = \Delta NEL \times 5/3 \times DMI$

where ΔNEL is the change in the energy and ΔC is change in the concentrate dry matter intake. Total forage intake is $F = DMI - C$, so total cost can be expressed as:

[22] $TC = r_c C + r_f F$

or

[23] $TC = r_c C + r_f(DMI - C)$

where r_c is the cost of a kg of concentrate dry matter and r_f is the cost of a kg of forage dry matter. The change in total cost with respect to a change in dry matter intake can then be stated as:

[24] $$\frac{\partial TC}{\partial C} = r_c - r_f$$

and total change in cost as

[25] $$(r_c - r_f)\Delta C$$

With a limit of .03 Mcal/kg placed on the change in energy for the herd, change in concentrate would be 5% of total dry matter intake. The final term in the equation, ΔC, can therefore be expressed as .05 x DMI.

The question to be considered is whether or not the decrease in feed cost could justify lost milk production from reduced feeding. Under the assumption that dry matter intake would remain constant and the opportunity cost of underfeeding has already been established, factors left to consider would be cost of forage and concentrate dry matter and price of milk. To justify a decrease in energy feeding, loss in revenue must be less than savings in feed costs, or

[26] $$p\Delta q \leq .05DMI(r_c - r_f)$$

However, while the assumption of constant dry matter intake could be easily justified when the ration remained constant, a change in the ration could easily cause a change in the dry matter intake. From the aggregate dry matter intake equation, change in daily kg dry matter intake with respect to a change in ADF% was

[27] $$\frac{\partial DMI}{\partial ADF} = .118 - .0078ADF$$

Since energy was already constrained to a change of .03 Mcal/kg, from the earlier equation, change in ADF% with this change in energy would be 37.311x.03, or 1.12%.[23]

Table 39 summarizes a set of assumptions that were used in estimating change in dry matter intake that would occur with a change in the fiber content of the ration. ADF% was derived from average energy fed for each of the herd production classes. Change in daily dry matter intake with respect to a change in the ADF% was figured, and change in total daily dry matter intake estimated. From these numbers, 28 d change in dry matter intake was calculated for each of the herd classes. Using parameter estimates for dry matter intake variables in Table 28, change in 4% FCM over the 28 day period was then computed.

To take into account the estimate of change in dry matter intake and change in 4% FCM directly attributable to change in dry matter intake, criterion for targeting energy to a lower than average cow in the group could be stated:

[28] $$p\Delta q + p(\mathrm{B}_1 \Delta DMI) \leq .05DMI(r_c - r_f) + r_c\Delta C + r_f\Delta F$$

where B_1 is the parameter estimate for the relationship between dry matter intake and 4% FCM, ΔDMI is the change in dry matter matter intake due to the change in the ration, r_c is the cost of the concentrate/kg, r_f is the cost of the forage/kg, ΔC is the change

[23] Parameter estimates for first period dry matter intake indicated a slight increase in dry matter intake with an increase in fiber content. With only a small proportion of cows in first period of lactation, expected change in dry matter intake was based strictly on estimates from later periods.

Table 39. Change in Dry Matter Intake with Change in Fiber Content

Variable	Herd Type Low	Medium	High
[1] NEL (Mcal/kg)	1.580	1.610	1.635
[2] ADF%	25.9	24.8	23.8
[3] dDMI/dADF% (kg daily from Table 3-3)	-.0840	-.0754	-.0676
[4] Change in ADF%	1.12	1.12	1.12
[5] Change in daily DMI (kg) ([3]*[4])	-.0941	-.0844	-.0757
[6] Change in 28 day DMI (kg) ([5]*28)	-2.635	-2.363	-2.120
[7] dFCM/dDMI (kg) (From Table 4-15)	1.215	1.442	1.566
[8] Change in 28 day FCM (kg) ([6]*[7])	-3.202	-3.407	-3.320
[9] Average 28 day DMI per cow (kg)	467.8	483.1	497.9
[10] Average 28 day DMI per cow * .05	23.4	24.2	24.9

in the concentrate due to the change in total dry matter intake, and ΔF is the change in forage due to the change in total dry matter intake. Substituting the figures previously explained in Table 4-26, as well as the computed $.05 \times DMI$, the equation for the low producing herds becomes:

$$[29] \qquad p\Delta q + 3.202p \leq 23.4(r_c - r_f) + r_c 2.635 \times CPCT + r_f 2.635 \times FPCT$$

For the medium producing herds:

$$[30] \qquad p\Delta q + 3.405p \leq 24.2(r_c - r_f) + r_c 2.363 \times CPCT + r_f 2.363 \times FPCT$$

The high producers:

$$[31] \qquad p\Delta q + 3.316p \leq 24.9(r_c - r_f) + r_c 2.120 \times CPCT + r_f 2.120 \times FPCT$$

There are three unknown prices as well as the unknown effect of the change in milk with respect to a change in the energy content of the ration. Given three of the variables, the fourth could be solved to estimate a price or quantity necessary to suggest underfeeding would be economically feasible. Figure 5 summarizes these equations and how they can be adjusted to solve for either a minimum difference in forage versus concentrate cost, a minimum price in milk, or a maxiumum decrease in milk production due to underfeeding.

Appendix B was added to simplify some of the conversions between metric and English measurements. One of the assumptions made in Table 40 was that the cost of forage was \$.10/kg on a dry matter basis. This can be easily converted using Appendix Table 2 to an as fed per ton basis. Assuming 35% dry matter, \$.10/kg converts to \$31.75 per ton on an as fed basis. This cost, as well as the concentrate costs, should include

Fig 5. Equations for Evaluation of Reduced Energy Feeding

To Justify Reducing Energy to Low Producing Herds:

$$p\Delta q + 3.202p < 23.4(r_c - r_f) + 2.635r_c \times CPCT + 2.635r_f(1 - CPCT)$$

Therefore:

$$p < \frac{(23.4 - 2.635CPCT)(r_c - r_f) + 2.635r_f}{\Delta q + 3.202p}$$

$$\Delta q < \frac{(23.4 - 2.635CPCT)(r_c - r_f) + 2.635r_f - 3.202p}{p}$$

$$r_c - r_f > \frac{p(\Delta q + 3.202) - 2.635r_f}{23.4 - 2.635CPCT}$$

To Justify Reducing Energy to Medium Producing Herds:

$$p\Delta q + 3.407p < 24.2(r_c - r_f) + 2.363r_c \times CPCT + 2.363r_f(1 - CPCT)$$

Therefore:

$$p < \frac{(24.2 - 2.363CPCT)(r_c - r_f) + 2.363r_f}{\Delta q + 3.407}$$

$$\Delta q < \frac{(24.2 - 2.363CPCT)(r_c - r_f) + 2.363r_f - 3.407p}{p}$$

$$r_c - r_f > \frac{p(\Delta q + 3.407) - 2.363r_f}{24.2 - 2.363CPCT}$$

To Justify Reducing Energy to High Producing Herds:

$$p\Delta q + 3.320p < 24.9(r_c - r_f) + 2.120r_c \times CPCT + 2.120r_f(1 - CPCT)$$

Therefore:

$$p < \frac{(24.9 - 2.120CPCT)(r_c - r_f) + 2.120r_f}{\Delta q + 3.320}$$

$$\Delta q < \frac{(24.9 - 2.120CPCT)(r_c - r_f) + 2.120r_f - 3.320p}{p}$$

$$r_c - r_f > \frac{p(\Delta q + 3.320) - 2.120r_f}{24.9 - 2.120CPCT}$$

p = price per kg of milk

Δq = change in quantity of milk produced due to reduced energy

r_c = cost per kg of corn (concentrate)

r_f = cost per kg of forage

CPCT = concentrate fraction of dry matter intake planting, harvesting, and storage costs. Table 40 summarizes the minimum cost of concentrate required to justify underfeeding energy by .03 Mcal/kg per herd.[24] The forage-concentrate ratio assumptions were derived using average as-fed energy concentrations of low, medium, and high producing herds. The 75%, 70%, and 65% forage corresponded closely to 1.58, 1.61, and 1.635 Mcal/kg. The very minor differences between results for low, medium, and high producing herds were attibutable to slightly different parameter estimates predicting change in dry matter intake with respect to change in fiber content for the different herd production classes, first, and then the different parameter estimates predicting change in 4% FCM with respect to a change in dry matter intake. Due to the similarity in results, only the medium herd class will be discussed.

It was assumed earlier that the least amount of concentrate would consist of 95% corn and 5% soybean meal. It was felt that this was close enough to 100% corn to justify a direct comparison to the cost of a bushel of corn.[25] Therefore, from Table 40, it can be seen that at a milk price of \$.30/kg and no change in milk production per cow except that due to a change in dry matter intake, corn cost must be at least \$.133 per kg of dry matter, or approximately \$3.00 per bushel, to justify underfeeding energy. The entire loss in revenue in this example was because of expected decrease in 4% FCM due to decrease in dry matter intake associated with increase in fiber. Since all possible scenarios from Table 31 indicated a decrease in 4% FCM due to a decrease in energy content, all situations for underfeeding energy to medium producing herds would require a

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[24] Except for a one group system, the cows in individual groups would not be underfed by exactly .03 Mcal/kg. The total herd would be underfed by .03 Mcal/kg divided by the herd standard deviation of within group nutrient requirements. Each group would be underfed by this ratio times the group standard deviation. In the case of high groups, this standard deviation would be small, while lower groups would be underfed by more than .03 Mcal/kg.

[25] If a higher protein concentration was required, the difference in the cost of the higher protein concentrate and the base (95% corn) concentrate could all be attributed to the soybean meal.

Table 40. Breakeven Analysis for Reduced Feeding of Energy

LOW PRODUCING HERDS

Minimum Cost of Concentrate/kg to Justify Reduced Feeding of Energy

Price of Milk per kg	Loss In Milk per Cow per Period Not Due to Change in DMI				
	0 kg	1 kg	2 kg	3 kg	4 kg
$.25	.124	.135	.146	.157	.168
.30	.131	.144	.157	.170	.183
.35	.138	.153	.168	.184	.199

ASSUME 75% FORAGE AT $.10/KG DRY MATTER

MEDIUM PRODUCING HERDS

Minimum Cost of Concentrate/kg to Justify Reduced Feeding of Energy

Price of Milk per kg	Loss In Milk per Cow per Period Not Due to Change in DMI				
	0 kg	1 kg	2 kg	3 kg	4 kg
$.25	.126	.137	.147	.158	.169
.30	.133	.146	.159	.172	.185
.35	.141	.156	.170	.185	.200

ASSUME 70% FORAGE AT $.10/KG DRY MATTER INTAKE

HIGH PRODUCING HERDS

Minimum Cost of Concentrate/kg to Justify Reduced Feeding of Energy

Price of Milk per kg	Loss In Milk per Cow per Period Not Due to Change in DMI				
	0 kg	1 kg	2 kg	3 kg	4 kg
$.25	.126	.136	.146	.157	.167
.30	.132	.145	.157	.170	.182
.35	.139	.154	.168	.183	.198

ASSUME 65% FORAGE AT $.10/KG DRY MATTER INTAKE

corn cost of greater than $3.00 per bushel, and in some cases, substantially greater. With a 4 kg loss in milk due to the decrease of .03 Mcal/kg in the herd ration, and a milk price of $.35/kg, corn costs would need to be $.20/kg to underfeed energy.

Table 41 was constructed combining economics introduced in Table 40 with assumptions obtained from Tables 30, 31, and 32 to determine a minimum concentrate cost to justify reducing herd energy concentration by .03 Mcal/kg. Once again forage costs were assumed to be $.10/kg, with an assumed milk price of $.30/kg. For low and medium producing herds, minimum concentrate costs necessary to target the lower than average cow occurred with a three group feeding system. If protein was fed to recommendations, this was $.140/kg ($3.16/bushel) for low producers, and $.162/kg ($3.66/bushel) for medium producers. If protein was underfed, these figures changed to $.140/kg ($3.16/bushel) and $.182/kg ($4.10/bushel). In a one group scenario, the cost of corn would need to be at least $.166/kg ($3.76/bushel) for low producing herds if protein was fed to recommendations, increasing to $.203 ($4.59/bushel) if protein was underfed. With medium producing herds, these figures would be $.194/kg ($4.38/bushel) and $.264 ($5.96/bushel) if protein was underfed.

High producing herds did not produce the same pattern as the other two groups. If protein was fed to recommendations, minimum loss in milk was with a one group system, but if protein was underfed, lowest opportunity cost occurred with a four group system. If protein was underfed with the four group system, cost of corn needed to exceed $.135/kg ($3.07/bushel) to justify underfeeding, but if fed to recommendations, cost needed to be at least $.232/kg ($5.24) per bushel. The higher necessary costs of concentrate with fewer groups suggests that underfeeding of high producing cows within a herd is detrimental and would occur with one and two group systems. It also implies

Table 41. Minimum Corn Prices to Reduce Energy by .03 Mcal/kg*
Assuming Forage Costs at $.10 per Kg Dry Matter, Milk = $.30/kg

LOW PRODUCING HERDS

	Groups 1	2	3	4
If Protein Fed to Group Average				
Loss in Milk (kg/cow/period)	2.664	1.731	.672	1.434
Price per kg dry matter ($)	.166	.153	.140	.150
If Protein Fed to Less than Group Average				
Loss in Milk (kg/cow/period)	5.457	3.780	-.336	-3.513
Price per kg dry matter ($)	.203	.181	.126	.084

MEDIUM PRODUCING HERDS

	Groups 1	2	3	4
If Protein Fed to Group Average				
Loss in Milk (kg/cow/period)	4.743	3.774	2.256	3.621
Price per kg dry matter ($)	.194	.182	.162	.180
If Protein Fed to Less than Group Average				
Loss in Milk (kg/cow/period)	10.191	9.372	3.834	-.402
Price per kg dry matter ($)	.264	.253	.182	.128

HIGH PRODUCING HERDS

	Groups 1	2	3	4
If Protein Fed to Group Average				
Loss in Milk (kg/cow/period)	3.387	6.285	7.434	8.007
Price per kg dry matter ($)	.175	.211	.225	.232
If Protein Fed to Less than Group Average				
Loss in Milk (kg/cow/period)	6.567	8.184	4.947	.234
Price per kg/dry matter ($)	.214	.234	.194	.135

*Energy concentration of total herd reduced by this amount
Individual groups reduced by .03 divided by Mcal in one half standard deviation for entire herd times one half standard deviation for group

that there is a changing relationship between protein and energy in the production of milk. In some situations it is more harmful to reduce both protein and energy, while in others, to reduce both is less detrimental than the reduction of only energy. For the most part, reducing energy is worse when protein is targeted to a lower than average cow.

Under the assumptions of milk price of \$.30/kg and forage price of \$.10/kg, it would seem that underfeeding in most cases would not be profitable until corn prices increased to at least \$.14 to \$.18 per kg (\$3.10 to \$4.00 per bushel). These figures would of course change if milk price was lower than \$.30/kg (\$13.61/cwt) or forage costs were more than \$.10/kg. A simple and fairly accurate method of accounting for a change in the forage cost would be to change the necessary cost of concentrates by \$.01/kg for an equal change in the cost per kg of dry matter. At 35% dry matter, a \$1.00 per ton increase in as-fed forage costs would offset a \$.07 increase in concentrate costs.

The Economics of Grouping and Underfeeding Protein

The concept used in analyzing reduced feeding of protein is very similar to that used in the energy analysis. One of the assumptions stated earlier was that relative value of protein would remain constant throughout the market. This means that if the price of one source of protein should increase, other sources would increase as well.[26] Soybean meal was selected as the main source of protein in the cow's diet. Economic analysis was based on a one percent change in dietary protein concentration and the fact that

[26] If a source of protein should increase due to a shortage, quantity demanded will decrease for that source because of the price increase. Quantity demanded for other sources will increase, thereby creating a price increase for those sources as well. Due to time lags, transportation costs, and imperfect information, this assumption will not be totally accurate.

crude protein could be reduced by substituting corn for soybean meal. To warrant a reduction in protein, the value of milk lost must not exceed savings accrued by substituting corn for soybean meal. A one percent decrease in crude protein percent would mean total kg of protein for one cow for one period would be reduced by .01 times the kg dry matter intake. Since corn is 10% CP and soybean meal 50% CP, every kg of corn substituted for a kg of soybean meal reduces protein content of the ration by .4 kg. Therefore, to reduce protein content of the ration by one percent, total amount of corn substituted for soybean meal would be:

[32] $$C = .025(DMI)$$

where C is kg of corn and DMI is total dry matter intake in kg, assumed to not be affected by change from soybean meal to corn. Total savings accrued would be the amount of the two feeds exchanged times the difference between price of corn and price of soybean meal, or

[33] $$.025(DMI) \times (r_s - r_c)$$

where r_s is the price of soybean meal, and r_c is the price of corn. To justify reduced feeding, lost revenue must be less than feed cost savings, or

[34] $$p\Delta q < .025(DMI) \times (r_s - r_c)$$

Table 42 presents the minimum cost per kg of soybean meal to induce underfeeding of protein for low, medium, and high producing herds at different milk prices and changes in milk production. The only difference between results is due to differences in dry matter intakes, 467 kg per cow per period for low producers, and 483 kg and 497 kg for medium and high producing herds. Although corn price was assumed to be \$.12/kg, a deviation from this price can be accounted for by a one to one corresponding change in price of soybean meal. The three different milk prices demonstrate that reduced feeding is sensitive to milk price. For example, with a change in quantity of milk produced per cow over a 28 day period, the necessary cost of soybean meal to vindicate underfeeding increases from \$.617/kg dry matter to \$.816/kg.

Table 43 uses assumptions derived earlier to report the minimum cost of soybean meal necessary to justify reduced protein feeding. If energy is fed to recommendations, three group feeding would be the most conducive to reducing protein for all three herd production categories. In the low production category with a three group feeding system, price of soybean meal would need to increase to \$.731/kg dry matter for reducing protein to be profitable. For medium producing herds, this figure would change to \$.630/kg, and high herds to \$.635/kg. The possibility of feeding less than recommended protein for the average cow in the group to enhance profitability would seem remote under the most favorable conditions when it is considered that with an as-fed corn price of \$.12/kg (\$2.71/bushel), as-fed price of soybean meal would need to incease to at least \$500 per ton, or the processed cost of a bushel of soybeans to at least \$14.50. The necessary increase in protein prices would become even more drastic in situations with a different total number of groups or when underfeeding energy to the medium and high producing herds.

Since reducing protein when energy was fed to recommendations was considered in the study, increasing protein concentrations slightly above recommendations could be profitable. In this case, slightly would mean one half the standard deviation of within group nutrient requirements. On an absolute basis, this statement would correspond to an increase of roughly one-half percent protein for the entire herd. Maintaining the con-

Table 42. Breakeven Analysis for Reduced Feeding of Protein
Corn Price Assumed $.12/kg

LOW PRODUCING HERDS

Minimum Cost of Soybean Meal/kg to Justify Reduced Feeding of Protein

Price of Milk per kg	Loss In Milk per Cow per Period				
	8 kg	16 kg	24 kg	32 kg	40 kg
$.25	.291	.463	.634	.805	.976
.30	.325	.533	.737	.942	1.148
.35	.360	.600	.839	1.079	1.319

MEDIUM PRODUCING HERDS

Minimum Cost of Soybean Meal/kg to Justify Reduced Feeding of Protein

Price of Milk per kg	Loss In Milk per Cow per Period				
	8 kg	16 kg	24 kg	32 kg	40 kg
$.25	.285	.451	.617	.782	.948
.30	.319	.517	.716	.915	1.114
.35	.352	.584	.816	1.047	1.279

HIGH PRODUCING HERDS

Minimum Cost of Soybean Meal/kg to Justify Reduced Feeding of Protein

Price of Milk per kg	Loss In Milk per Cow per Period				
	8 kg	16 kg	24 kg	32 kg	40 kg
$.25	.281	.442	.603	.764	.925
.30	.313	.506	.699	.893	1.086
.35	.345	.571	.796	1.021	1.247

Table 43. Minimum Soybean Meal Prices to Reduce Protein by 1%
Corn Costs Assumed at $.12 per Kg Dry Matter and Milk = $.30/kg

LOW PRODUCING HERDS

	Groups 1	2	3	4
If Energy Fed to Group Average				
Loss in Milk (kg/cow/period)	32.700	30.036	23.770	29.859
Price per kg dry matter ($)	.960	.899	.731	.887
If Energy Fed to Less than Group Average				
Loss in Milk (kg/cow/period)	37.104	33.145	22.262	22.667
Price per kg dry matter ($)	1.073	.972	.692	.702

MEDIUM PRODUCING HERDS

	Groups 1	2	3	4
If Energy Fed to Group Average				
Loss in Milk (kg/cow/period)	30.059	26.063	20.524	33.390
Price per kg dry matter ($)	.867	.768	.630	.950
If Energy Fed to Less than Group Average				
Loss in Milk (kg/cow/period)	38.605	34.602	22.978	26.808
Price per kg dry matter ($)	1.079	.980	.691	.786

HIGH PRODUCING HERDS

	Groups 1	2	3	4
If Energy Fed to Group Average				
Loss in Milk (kg/cow/period)	31.528	28.492	21.315	35.666
Price per kg dry matter ($)	.881	.808	.635	.981
If Energy Fed to Less than Group Average				
Loss in Milk (kg/cow/period)	39.346	36.257	23.195	29.218
Price per kg/dry matter ($)	1.070	.995	.680	.825

*Protein concentration of total herd reduced by this amount
Individual groups reduced by 1% divided by CP% in one half standard deviation for entire herd times one half standard deviation for group

straint of a maximum of 19% CP in any of the rations, high producing groups in multiple group situations would be increased very little since they are already near maximums in most situations. From a visual analysis of Tables 22, 23, and 24, it could be stated that one-half standard deviation in a one group feeding system would be approximately 1.2%. Lower producing groups in two, three, and four group feeding schemes could have their protein concentration increased by .9%, .7%, and .6% of dry matter, respectively.

To briefly summarize reduced feeding of nutrient concentrations, targeting energy to less than the average cow in the group would not usually maximize profitability. When reduced feeding was profitable, it would have to be in a situation with a minimum of three groups. Relative value of protein would tend to encourage targeting CP concentrations to a higher than average cow in the group.

Chapter V

SUMMARY

The three objectives of this research were to make recommendations concerning nutrient concentrations for lactating dairy cows, segregate the effect of grouping or individually feeding lactating dairy cows on production of 4% FCM, and make statements regarding grouping and individual feeding that can be based on prevailing economic conditions.

The first objective required derivation of prediction equations for daily dry matter intake and 4% FCM. These equations were necessary to accomplish the first objective, nutrient concentration recommendations, and use in the second procedure, a simulated feeding of cows to collect data on milk production and dry matter intake under different feeding and grouping scenarios. Feeding data collected by Holter at the University of New Hampshire were used to analyze dry matter intake and milk production in lactating dairy cows. Achieving the first objective entailed constructing a model to predict dry matter intake in lactating dairy cows. A model that used days in milk, calving date, lactation class, and acid detergent fiber of the ration explained 49.5% of the variability in dry matter intake of cows. However, if previous dry matter intake was added to the model, the R^2 increased to 80.1%. This indicated that once there was information available on dry matter intake of a cow within a lactation, predictability of future dry matter intake increased sharply. For the final prediction equation, heifers and older cows were separated and two prediction equations used.

Since dry matter intake was based on previous dry matter intake, an equation to predict daily dry matter intake for the first period also needed to be generated. Independent variables included first period body weight, first period average daily 4% FCM, ADF%, and calving date. An R^2 of 52.6% indicated that there was a great deal of variability of dry matter intake among similar cows. This was consistent with literature in maintaining that prediction of dry matter intake is inexact among cows. With the technique used in this modeling procedure, a much higher degree of unexplained variability occurred in the first period relative to later periods. First period data were separated so that there was a first period dry matter intake equation for both heifers and multiparous cows.

Milk prediction equations were based on the premise that dry matter intake and previous milk production are the most important factors influencing 4% FCM. Separate equations for the two classes of cows were estimated. With average daily 4% FCM as the dependent variable, calving date, previous 4% FCM, days in milk, and available nutrients provided an R^2 of 89.6 and 93.4 for heifers and multiparous cows, respectively.

The milk equation and two dry matter intake equations for each lactation class of cow were used to establish a relationship between 4% FCM and nutrient concentrations necessary to fulfill absolute nutrient requirements as set forth by the National Research Council. These equations predicted daily dry matter intake for all periods and daily 4% FCM for all periods after the first period. To model an entire lactation for a cow, a figure for first period milk had to be generated. In generating a set of lactation data, it was desired to examine a range of first period daily 4% FCM. A minimum figure for 4% FCM was generated (9 kg for heifers, 10 kg for the older cows) and incremented by 2 kg for each new cow at the same starting body weight, up to 39 kg for the heifers, and 50 kg for the older cows. First period body weights also needed to be generated to determine first period dry matter intake. These started at 400 kg for all cows, increasing in 10 kg increments to 700 kg for the heifers and 800 kg for the older cows. Rations were balanced, constrained to a maximum of 1.80 Mcal/kg of NEL and no more protein than required for maintenance, lactation, and weight change predicted by energy balance, so that the heifers would gain 50 kg and older cows 5 kg by 308 days in milk.

A total of 3328 observations were generated for heifers and 5733 for older cows. Equations were estimated using previous milk production, body weight, and days in milk to establish a relationship between these variables and recommended energy and protein concentrations. For energy, all observations of 1.80 Mcal/kg were deleted since this recommendation could distort a linear relationship if one existed. This left 2193 observations for heifers and 4779 observations for older cows to estimate parameters. The R^2 for the four equations, two nutrients by two ages, ranged from 93.7% to 97.8%.

This relationship was examined dropping all independent variables except average daily 4% FCM in the previous period. With an R^2 of 92.0%, recommended protein concentration for heifers was described as $6.556 + .416PREFCM$, where PREFCM was average daily 4% FCM from the previous period. For older cows, the equation was $8.064 + .2916PREFCM$, with an R^2 of 90.6%. Recommended energy concentration for heifers was $1.24 + .019PREFCM$ and for older cows, $1.23 + .013PREFCM$. The R^2 for these two equations was 79.2% and 72.8%, respectively.

The second procedure involved generating 100-cow dairy herds to estimate the effect of grouping or feeding changes on 4% FCM. Three levels of average herd production (8845.2 kg, 7711.2 kg, and 6577.2 kg), three average herd calving intervals (370 d, 390 d, and 410 d), and three different standard deviations of within-herd 305 day Mature Equivalent 4% FCM (1587 kg, 1134 kg, and 680 kg) were used to generate 27 different herds for individual, one, two, three, and four-group feeding schemes. In addition to feeding the group average, recommended nutrient concentrations were targeted to the cow one-half standard deviation below group average for energy once, for protein once, for both protein and energy once, and one-half standard deviation above for protein once. In absolute terms, the value of overfeeding or underfeeding varied.

Holding dry matter intake and nutrient contents of the ration constant, expected improvement in 4% FCM per milking cow over a 28-day period achieved by switching from one group to individual feeding ranged from 2 to 4%, depending on herd production, variability of production within the herd, and calving interval. Changing from two groups to individual feeding, improvement ranged from 0 to 3%. High calving intervals were associated with the higher figure.

In determining an optimal number of groups, the most dramatic improvement in FCM came with a switch from one group to two groups. Once again holding dry matter intake and nutrient concentrations constant, expected per cow increase in 4% FCM over 28 days ranged from 0 to 3%. Increasing to three groups, additional improvement of 0 to 2% was seen. A further increase to four groups had a smaller effect on 4% FCM, ranging from 0 to 1%. High variability of 305 day FCM within the herd was associated with the higher figure.

Reducing recommended nutrient concentrations appeared more favorable with at least three groups. With a very small standard deviation in any high producing group, a minimum of three groups is required to feed high producers adequately. For example, in medium producing herds, within group standard deviation of protein recommendations was 1.00% with a two group system, but only .51% with three groups. The ability to more selectively underfeed because of the extra group when changing from two groups to three groups decreased lost milk due to reducing overall energy concentration. In low producing herds, the third group decreased lost FCM due to a reduction in herd energy concentration of .01 Mcal/kg by 61 to 91% relative to two groups, depending on the feeding level of protein. In medium producing herds, the reduction was 40 to 59%, and in high producing herds, by up to 40%. In all three cases, the higher figure represented the savings accrued when protein was also underfed. Increasing from two groups to three groups reduced lost milk by 21% to 33% in low producing herds, 21% to 48% in medium producing herds, and 25% to 46% in high producing herds when the overall herd ration was decreased by 1% CP. In all producing herds, the higher figure represented the case when energy was also underfed.

The final procedure involved combining economic concepts with assumptions derived in the earlier part of the research. With a milk price of $.30/kg and an increase in variable feeding cost (extra labor and machine time spent feeding) of $3000 per year, a one-group dairy that averaged 100 cows milking over the course of the year could afford to invest $17,491 in individual feeding equipment and facilities as an average low producing herd, $33,556 as an average medium producing herd, and $33,445 as an average high producing herd. If a change from two groups to individual feeding was being considered, maximum investment would decrease to $18,880 for medium producing herds with the same change in variable cost, while the increase in variable cost would have to be lower for the change to be economically feasible for low and high producing herds. High calving intervals favored individual feeding. An increase in average CI of 20 days increased maximum allowable investment by $8,415 to $23,843, depending on herd production level and whether one or two groups was being fed.

In evaluating economics of grouping, a minimum of two groups was economically feasible for most situations with medium and high producing herds. Information was conflicting concerning low producing herds. With an indirect method of comparing one group feeding systems to two group feeding systems by contrasting one group feeding to individual feeding and two group feeding to individual feeding, improvement in 4% FCM in low producing herds was comparable to the improvement found in medium producing herds. However, when one group feeding was directly compared to two group feeding, the increase in 4% FCM was negligible and economically impractical in many situations.

With a milk price of $.30/kg and an increase in the daily cost of feeding of $10, milk production would be expected to increase enough to economically justify a change from one group to two groups and re-allocation of the same feed to as few as 61 milking cows with medium producing herds. For a medium producing herd with average characteristics, 136 cows could justify adding a second group, with the least likely situation needing 205 cows in the herd. For an increase to three groups, group size could decrease, but overall herd size would have to increase about 10%. Generally, high SD's favored additional groups.

Under the same economic scenario, high producing herds would need to have only 52 cows, with a range of 40 to 57, to justify a second group. Minimum cow numbers increased significantly for a change to three groups. The average high producing herd would require 162 cows per group, nearly ten times the size of the necessary minimum herd size required to justify a move from one to two groups.

The most favorable grouping situation for underfeeding occurred with three and four groups, where the high producers in a herd were not as drastically underfed. In a three group feeding situation, reducing energy concentration of the herd by one-half standard deviation of within-group nutrient recommendations should be considered with low producing herds if forage cost were a maximum of $.10/kg dry matter, and corn cost a minimum of $.126/kg dry matter ($2.85 per bushel). Reduction in energy for the entire herd should be limited to .03 Mcal/kg of Nel. Lower producing groups of cows in multiple group situations would exceed this amount, but the high producing group of cows would not be reduced in energy.

If protein was fed to recommendations for medium and high producing herds, the minimum cost of corn, with forage at the same price as above, would have to be $.162/kg and $.225/kg on a dry matter basis, respectively $3.66 and $5.08 per bushel. Underfeeding protein would change minimum corn price to $.182/kg and $.225/kg, but this should not be seriously considered since the price of protein would have to increase to ridiculously high levels before it would be profitable to target protein concentrations to less than group average. In fact, if energy is fed to recommendations, increasing protein to one-half standard deviation above group average should be considered. This would entail feeding the group of high producing cows in multiple group situations maximum allowable recommendations. In a one group scenario, protein could be increased an additional 1.2% of dry matter (one-half standard deviation of within group protein requirements). Lower producing groups in two, three, and four group situations could be increased an additional .9%, .7%, and .6%, respectively representing one half standard for each of the grouping systems. These increases reflect data limits of this research.

Chapter VI

CONCLUSIONS

Recommendations of nutrient concentrations were made that were designed to increase body weight of heifers by 50 kg over a 308 day lactation and older cows by 5 kg over the 308 day lactation. Recommended Mcal/kg for heifers was $1.24 + .019PREFCM$ and for older cows, $1.23 + .013PREFCM$, where PREFCM was the average daily 4% FCM from the previous period. Recommended CP% of dry matter for heifers was described as $6.556 + .416PREFCM$, and for older cows, $8.064 + .2916PREFCM$. Higher nutrient concentration recommendations would not have to be constrained to heifers, but would be suitable for underconditioned cows as well. By the same token, lower nutrient concentrations could be more appropriate for heifers in good condition. If it was desired to balance a ration based on group average FCM rather than the averaged sum of the recommendations of the individual cows in the group, a weighted average of the two sets of equations could be used. Assuming that approximately one-third of the lactating animals were heifers, recommended Mcal/kg could be stated $1.24 + .015PREFCM$ and recommended CP% of dry matter $7.56 + .33PREFCM$. These recommendations have a higher concentration of nutrients per kg of dry matter than NRC. Maximum concentrations of 1.76 Mcal/kg and 19% CP would be fed to any group averaging at least 34.67 kg 4% FCM.

A policy of equal size groups may be the best path to pursue in planning of facilities, but grouping should minimize variation of nutrient requirements with the groups. If the distribution of nutrient requirements is skewed for a grouping period, group sizes should be altered accordingly.

Based only on simulated feeding of dairy cows, it would appear that in most cases individual feeding or a minimum of two groups would be preferred. The advantages of individual feeding over one group feeding were so dramatic that the minimum number of cows required to be in milk would suggest that the herd could be fed with a pitchfork and pail if investment in a computerized feeding system was not desired. Advantages of individual feeding over two group feeding were clear, but not as strong. In deciding between individual or two-group feeding, the cost of the respective systems and herd size would need to be considered. Another factor to consider in individually feeding cows is availability of information and ability to use the information on a timely basis. High calving intervals made the relative advantage of individual feeding stronger. However, high calving intervals could also imply a lack of attention to detail. Individual feeding means that nutrients are being allocated precisely. If nutritional information is not available or kept up to date, advantages of extra preciseness are lost, and group feeding may be preferred.

Once the decision to group cows has been made, number of groups must be determined. High feed prices are a legitimate production-related reason for adding a third group. With the third group, energy could be underfed by one-half standard deviation of nutrient requirements within the groups without underfeeding the high producing cows in the herd. It is important to meet the nutrient requirements of cows in early lactation. Since current milk production influences future milk production both in modeling and in real life, a decrease in milk production in early lactation would have an adverse affect on future milk production for an extended period of time. Benefits from underfeeding energy would have to come from cows in mid- to late-lactation. Underfeeding of energy should occur through replacement of forage for concentrate, not through reduction of available dry matter. This is not to say, however, that excess feed should be placed in front of cows and wasted.

High producing herds seemed to fare as well with two groups as they did with three. This could be because the high producing cows in high producing herds are fed at maximum recommendations with only two groups. In lower producing herds, addition of a third group was necessary for high producing groups to be fed maximum recommendations. In selecting between two and three groups, this factor, as well as the drop in nutrient concentration between subsequent groups, should be taken into account. A three group feeding system makes it easier to underfeed energy if concentrate prices should be high relative to forage prices. However, if the high groups receive maximum allowable concentrations (1.76 Mcal/kg NEL and 19% CP) and the drop between groups is not substantial, a two group feeding situation could suffice.

Additional groups may also be desired due to factors not tested in this project. Social factors in a two-group system could be a detrimental influence on FCM not considered in the simulation. There may also be reasons to add a group that are not directly related to milk production. The dairy producer could desire to isolate sick cows, or cows that have not been bred but have exceeded a minimum days in milk.

Although there are situations where the underfeeding of energy in group situations could increase profitability, underfeeding of protein would adversely affect profitability without significant increases in the relative cost of protein. If energy is fed at recommended levels, it may be beneficial to increase the herd crude protein percent by 1.2, .9, .7, and .6, for one, two, three, and four group feeding systems.

Contributions and Future Implications

It was hoped that the methods used in this research would help identify situations that would make individual feeding or additional groups more profitable relative to an average situation. This was the case with herds that had cows with a high degree of variability in 305 day milk production. It was also thought that additional groups or individual feeding would be more profitable in herds with high calving intervals. However, this was not always the case. Due to a lack of data, it could have been that dry matter intake equations did not accurately reflect true dry matter intake in late lactation, particularly after 308 days in milk. As milk production per cow increases in the future, the need for data on nutrient intake and milk production for a period of 300 to perhaps 500 days post partem will increase. Information provided by this data would help in nutritional modeling for cows in late lactation as well as providing input for analyzing optimal calving intervals in higher producing cows. Higher calving intervals have traditionally been associated with poor management practices. However, it could be that as milk production for cows increases, particularly if persistency is high, longer calving intervals would increase profitability. This does not mean that heats should be missed or poor conception techniques used, but that increasing calving intervals for selected high producing cows could be practiced as a method of increasing profits.

In defining nutrient concentration recommendations, monthly dry matter intake was found to be fairly predictable if based on previous dry matter intake from the same lactation. The prediction of 4% FCM was even more accurate than the dry matter intake equations when previous milk and nutrient contents of the ration were known. Until accurate information on dry matter intake and ration contents is available on the farm, practical application of these modeling procedures is impossible. However, as large scale information management becomes more sophisticated, the possibility of accurate farm-level prediction of future dry matter intake and milk production for individual cows has implications for more precise allotment of nutrients. Combined with accurate and up-to-date feed analysis, nutrients could be allocated on an absolute rather than concentration basis.

This research has presented recommended nutrient concentrations based only on 4% FCM that, except when limited by constraints on energy concentrations, should meet or exceed the absolute requirements of lactating dairy cows as set forth by NRC. Assumptions about benefits of grouping and reduced feeding were established to assist in a producer's policy decision concerning these factors. However, it was obvious that if cows were not individually fed, a minimum of two groups would be desired. This study also supported work that suggests that underfeeding of energy to high producing cows would have a negative impact on profitability, and that it would take an unusual combination of economic events to justify reduced feeding of protein to any lactating cows.

The biological process in production of milk changes slowly over time compared to milk and feed price changes. Fluctuating prices, combined with a degree of uncertainty in explanation of the biological process and numerous different farm situations, make hard and fast statements concerning strategies to maximize profitability the exception rather than the rule. For this reason, not only were answers presented to reflect prevailing economic conditions, but assumptions stated that could be applicable as prices change over time. In evaluating investment decisions, often the most difficult task is assessing proper costs and benefits. When decisions are spoken in absolutes they become obsolete. By segregating the grouping effect, benefits can be properly identified and termed on a relative basis. A major contribution of this work is a statement of the relative value of benefits associated with changing from group to individual feeding or increasing group numbers. Combined with cost evaluations tailored to the manager's farm, expected benefits presented in this paper can be combined with economic principles to evaluate a proposed change in grouping policy.

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Appendix A - Sample Rations with Minimum 50% Forage
kg of Feed per kg of Dry Matter

NEL Mcal/kg	CP %	Excellent Corn Silage	Excellent Alfalfa Silage	Avg Corn Silage	Avg Alfalfa Silage	Corn Grain	Soybean Meal
1.78	21.0	.50	.00	.00	.00	.20	.30
1.78	17.0	.50	.00	.00	.00	.30	.20
1.78	13.0	.50	.00	.00	.00	.40	.10
1.75	22.8	.35	.15	.00	.00	.20	.30
1.75	18.8	.35	.15	.00	.00	.30	.20
1.75	14.8	.35	.15	.00	.00	.40	.10
1.74	20.5	.00	.00	.50	.00	.20	.30
1.74	16.5	.00	.00	.50	.00	.30	.20
1.74	12.5	.00	.00	.50	.00	.40	.10
1.72	24.6	.20	.80	.00	.00	.20	.30
1.72	20.6	.20	.80	.00	.00	.30	.20
1.72	16.6	.20	.80	.00	.00	.40	.10
1.71	22.0	.00	.00	.35	.15	.20	.30
1.71	18.0	.00	.00	.35	.15	.30	.20
1.71	14.0	.00	.00	.35	.15	.40	.10
1.71	15.8	.35	.15	.00	.00	.20	.30
1.71	13.4	.35	.15	.00	.00	.30	.20
1.71	11.0	.35	.15	.00	.00	.40	.10
1.68	23.5	.00	.00	.20	.30	.20	.30
1.68	19.5	.00	.00	.20	.30	.30	.20
1.68	15.5	.00	.00	.20	.30	.40	.10
1.66	18.3	.49	.21	.00	.00	.12	.18
1.66	15.9	.49	.21	.00	.00	.18	.12
1.66	13.5	.49	.21	.00	.00	.24	.06
1.65	15.1	.00	.00	.70	.00	.12	.18
1.65	12.7	.00	.00	.70	.00	.18	.12
1.65	10.3	.00	.00	.70	.00	.24	.06
1.64	10.6	.90	.00	.00	.00	.04	.06
1.64	9.8	.90	.00	.00	.00	.06	.04
1.64	9.0	.90	.00	.00	.00	.08	.02
1.62	20.8	.28	.42	.00	.00	.12	.18
1.62	18.4	.28	.42	.00	.00	.18	.12
1.62	16.0	.28	.42	.00	.00	.24	.06
1.60	17.2	.00	.00	.49	.21	.12	.18
1.60	14.8	.00	.00	.49	.21	.18	.12
1.60	12.4	.00	.00	.49	.21	.24	.06
1.57	14.6	.63	.07	.00	.00	.12	.18
1.57	13.8	.63	.07	.00	.00	.18	.12
1.57	13.0	.63	.07	.00	.00	.24	.06
1.56	19.3	.00	.00	.28	.42	.12	.18
1.56	16.9	.00	.00	.28	.42	.18	.12
1.56	14.5	.00	.00	.28	.42	.24	.06
1.56	9.7	.00	.00	.90	.00	.04	.06
1.56	8.9	.00	.00	.90	.00	.06	.04
1.56	8.1	.00	.00	.90	.00	.08	.02
1.52	17.1	.36	.54	.00	.00	.04	.06
1.52	16.3	.36	.54	.00	.00	.06	.04
1.52	15.5	.36	.54	.00	.00	.08	.02
1.50	12.4	.00	.00	.63	.27	.04	.06
1.50	11.6	.00	.00	.63	.27	.06	.04
1.50	10.8	.00	.00	.63	.27	.08	.02
1.45	15.1	.00	.00	.36	.54	.04	.06
1.45	14.3	.00	.00	.36	.54	.06	.04
1.45	13.5	.00	.00	.36	.54	.08	.02

Appendix B - Converting Metric to English

MILK PRICES

$ PER KG	$ PER CWT
.25	11.34
.30	13.61
.35	15.88

CONCENTRATE PRICES

56 lbs/bushel 89% Dry Matter

DRY MATTER $ PER KG	AS FED $ PER BUSHEL	AS FED $ PER TON
.10	2.26	80.74
.12	2.71	96.89
.14	3.16	113.03
.16	3.62	129.18
.18	4.07	145.33
.20	4.52	161.48
.22	4.97	177.63
.24	5.42	193.78
.26	5.88	209.22
.28	6.33	226.07
.30	6.78	242.22
.32	7.23	258.37
.34	7.68	274.52
.36	8.13	290.67
.38	8.59	306.81
.40	9.04	322.96

FORAGE PRICES PER TON AS FED

DRY MATTER	PERCENT DRY MATTER					
$ PER KG	25	30	35	40	45	50
.04	9.07	10.89	12.70	14.52	16.33	18.14
.06	13.61	16.33	19.05	21.77	24.49	27.22
.08	18.14	21.78	25.40	29.03	32.66	36.28
.10	22.68	27.22	31.75	36.29	40.82	45.36
.12	27.21	32.66	38.10	43.55	48.99	54.42
.14	31.75	38.10	44.45	50.80	57.15	63.50
.16	36.29	43.55	50.80	58.06	65.32	72.58
.18	40.83	49.99	57.15	65.32	73.48	81.66
.20	45.36	54.43	63.50	72.58	81.64	90.72
.22	49.90	59.88	69.85	79.84	89.81	99.80
.24	54.43	65.32	76.20	87.09	97.98	108.86

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