Estimating Production Benefits Through Simulation of Group and Individual Feeding of Dairy Cows

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ABSTRACT

Objectives were 1) to develop DMI and milk prediction equations, 2) to use these equations to simulate group and individual feeding of dairy herds, and 3) to estimate effects of group and individual feeding on FCM production. University of New Hampshire data were used to predict DMI from previous DMI and cow and ration characteristics. The same data were used to predict milk production from DMI and previous milk production. Feeding was simulated for 100 cows over 50 4-wk periods in a number of trials. Effects of individual feeding, additional groups, herd calving intervals, and within-herd variation of annual milk production per cow on daily FCM per cow were isolated in average and high producing herds. Changing from one group to individual feeding can increase daily FCM per cow by .5 to 1.1 kg and two groups to individual feeding by 0 to .8 kg without changing total herd nutrient intake. Reallocation of the same amount of nutrients to two groups instead of one can increase daily milk production by .15 to .8 kg of FCM per cow, reallocation to three groups instead of two by 0 to .6 kg of FCM per cow, and reallocation to four groups instead of three by 0 to .35 kg of FCM per cow.

(**Key words**: production, simulation, grouping, individual feeding)

Abbreviation key: CI = calving interval, HP = herd production, SM = standard deviation of 305-d FCM.

INTRODUCTION

The increased use of TMR on dairy farms has heightened the need to estimate benefits, if any, of group feeding. There are several possible advantages to dividing the herd for feeding purposes into more than one group. If a single ration is meeting the needs of high performance cows, lower producers will be overfed, and income over feed cost may then be improved more through a reduction in concentrate cost than an increase in milk produced (18) and a reduction in health problems caused by fat cow syndrome (13). If a single ration is not overfeeding low producers, then high producers may be deficient in nutrients, resulting in lower peak milk (20).

Expected benefits of two-group rations relative to single-group rations have not been consistent among researchers (4, 5, 9, 25). When no significant differences were found between one- and two-group feeding systems, loss in production could have been attributable to a rapid switch in rations (19). Nocek et al. (16) suggested that differences in production averages for which rations are balanced be no more than 15% between groups. This could partially explain the finding (6) that those feeding TMR should have a minimum of three groups.

The primary goal of this research was to estimate production benefits because of addi-

Received November 27, 1991.
Accepted January 28, 1992.

TABLE 1. Parameter estimates for equations predicting DMI.

Variable	Primiparous[1] Parameter estimate	SE	Multiparous[2] Parameter estimate	SE
Second 28-d period and later				
Intercept	16.6550	1.6056	24.8132	1.6720
Previous DMI, kg/d	.7804	.0164	.7387	.0126
SAS® Calving date[3]	.0001	.00002	.0001	.00002
DIM	.0402	.0067	.0440	.0081
ln DIM	−4.0003	.4681	−5.5833	.5412
DIM^2	−.00005	.00001	−.00004	.00001
ADF, %	.1259	.0632	.1387	.0456
ADF, %^{2}	−.0038	.0015	−.0043	.0009
First 28-d period[4]				
Intercept	−15.7834	9.4795	−22.1115	9.4410
SAS® Calving date	−.0008	.0001		
First 28-d 4% FCM, kg/d	.2110	.0399	.2163	.0195
ln BW, kg	4.2221	1.5830	4.8584	1.4921
ADF, %	.1541	.0531		
ADF, %^{2}			.0051	.0013

[1]Second and later 28-d period primiparous R^2 = .71; Durbin-Watson = 2.08; n = 1192.

[2]Second and later 28-d period multiparous R^2 = .79; Durbin-Watson = 2.08; n = 2355.

[3]The SAS® calving date = 1 on January 1, 1960.

[4]Primiparous, R^2 = .41, n = 120; multiparous, R^2 = .43, n = 251.

tional groups or a change from group to individual feeding. Accomplishment of the main objective required completion of two preliminary objectives, the first of which was derivation of DMI and milk prediction equations for lactating cows. The second preliminary objective was to use these equations in a simulated feeding of herds to collect data to use for the primary goal.

MATERIALS AND METHODS

University of New Hampshire data collected from 1966 through 1983 were used to derive DMI and milk prediction equations. Cows were fed forages consisting of 1) corn silage and hay silage or hay or 2) corn silage, hay silage, and hay. Concentrates varied from year to year but were commercial mixes that included combinations of wheat middlings, wheat bran, hominy, corn gluten meal, brewers grains, distillers grains, oat hulls, and soybean meal. Individual cow data were obtained on milk production, DMI, BW, and lactation number; birth, calving, and date dry; milk fat, SNF, and protein percentage of milk; and ration NE_L (megacalories per kilogram) and CP and ADF percentage of DM. There was a total of 4149 observations, most consisting of 28-d periods, on 377 lactations from 171 Holstein cows. If a cow averaged less than 8 kg of DMI/d in a period, records for that and all subsequent periods were deleted. The final period was dropped if it contained less than 28 d, reducing the number of observations to 3918. This was done so that all daily occurrences would have an equal (1/28) influence on a single observation.

Predicting DMI

A range of daily DMI between 2 and 4% of BW has been observed within herds by researchers (14). The most influential factors affecting this variation include milk production, DIM, BW, and digestibility of the ratio (1); milk production was the single most important factor (1, 11). Estimates of ratio of change in DMI to change in milk production range from .1 to .36 (1, 12, 15, 21).

Derivation of DMI equations for the simulation assumed that previous intake would account for a great deal of variation between cows. Table 1 presents regression coefficients

TABLE 2. Parameter estimates for equations predicting 4% FCM per lactating cow.

	Primiparous[1]		Multiparous[2]	
Variable	Parameter estimate	SE	Parameter estimate	SE
Intercept	21.6833	2.0233	22.3409	2.2608
Previous 4% FCM, kg/d	.6303	.1257	.5868	.0103
SAS® Calving date[3]	.0001	.00002	.00005	.00002
DIM	.0623	.0067	.0599	.0109
ln DIM	−5.7309	.4681	−5.5280	.7018
DIM^2	−.00008	.00001	−.00008	.00002
$RMNE_L$,[4] Mcal/d			.1648	.0192
RMCP,[5] kg/d	2.1123	.5802		
$RMNE_L$ × LCP	.1323	.0084	.0669	.0051
$RMCP^2$	−.7641	.1423		

[1]Primiparous R^2 = .90; Durbin-Watson = 2.15; n = 1192.

[2]Multiparous R^2 = .93; Durbin-Watson = 2.05; n = 2355.

[3]The SAS® calving date = 1 on January 1, 1960.

[4]RMNEL = Intake NE_L minus maintenance NE_L.

[5]RMCP = Intake CP minus maintenance CP.

predicting daily DMI for first lactation cows and those with previous lactations. Stepwise regression was used to select variables from previous period DMI, calving date (yearly trend), linear and nonlinear forms of ADF percentage of DM (digestibility), and linear and nonlinear forms of DIM. The conclusion that excluding previous DMI led the model to consistently under- or overpredict DMI for individual cows was based on positively correlated residuals indicated by low Durbin-Watson test scores. A smaller intercept and larger regression on previous DMI was indicative of lower initial intake and more persistency for first lactation cows.

Predicting DMI based partially on previous 28-d period DMI necessitated an equation to predict initial DMI. Stepwise regression was used to select variables in a second equation predicting first 28-d period daily DMI. To account for DMI-FCM and DMI-BW correlations, FCM and linear and nonlinear forms of BW were analyzed with calving date and linear and nonlinear forms of ADF as independent variables. Table 1 also reports parameter estimates for the variables selected in the stepwise regression procedure. Lower R^2 values for first period DMI than for subsequent periods demonstrate more unexplained DMI variation among different cows than for observations from the same cow and lactation.

Predicting 4% FCM

Partitioning of energy was selected as the method in this research for predicting milk production (8, 17, 23). Nutrients remaining after subtraction for maintenance requirements were divided between milk production and BW change. For simplicity, pregnancy requirements were not considered because they were small (23), applicable primarily in the dry period, and nearly the same for all cows.

To predict milk production through energy partition, estimates of energy intake were calculated. From NRC (14), the megacalories of NE_L required to support daily maintenance are .08 times kilograms of $BW^{.75}$. Energy ingested by the lactating cows was computed by adding maintenance energy, milk energy (.74 Mcal of NE_L/kg of FCM), and BW change energy (5.12 Mcal of NE_L/kg for gain or minus 4.92 Mcal of NE_L/kg for loss). Data on intake CP were used to calculate CP available for lactation. Grams of CP required for daily maintenance of lactating cows are 7.934 × $BW^{.616}$. Energy and CP maintenance requirements were subtracted from energy and CP intake to calculate remaining energy and protein. Remaining energy and protein were then used with three forms of DIM (actual, squared, and natural logarithm), calving date (to detect long-term production trends), and previous period FCM to predict current period FCM. As reported in

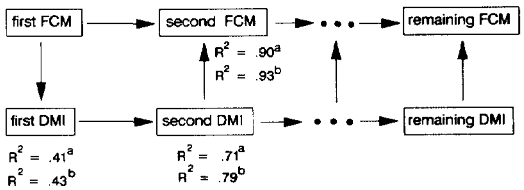

Figure 1. Relationship between FCM and DMI in prediction equations: a = primiparous R^2; b = multiparous R^2.

Table 2, independent variables explained 90% of the variation in primiparous 4% FCM and 93% of the variation in 4% FCM for the older cows. Similarly to DMI prediction, serial correlation among residuals that existed in a preliminary model was eliminated for both sets of animals when FCM from the previous period was included. Energy-protein interaction was significant for both heifers and older cows, indicating that milk response to energy or protein was dependent on the other. Although FCM response to DIM declined, diminished response to energy intake found in other models (2, 7, 10) was not directly demonstrated.

Establishing Nutrient Concentration Recommendations

Prior to the start of the simulation, standards for nutrient concentrations for group and individual feeding had to be determined. From a preliminary simulation, correlations were determined between milk production and nutrient concentrations that would satisfy established absolute nutrient requirements (14). Figure 1 reviews the relationship between DMI and FCM in the prediction process. Because DMI is influenced by ration fiber content, which is correlated highly with energy concentration, concentration recommendations were based on DMI from the previous, instead of upcoming, period. Furthermore, most rations are balanced on a function of previous milk production rather than on estimates of future milk production. Therefore, FCM and DMI from the previous period were used to establish a relationship between FCM in the previous period and nutrient concentrations that would meet absolute requirements in the upcoming period.

Parturition BW of 400 to 700 kg with 10-kg increments and first period daily FCM of 9 to 39 kg with 2-kg increments were generated for first parity cows. For multiparous cows, identical increments with BW range of 400 to 800 kg and FCM range of 10 to 50 kg were used. First period DMI for each of the animals was generated using parameter estimates from Table 2 with the assumption that all first period CP concentrations were 19% of DM, and energy concentrations were 1.72 Mcal of NE_L/kg of DM; ADF percentage of DM was a function of energy concentration. Derived from the energy-fiber relationship between 124 feeds (14) and with R^2 = .83,

$$\text{ADF\%} = 85.04 - 37.43 \times \text{Mcal of NE}_L\text{/kg of DM.} \quad [1]$$

Energy requirements for maintenance (based on beginning of period BW) and lactation (based on predicted FCM) were subtracted from energy intake. Magnitude and direction of BW change were assumed from energy balance. Estimates of second period energy and protein concentrations for a balanced ration were calculated using first period FCM and, as an allowance for depressed first period DMI, first period DMI plus 10%. Estimates of lactation energy requirements for the third period and beyond were calculated from previous period FCM; concentration recommendations were based on previous period DMI. Because protein concentration did not directly affect DMI, and to ensure adequate CP in the ration, CP requirements were calculated after FCM was known. Beginning with the third period, in addition to maintenance and lactation requirements, additional energy and protein (320 g/kg of BW change) were added to the diet so that primiparous cows could gain 50 kg and multiparous cows 5 kg over calving BW by the end of period 11, or 308 DIM. The difference between desired BW at the end of period 11 and BW in the evaluated period was divided by 11 minus the evaluated period number to allocate desired BW gain over the lactation. Maximum concentration of NE_L was constrained to 1.80 Mcal/kg of DM. Although slightly higher than the maximum concentration allowed in the simulation, this allowed for energy balance sooner in lactation so that correlations in late lactation between previous period milk production and energy concentra-

TABLE 3. Summary of assumptions used in simulation.

Category	Assumption		Source[1]
	$\overline{X}$	SD	
Beginning primiparous BW, kg	504.5	53.1	UNH data
Beginning multiparous BW, kg	589.6	58.1	
Primiparous DMI after 308 DIM, % of previous DMI	96.7		UNH data
Multiparous DMI after 308 DIM, % of previous DMI	96.3		
Primiparous portion of herd, %	32.4		Virginia DHIA (22)
Primiparous 305-d ME[2] 4% FCM, kg	7533		Virginia DHIA (22)
Multiparous 305-d ME 4% FCM, kg	7830		
All 305-d ME 4% FCM, kg	7740		
Calving intervals, minimum d	360		Virginia DHIA (22)
High, d	430	28	
Average, d	410	28	
Low, d	390	28	
Within-herd 305-d FCM SD, kg			
High	1587		Butcher et al. (3)
Average	1134		
Low	680		
Herd FCM production, kg			
High	8845		Virginia DHIA (22)
Average	7711		

[1]UNH = University of New Hampshire.

[2]ME = Mature equivalent.

tions required for maintenance and milk production would not be overly influenced by energy required for desired BW change. An indirect protein constraint was provided by restricting CP to that required for maintenance, milk production, and BW change as dictated by energy balance.

Totals of 3328 observations for heifers and 5733 observations for multiparous cows were used to predict recommended CP concentration from previous 28-d FCM production. Primiparous (R^2 = .92) and multiparous (R^2 = .91) recommendations were, respectively

$$RCPP = 6.55 + .416 \times PREFCM \quad [2]$$
$$RCPP = 8.06 + .292 \times PREFCM \quad [3]$$

where RCPP = recommended CP as percentage of DM, and PREFCM = previous 28-d average daily 4% FCM.

In deriving individual recommendations, energy was constrained to 1.80 Mcal of NE_L/kg of DM without regard to FCM production. Therefore, observations containing 1.80 Mcal of NE_L/kg of DM could have distorted regressions, and those observations were deleted. Recommendations for primiparous (n = 2193, R^2 = .79) and multiparous cows (n = 4799, R^2 = .73) were, respectively,

$$RNE_L = 1.24 + .019 \times PREFCM \quad [4]$$
$$RNE_L = 1.23 + .013 \times PREFCM \quad [5]$$

where RNE_L = recommended megacalories of NE_L per kilogram of DM and PREFCM as before.

Creating the Simulated Herd

Table 3 presents the assumptions used in constructing the simulation. Large within-herd differences in daily milk production were expected to increase benefits of additional groups or individual feeding. Large variation in annual milk production of cows within the herd and long calving intervals (CI) would both be expected to contribute to daily within-herd milk variation. Herds with three levels of mean CI and two levels of mean herd production (HP) were evaluated (22). Three levels of standard deviation of annual 305-d FCM production within the herd (SM) also were analyzed (3), producing 18 simulation runs from the possible combinations of CI, HP, and SM. Daily milk production and DMI were generated and recorded in 28-d periods. Predictions were assumed to occur on d 14 and to remain constant. Calvings were distributed equally throughout the year. All parturition occurred on the 1st d of a period, and no milk was discarded. Each simulated herd consisted of 100 cows, and data were collected over 50 of the described 28-d periods. Although dry periods were taken into account, no DMI data were collected for nonlactating cows.

Before first period herd data could be collected for analysis, beginning data had to be created for each of the 100 cows. Cow data were created with a 32.4% chance of being primiparous (22). Number of 28-d periods in her CI, periods in milk at first period of herd data collection, beginning BW, and 305-d FCM were randomly generated based on estimates of mean and standard deviation. Herd 305-d FCM was used to generate first period FCM based on the following derived formulas (24). For primiparous cows

$$FPFCM = \frac{TFCM - 372.572 \times HA}{147.767}, \quad [6]$$

and for the older animals

$$FPFCM = \frac{TFCM - 418.397 \times HA}{132.363} \quad [7]$$

where FPFCM = first period average daily 4% FCM, TFCM = 305-d FCM, and HA = annual herd average FCM divided by 1000.

Average daily DMI for a cow's first period postparturition was predicted from average daily FCM in the same period, BW, ADF percentage (derived from 1.72 Mcal of NE_L/kg and Equation [1] fiber-energy relationship), and, if primiparous, SAS® calving date of 8401, corresponding to January 1, 1983. Change in BW was computed from energy balance, and new BW was stored. After the first cow period, energy and protein were fed to the cow at concentrations recommended from Equations [2] through [5]; NE_L constraints were set at 1.76 and 1.35 Mcal/kg of DM, and CP constraints were set at 19 and 12% of DM. Both DMI and FCM were predicted, new BW was calculated, and the process was repeated for the number of periods in milk. This procedure was followed for each of the 100 cows. If a cow was in one of her last two CI periods, she was considered dry, and only data on periods since parturition and CI length were collected. For all others, an array existed at the beginning of the first period of herd data collection with information on periods in milk, periods in a CI, BW, previous period FCM, and previous period DMI.

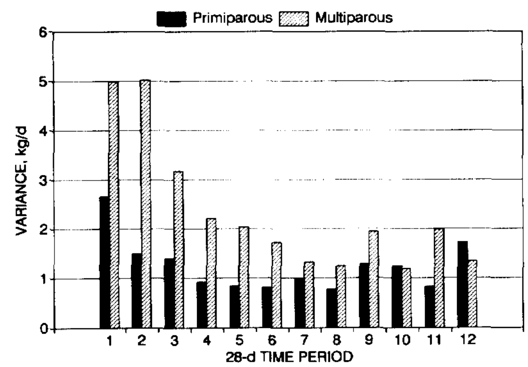

Figure 2. Estimated variance in predicted DMI.

Using the Simulated Herd for Data Collection

A difference between predata modeling and modeling for data collection was that calculations were made one cow at a time in precollection periods and one period at a time in collection periods. In addition, random variation in DMI was introduced in the collection periods using the mean square error from each period of the DMI prediction as an estimate of the variance. Figure 2 shows estimated DMI variance for each period by animal class. Because of the large amount of variation explained in the FCM models and the relationship of the FCM models with DMI prediction, randomness in milk prediction was limited to average daily first period FCM predicted from annual milk production.

After all cows had been initialized, herd data were collected. Individual cow data were recorded, and cows were fed in individual systems according to recommendations based on previous period milk production. A cow in her last production period did not contribute to recommendations, and a cow in her last dry period contributed 1.72 Mcal of NE_L/kg of

TABLE 4. Herd means at recommended feeding levels only.

Variable	Number of groups				Individual
	One	Two	Three	Four	
Average producing herds					
4% FCM per cow, kg/d	24.4	24.8	24.4	24.6	24.6
DMI per cow, kg/d	17.8	17.3	17.2	17.3	17.3
Daily BW change per cow, kg	.214	.092	.083	.084	.069
Average ration NE_L, Mcal/kg of DM	1.62	1.64	1.63	1.63	1.62
Average ration CP, % of DM	16.2	16.6	16.3	16.4	16.3
FCM, kg/Mcal of NE_L	.847	.873	.870	.872	.876
FCM, kg/kg of CP	8.49	8.64	8.68	8.68	8.71
High producing herds					
4% FCM per cow, kg/d	27.3	27.0	26.9	27.1	27.3
DMI per cow, kg/d	18.3	17.8	17.8	17.8	17.9
Daily BW change per cow, kg	.143	.023	.019	.016	.007
Average ration NE_L, Mcal/kg of DM	1.66	1.65	1.65	1.65	1.65
Average ration CP, % of DM	17.1	16.9	16.8	16.9	16.9
FCM, kg/Mcal of NE_L	.900	.918	.918	.921	.924
FCM, kg/kg of CP	8.76	8.99	9.01	9.01	9.05

DM and 19% CP, reflecting first period nutrient concentration recommendations. For group feeding, recommendations were based on the average of individual recommendations, and data were kept regarding group DMI, FCM, CP percentage of DM, and megacalories of NE_L per kilogram of DM. With multiple groups, cows in their first production period were always in the highest group, and those in their last production period were always in the lowest group. Others were sorted by recommended energy concentration (protein concentrations as a secondary sort for ties), had a constraint of not moving to a higher nutrient concentration group, and were distributed so that groups were of equal size.

RESULTS

Comparing Individual to Group Feeding

Table 4 displays herd means for group and individual feeding systems. Fifty periods with three levels of SM and CI resulted in 450 observations for each of the group and individual feeding systems in the average and high producing herds. Largest DMI and BW change occurred in one-group feedings. Largest FCM production occurred with two-group feedings in average producing herds and individual and one-group feeding with high producing herds. When only means are examined, the best indicators of feed efficiency, ratios of milk production to protein and energy intake, were largest with individual feeding.

To analyze and to separate effects of the data better, parameter estimates for equations predicting kilograms of 28-d 4% FCM per cow are shown in Tables 5 and 6. In Table 5, data from individual and one-group systems were evaluated separately from individual and two-group systems. Because of its high correlation with NE_L, CP was not used as an independent variable. Other than DMI and NE_L, all independent variables were dummy variables (0 or 1) used to describe the estimated effect of grouping, CI and SM. In the first case, taking the first derivative of 4% FCM with respect to method of feeding allowed estimation of expected change in period 4% FCM per cow because of a change from one-group feeding to individual feeding while holding total herd nutrient intake constant. The second situation was identical, but change was from two-group feeding to individual feeding. Examination of the means revealed that neither nutrient concentration nor DMI was the same between individual and one- or two-group feeding. This method isolates the effect of a change in feeding systems on FCM production from the effect of a change in total nutrient intake on FCM production. Results, after dividing by 28 to convert to daily figures, are displayed in

TABLE 5. Parameter estimates for equations predicting 28-d FCM per lactating cow with individual and one- and two-group feedings.

	Average producing herds		High producing herds	
	Parameter estimate	SE	Parameter estimate	SE
One-group and individual feeding				
Intercept	−1817.46		−1985.50	
DMI, kg	1.49	.05	1.57	.05
NE_L, Mcal/kg	1097.75	37.38	1189.33	32.27
Grouped[1]	−22.92	1.38	−22.87	1.07
Low calving interval[1]	8.56	1.16	5.27	.90
High calving interval × grouped[1]	−5.16	1.28		
Low calving interval × grouped[1]	−4.55	1.69		
High SD 305-d FCM[1]	4.17	.91	6.21	1.31
Low SD 305-d FCM[1]	−3.84	1.20	−8.83	1.04
High SD 305-d FCM × grouped[1]			−13.58	1.82
Low SD 305-d FCM × grouped[1]	7.68	1.58		
R^2		.91		.92
Two-group and individual feeding				
Intercept	−2319.17		−2442.85	
DMI, kg	1.52	.05	1.57	.05
NE_L, Mcal/kg	1399.06	47.08	1466.45	54.67
Grouped[1]	−16.29	1.57	−5.03	1.48
High calving interval[1]	3.28	1.24		
Low calving interval[1]	8.28	1.25	3.28	.97
High calving interval × grouped[1]	−9.34	1.74	−3.82	1.31
Low calving interval × grouped[1]	−5.04	1.71		
High SD 305-d FCM[1]	5.14	.87	9.16	1.46
Low SD 305-d FCM[1]	−6.15	1.17	−11.02	1.49
High SD 305-d FCM × grouped[1]			−6.58	2.04
Low SD 305-d FCM × grouped[1]	6.83	1.53	4.01	1.99
R^2		.91		.89

[1] 1 if true; otherwise, 0.

Figure 3. High producing herds showed .6 to 1.1 kg/d per cow increase in 4% FCM, with total forage and concentrate intake held constant, whereas average producing herds showed .5 to 1.0 kg/d per cow increase. As expected, largest increases in high producing herds were seen with long CI, but smallest increases were seen with short CI and average SM. In average producing herds, differences were largest with long CI and, again surprisingly, with average SM.

The bottom of Table 5 shows parameter estimates for an equation explaining individual versus two-group feeding. These parameter estimates were used to generate Figure 4, which shows the expected increase in daily kilograms of 4% FCM per cow by changing from two

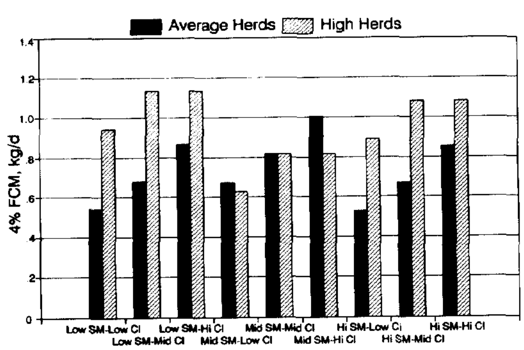

Figure 3. Estimated increase in daily FCM per lactating cow at different levels of standard deviation within herd FCM (SM) and calving interval (CI) combinations attributable to change from one-group to individual feeding with total herd nutrients held constant.

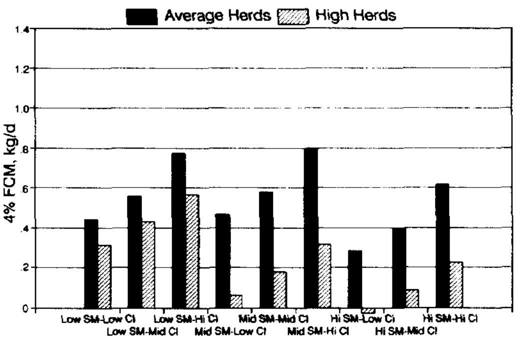

Figure 4. Estimated increase in daily FCM per lactating cow at different levels of standard deviation within herd FCM (SM) and calving interval (CI) combinations attributable to change from two-group to individual feeding with total herd nutrients held constant.

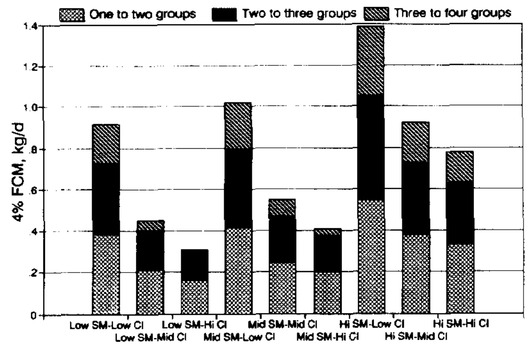

Figure 5. Estimated increase in daily FCM per lactating cow at different levels of standard deviation within herd FCM (SM) and calving interval (CI) combinations in average producing herds attributable to additional groups with total herd nutrients held constant.

groups to individual feeding. These changes were much smaller in high producing herds than those found with a switch from one-group to individual feeding. Increase in high producing herds ranged from 0 kg with high SM and short, or low, CI to .5 kg/d per cow with low SM and high, or long, CI. Daily increase in average producing herds gave a low of .25 kg per cow with high SM and low CI and a high of .8 kg per cow with average SM and high CI.

Production Benefits of Additional Groups

Table 6 presents parameter estimates of regression equations predicting 28-d 4% FCM based on DMI, megacalories of NE_L per kilogram of DM, CP percentage of DM, number of groups, SM, and CI. To investigate the possibility of nonlinear interactions between number of groups and SM and between number of groups and CI, interactions between CI and groups squared and between SM and groups squared were included in the model. In addition to feeding to group average, a series of simulations was run with the cows fed energy to group average and protein to group average plus .5 SD, another series with cows fed protein to group average and energy .5 SD below average, and a final series with cows fed both protein and energy at a level .5 SD below group average. Because CP and NE_L were no longer always fed to group average, both were included in the model. First derivatives were taken for FCM with respect to number of groups to estimate the effect of an additional group. Figures 5 and 6 were constructed with recommended feeding levels assumed and 28-d FCM converted to daily FCM. Figure 5 shows the grouping effect on FCM production for average producing herds. Adding a second group showed increases ranging from less than .2 kg/d per cow with low SM and long CI to more than .5 kg/d per cow with high SM and short CI. Similar increases, but only about 90% as large, were noted when a third group was added. A larger decline in production increase occurred with addition of a fourth production group. Although expected production increased up to .35 kg/d per cow with high SM and low CI, other combinations showed no increase, as with low SM and high CI.

High producing herds (Figure 6) displayed expected FCM increases of .5 kg/d per cow (low SM and high CI) to .8 kg/d per cow (high SM and low CI) when a second group was added. However, additional groups increased FCM production by much smaller amounts. With a third group, daily increases ranged from 0 to .3 kg per cow; with a fourth group, increases ranged from 0 to .2 kg per cow.

Expected increases in FCM production by adding a second group were similar to those derived from the difference in expected increases between one-group and individual feeding and expected increases between two-group and individual feeding. However, the reversal of the effect of SM and CI was not

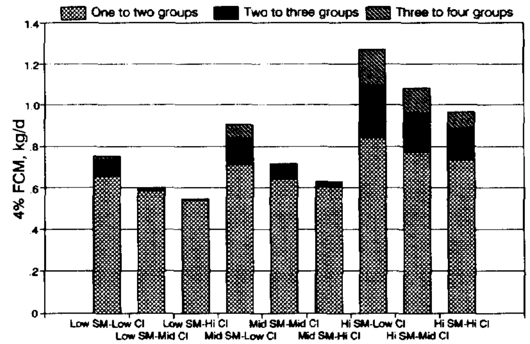

Figure 6. Estimated increase in daily FCM per lactating cow at different levels of standard deviation within herd FCM (SM) and calving interval (CI) combinations in high producing herds attributable to additional groups with total herd nutrients held constant.

anticipated. The higher CI effect was as expected with individual feeding, and the higher SM effect was as expected with group feeding. A possible explanation for this switch may be related to precision of nutrient allocation and time of response to a change in milk production with group and individual feeding. Individual feeding could work better in herds with long CI and higher numbers of low producing cows in late lactation than the group feeding that would continue to overfeed these cows and probably underfeed midlactation cows in the group. Group overfeeding of lower producing cows in early to midlactation (and underfeeding the higher producing cows in the group) could provide a more favorable situation than precise nutrient allocation. If so, this implies that nutrient recommendations were not high enough for low producing cows in early lactation, and recommendations for these cows should be increased somewhat.

CONCLUSIONS

Derivation and simulation of data indicated that prediction of future DMI and milk production for an individual cow was greatly enhanced by knowledge of her previous DMI and milk production. In a practical sense, grouping should be based on expectations of future performance, which is to a great extent based on previous performance. For those cows without actual data on DMI, other methods of measurement of previous performance could be used and incorporated into the grouping criteria. For example, body condition scoring may provide information that should not be discounted on

TABLE 6. Parameter estimates for equations predicting 28-d FCM per lactating cow in one-, two-, three-, or four-group feedings.

	Average producing herds		High producing herds	
	Parameter estimate	SE	Parameter estimate	SE
Intercept	−1085.34		−1016.73	
Number of groups	32.76	7.41	−58.53	7.76
ln number of groups	−23.64	7.77	94.28	8.18
Number of groups squared	−3.39	.80	4.55	.83
Average 28-d DMI per lactating cow	1.44	.02	1.57	.02
Average NE_L, Mcal/kg of DM	201.24	22.52	170.12	18.68
Average CP, % of DM	43.08	1.17	44.04	1.10
High SD 305-d FCM[1]	−4.84	1.12		
High SD 305-d FCM × number of groups[2]	4.12	.75	4.09	.33
Low SD 305-d FCM × number of groups[2]	−.97	.11	−1.69	.33
High SD 305-d FCM × number of groups squared[2]	.14	.03	−.14	.03
Low SD 305-d FCM × number of groups squared[2]			.05	.03
Low calving interval[1]	−5.98	1.14		
High calving interval × number of groups[2]	−1.33	.11	−1.09	.13
Low calving interval × number of groups[2]	5.39	.76	2.24	.30
Low calving interval × number of groups squared[2]			−.09	.02
R^2		.95		.93

[1]1 if true; otherwise 0.

[2]Number of groups or number of groups squared if true; otherwise 0.

the past relationship between milk production and DMI for an individual cow.

In this study, reallocating but holding total nutrient intake constant when changing from one-group to individual feeding increased FCM 2 to 4% and when changing from two-group to individual feeding increased FCM 0 to 3%. With the same conditions, increasing from one to two groups increased FCM 1 to 3%, from two groups to three groups 0 to 2%, and three groups to four groups 0 to 1%. Because the effect of a change in feeding system on milk production was isolated statistically, actual FCM increases could be higher if total herd DMI increased.

If individual feeding was considered group feeding with a maximum number of groups, there were inconsistencies in determining influence of CI and SM on FCM benefits from adding groups or changing from group to individual feeding, possibly from low nutrient recommendation to low producing cows fed individually in early lactation. Total expected FCM increases were, however, consistent. Based on the results, general comments could be made that two production groups could be sufficient for high producing herds in a group feeding system because of smaller differences in nutrient concentration between high and low groups. In average producing herds, a much smaller between-group decrease in nutrient concentration with three groups rather than two could justify a third group. Either of these situations should, however, simultaneously account for the costs (dependent on extra labor and facility costs) and benefits (increased production) of added groups. In addition, analyzed benefits were on a per cow basis; total benefits increase with larger numbers of cows.

Considering only milk production response, as few as three or four production groups can perform as well as individual feeding systems. However, decisions regarding individual compared with group feeding and number of groups extend beyond simulated production benefits. Individual feeding affords excellent opportunities for individual cow data in conjunction with automated management systems (transponders, electronic identification, etc.). The importance of this factor is, of course, correlated with computerized record-keeping capabilities of management. If data on individual cows have less priority, group feeding becomes more favorable. Optimal number of groups might be based not only on direct production benefits but also on indirect production benefits from bovine social factors, herd health reasons, reproductive management considerations, optimal use of facilities, and labor considerations. The importance of any of these factors is closely related to its economic relevance as a declining marginal return to additional groups is observed within a herd.

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