Estimating Effects of Herd Characteristics on Milk Production in Minnesota Dairy Farms

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ABSTRACT

The objectives of this study were to estimate influence of genetic and environmental measures on herd milk production and to determine the relationship between these effects. Genetic evaluations were assessed by weighted herd PTA dollars. Environmental factors were categorized by nutrition, reproduction, and lactational health. Variables selected to represent these categories were, respectively, grain and forage DMI, days open, and percentage of herd scoring less than five on linear SCC test. A total of 3967 Holstein herds on Minnesota DHIA in December 1989 that had been on DHIA for at least 1 yr and had complete data for all selected variables were used to explain rolling herd 4% FCM.

Results indicated that expected difference among herds attributable to any individual herd characteristic was dependent on levels of other herd characteristics. Both largest and smallest expected differences in herd FCM were associated with high levels of grain feeding. Largest FCM difference due to days open occurred with low genetics and lactational health. Greatest FCM differences due to genetics occurred with high days open in healthy herds. Greatest FCM differences between herds due to mastitis were with long days open and high genetics. At \$.30/kg of FCM and selected management levels, ranges for the effect of a decrease in days open by 1 were –.57 to \$1.05 per cow, an increase by 1 PTA dollar from 2.28 to \$4.17 per cow, 1 kg increase in grain DMI .13 to \$.17 per cow, and a decrease by 1 in percentage of cows infected with mastitis 6.72 to \$8.97 per cow.
(Key words: herd characteristics, effects, milk production)

Abbreviation key: DRPC = Dairy Records Processing Center, PTA\$ = PTA dollars.

INTRODUCTION

A number of studies have evaluated relative importance of management characteristics on herd milk production and profitability. Determining the percentage of variation in profit or milk production that a management characteristic explains can allow a guideline for relative importance of a particular management practice (13). Goodger et al. (4) found 13 of 91 management practices that he evaluated to have a significant influence on milk production. Azzam et al. (1) concurred in finding the value of DHI information to be dependent on herd management practices. Business and management measures have been shown to be correlated with production costs (14) and herd profitability (5, 7, 12).

Although management practices may either directly affect herd milk production or else be strongly correlated with higher herd milk production, a cause and effect relationship should exist between genetic and environmental herd characteristics and herd milk production. Some management practices might actually influence the herd characteristics that directly affect milk production. An example of this type of indirect influence of management on average herd milk production might be poor AI procedures, resulting in long herd calving intervals (high days open) and lower herd milk production than would be expected with a shorter calving interval. Improved AI techniques would result in lower days open, and lower days open could result in higher expected average annual herd

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milk production due to cows spending a higher portion of lactation in peak milk production. In this example, an improved management practice could alter a herd characteristic (days open), and the direct result of the transformed herd characteristic could be a change in average herd milk production.

Other management practices may cause a modification in the rate of transformation of nutrients into milk production without directly affecting genetic and environmental characteristics of the herd. An example of this might be frequency of feeding (3). Two herds with identical genetics, rations, DMI, and levels of mastitis could have different production levels due solely to different feeding frequencies. Because frequency of feeding was not considered a herd characteristic, its effect would appear in the error term of a model that explained herd milk production as a function of genetic and environmental herd characteristics.

If a cow's milk production can be considered the sum of herd genetic and environmental characteristics, and herd milk production the average sum of individual cow milk production, herd milk production can be implied to be the sum of herd genetic and environmental effects. Genetic and environmental measurements from DHIA records could then be used to explain milk production in dairy herds. Once the effect on milk production of genetic and environmental categories was estimated, a cost or benefit based on milk price could be evaluated for a one unit difference between herds in the separate categories. The objectives of this study were to estimate the effects of herd characteristics on milk production and demonstrate their relationships with each other.

MATERIALS AND METHODS

If a cow's phenotypic expression is the sum of genetic and environmental effects, or

$$P = G + E \qquad [1]$$

where P is the cow's phenotype, G is genetic effects, and E environmental effects, then the herd's average phenotypic expression can be deduced as the average of the sum of the genetic and environmental expressions of the cows within the herd, or

$$\Sigma P/n = \Sigma G/n + \Sigma E/n \qquad [2]$$

where

ΣP = the sum of the phenotype of the cows in the herd,
ΣG = the sum of the genetic effects of the cows in the herd,
ΣE = the sum of the environmental effects of the cows in the herd, and
n = the number of cows in the herd.

With the phenotype defined as average annual herd milk production, an equation was developed to explain 4% FCM production as a function of genetic and environmental measurements that were available from official DHIA records processed at the Minnesota Dairy Records Processing Center (DRPC). The dependent variable was specifically the rolling herd average corrected to 4% FCM.

In selecting independent variables to use in the model, it was important to choose environmental and genetic variables that directly affected herd milk production. In addition, to reduce the possibility of multicollinearity, it was important that two independent variables that explained the same variation in the dependent variable not be chosen. For example, days open and calving interval could be expected to explain a great deal of the same variation and have a high degree of correlation.

Herd genetics were measured by PTA dollars (PTA$). The DHIA data processed at the Minnesota DRPC divide PTA$ into categories for first lactation animals and cows with at least one previous lactation. A single dependent genetic variable, weighted herd average PTA$, was obtained by using the PTA$ for the first lactation heifers and the PTA$ for older cows and respectively weighting by percentage of first lactation and older cows in the herd.

Environmental characteristics were divided into three major categories: nutrition, health, and reproduction. Nutrition is a significant component of the environmental effect. Not only does feed account for 45 to 60% of the cost of producing milk (9), but it provides the ingredients necessary for milk production.

Minnesota DHIA data for average annual grain and forage DMI were used to represent nutrition effects on milk production. Because energy and protein differences within grain and forage nutritional subclasses were not quantified, variations of feed quality and type, particularly among forages, could add to random variation (15). However, summary data were available only for average grain and forage DMI, and, therefore, these variables were selected as the best nutritional factors available to explain herd milk production. Herds that reported less than 100 kg of grain or 1000 kg of forage annually per cow were deleted from the data.

Lactational health is an important component of the environmental effect. One of the major concerns of dairy producers is the rate of mastitis infection. Infected cows can result in decreased profits due to lost milk production as well as disposal of milk with antibiotic residues. Blosser (2) estimated annual lost milk production due to mastitis at 386 kg per cow and 62 kg of discarded milk per cow. To represent the relative lactational health or mastitis-free state of the herd, the percentage of cows scoring 4 or less on the linear SCC test as reported on the Minnesota DHIA data was selected as an independent variable. Any herd that did not report this variable was eliminated from the analyzed data.

The third environmental category, reproductive efficiency, has been shown to influence annual milk production (6, 8, 10). Inability of lactating cows to conceive can result in a relatively smaller proportion of lactation spent in peak milk production and subsequently less annual milk production. Cost estimates of additional days open, a common measure reflecting reproductive efficiency, have varied widely; some situations in which extension of calving interval actually increased income have been reported (6). Generally, an increase in days open was associated with decrease in profits. The variable selected from the DRPC data to represent reproductive efficiency was days open of cows confirmed pregnant. To eliminate herds that did not report breeding dates, those herds with calculated days open greater than 240 were deleted from the data base.

In summary, environmental effects were defined as

$$\Sigma E/n = \Sigma N/n + \Sigma H/n + \Sigma R/n \quad [3]$$

where

$\Sigma E/n$ = average herd environmental effects;
$\Sigma N/n$ = average herd nutritional effects, as measured by grain and forage DMI;
$\Sigma H/n$ = average herd lactational health effects, as measured by percentage of cows in herd scoring 4 or less on linear SCC score; and
$\Sigma R/n$ = average herd reproductive effects, as measured by days open of cows confirmed pregnant.

Substituting Equation [3] into Equation [2],

$$\Sigma P/n = \Sigma G/n + \Sigma N/n + \Sigma H/n + \Sigma R/n \quad [4]$$

where

$\Sigma P/n$ = average herd phenotype, as measured by rolling herd 4% FCM; and
$\Sigma G/n$ = average herd genetic effects, as measured by weighted herd PTA$.

Records from Minnesota DHIA members obtained from the Minnesota DRPC were used as the source of data. Data were obtained from December 1989 records of those Holstein herds that had been on test for at least 1 full yr and passed the screenings described for each of the particular independent variables. After deletion of records for the reasons just described, 3967 herds remained for analysis. Table 1 summarizes statistics for all variables. Because there was evidence of skewness (2.088) and kurtosis (8.614) in days open and skewness in herd health (−.921), percentiles were reported as well. Although not affecting regression procedures, the percentiles were used when evaluating management effects at management levels defined as high or low.

In addition to basic linear forms, quadratic forms of each of the variables described were

TABLE 1. Herd characteristic data on a per cow basis.

Variable	$\overline{X}$	SD	SE	Median	25th Percentile	75th Percentile
4% FCM, kg	7518.3	938.9	15.113	7516.1	6914.1	8157.6
Grain, kg	2694.1	571.6	9.247	2665.4	2335.1	3044.1
Forage, kg	4091.3	633.0	10.032	4086.9	3701.4	4466.4
Days open	125.3	27.6	.406	120.0	136.0	107.0
Percentage herd not positive SCC	73.5	11.9	.185	75.0	67.0	82.0
Herd PTA dollars	55.5	20.0	.322	56.8	42.7	68.4

included for evaluation to investigate the possibility of diminishing marginal returns. Response to any of the variables could depend on levels of other factors. For example, the effect of low levels of genetics on 4% FCM in a herd with high nutritional levels could be different than the effect of low levels of genetics on 4% FCM in a herd at low nutritional levels. In genetics (PTA$) and lactational health (percentage of herd not scoring 4 or more on linear SCC test), high management levels were defined as the 75th percentile; higher PTA$ and percentage mastitis-free numbers represented higher percentiles. In reproduction (days open), high management levels were defined as the 75th percentile; lower days open were a higher percentile. To define high nutritional levels to include both forage and grain DMI might reflect body size as much as nutritional level, and only grain was used to represent high nutritional levels (11). Therefore, although forage remained a predictor of average annual herd 4% FCM and a grain × forage interaction was also tested, only interactions between independent variables representing categorical management levels were tested. This produced possible two-way interactions of grain × forage, grain × days open, grain × PTA$, grain × SCC, days open × PTA$, days open × SCC, and PTA$ × SCC. Possible three-way interactions included grain × days open × PTA$, grain × days open × SCC, and days open × PTA$ × SCC. Grain × days open × SCC × PTA$ was the tested four-way interaction.

Ordinary least squares were used to evaluate a model explaining rolling herd FCM as a function of the described independent variables. In the absence of DMI (grain and forage), the regression line would be expected to pass through the origin. Therefore, the inter-

TABLE 2. Kilograms of 4% FCM estimated from herd characteristics.

Variable	Parameter estimate	SE	*T* ratio	*P*
Grain (G)	2.01283161	.13053770	15.420	.0001
Forage (F)	.13058691	.01992843	6.553	.0001
Days open (D)	19.05407253	2.24964447	8.470	.0001
Percentage not positive SCC (S)	46.57480426	3.42532982	13.597	.0001
PTA dollars (P)	42.27292643	5.38226576	7.854	.0001
Days open^2	−.01752734	.00665665	−2.633	.0084
G × S Interaction	−.01028107	.00148419	−6.927	.0001
G × P Interaction	−.01507277	.00214361	−7.031	.0001
G × D Interaction	−.00730797	.00075986	−9.617	.0001
S × P × D Interaction	−.00415513	.00055062	−7.546	.0001
G × S × P × D Interaction	.00000187	.00000022	8.533	.0001
MS Error	622,604.9			
Root MS error	788.4			
R^2	98.9			
Number of observations	3967			

cept term was dropped, and the regression was forced through the origin. Backward stepwise regression procedure was used to select the model; all remaining variables were significant at the .01 level. Table 2 reports the results of model estimation. Because the intercept term was dropped, the R^2 of 98.9% reflects the variation about the origin in the model. An indicator of variation about the regression line for individual observations could be derived from an estimate of σ_e^2, the mean square error, in this case 788.4 kg.

RESULTS AND DISCUSSION

All linear effects in the model were statistically significant at the .01 level. The squared term relating to days open was the only quadratic determined significant. All significant two-way interactions related to grain DMI. These factors included health, genetics, and days open. The only three-way interaction found significant was among these same three variables. Negative parameter estimates were found with all two- and three-way interactions, whereas a positive parameter estimate was reported for the four-way interaction.

Table 3 reports equations to estimate differences in FCM between herds due to a 1-unit difference in any one of the independent variables with all other independent variables equal. These equations were obtained by taking first derivatives with respect to each of the herd characteristics. Because forage was a predictor of 4% FCM with no quadratic term or interactions, the expected effect of forage DMI on herd FCM was strictly linear. With this exception, the extent of differences in FCM between herds due to a 1-unit difference in a herd characteristic depended on levels of other herd characteristics. A 1-kg difference in average forage DMI between two herds with all other examined herd characteristics identical would expect to produce a difference in average annual FCM of .13 kg. The expected difference in FCM due to differences in grain, days open, PTA$, and percentage of herd scoring less than 5 on the linear SCC test fluctuated and was not so readily available on inspection.

Figures 1 through 4 display expected differences in FCM due to a 1-unit change in the category being examined. Expected FCM differences for each of the genetic and environmental categories were examined at low (25th percentile), medium (50th percentile), and high (75th percentile) for days open and at low and high levels of the management categories that were interacting with the examined herd characteristic. The graphs were derived by substituting the percentiles from Table 1 into the equations in Table 3. These figures represent the difference in expected average herd FCM production between two herds for which the only difference is a 1-unit change in the variable being examined.

Figure 1 reports expected difference in herd FCM due to a 1-kg change in grain fed. With the shortest examined days open, 107 d, the highest expected difference in FCM between herds occurs with high genetics and high herd health, but the second highest response takes place with the situation exactly reversed. As days open increase, expected response with low health and low genetics decreases until it is the smallest of the four possible combinations. At any level of days open, the largest effect of a change in grain DMI occurs in a healthy herd (low levels of mastitis infection) with high genetics. However, it is noteworthy that the magnitude of that effect is strongest with the lowest reproductive percentile rating (high days open).

TABLE 3. Kilograms of 4% FCM change due to herd characteristic change.[1]

$\partial FCM/\partial D$	=	$19.054072 - .035054 \times D - .007308 \times G - .004155 \times S \times P + .00000188 \times G \times S \times P$
$\partial FCM/\partial S$	=	$46.574804 - .010281 \times G - .004155 \times P \times D + .00000188 \times G \times P \times D$
$\partial FCM/\partial P$	=	$42.272926 - .015073 \times G - .004155 \times S \times D + .00000188 \times G \times S \times D$
$\partial FCM/\partial G$	=	$2.012832 - .010281 \times S - .015073 \times P - .007308 \times D + .00000188 \times S \times P \times D$
$\partial FCM/\partial F$	=	$.130587$

[1]D = Days open, S = percentage of cows without positive SCC, P = weighted herd average PTA dollars, G = grain (kilograms), F = forage (kilograms).

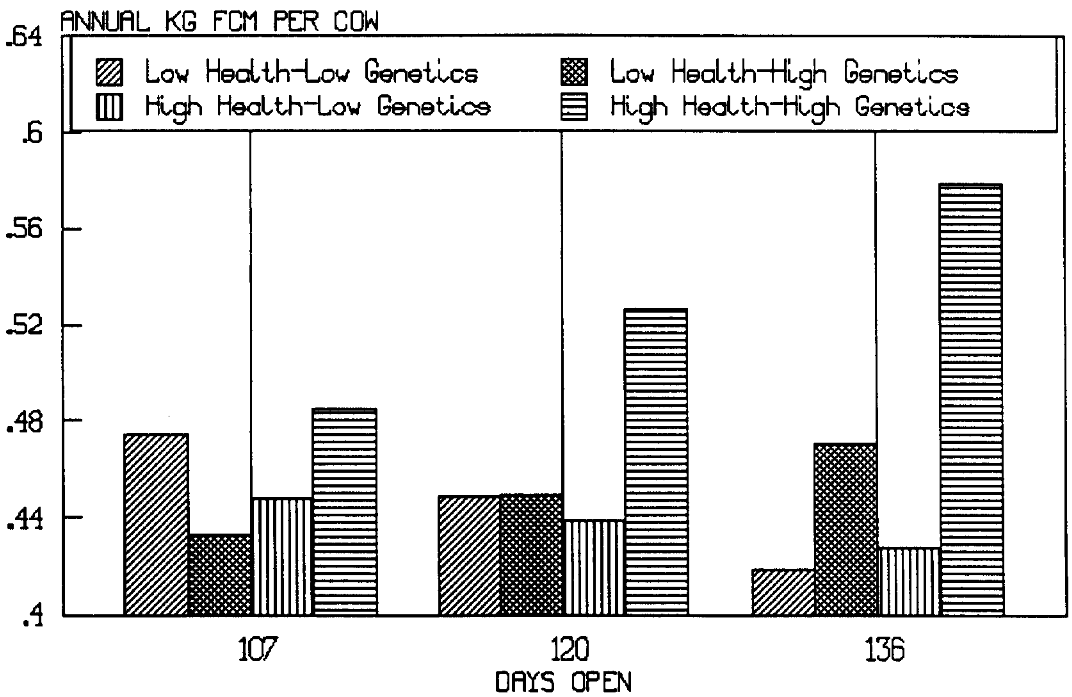

Figure 1. Expected difference in herd 4% FCM per cow per year due to 1 kg per cow of additional grain DMI while holding average herd PTA dollars, days open, and percentage of herd scoring less than 5 on linear SCC score constant.

Figure 2 displays expected differences in FCM due to decreasing days open by 1. For each of the reproductive categories examined (high at 107 d open, medium at 120 d open, and low at 136 d open), maximum positive effect of a decrease in days open by 1 takes place with high grain feeding, low health, and low genetics. For a herd with high grain, high health, and high genetics, the expected advantage of a decrease in days open by 1 was not obvious. It is, however, apparent from examining the bars on the graph that the advantage gained by reducing days open is higher with longer days open.

Figure 3 summarizes the effects of genetics on herd 4% FCM. At 107 d open, the smallest effect is found with high grain feeding and low herd health, although this combination ranked second with 136 d open. At all levels of days open, maximum FCM response to genetic improvement is achieved with high percentile rankings for health and grain feeding. As with grain effects, the magnitude of this response is greatest in herds with low reproductive percentile rankings.

Maximum FCM response to a change in level of mastitis infection occurred with high percentiles of grain feeding and genetics, as reported in Figure 4. The effect of the other three combinations was relatively similar. A striking result is the effect of health improvement. Even at a minimum, expected difference in average annual herd FCM per cow is approximately 22 kg.

Table 4 summarizes levels for the combinations of herd characteristics that resulted in maximum and minimum responses to a unit change between herds. Response to 1-kg grain DMI varied from .418 kg FCM to .579 kg; the smallest FCM difference occurred with poor lactational health and genetics and long days open, and the largest FCM difference occurred with strong health and genetics and long days open. This intimates that a healthy and genetically strong herd with long days open could increase profitability with higher feeding of concentrates as well as by decreasing days open. This suggestion is corroborated by response extremes in the days open category.

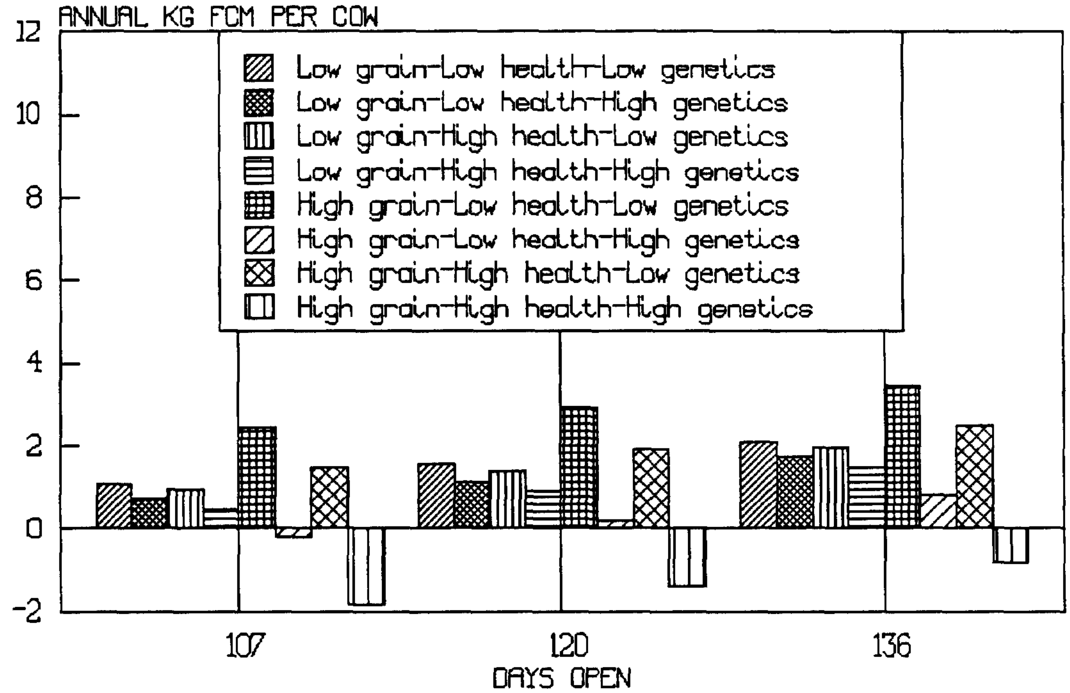

Figure 2. Expected difference in herd 4% FCM per cow per year due to 1 less day open per cow while holding herd PTA dollars, average grain DMI, and percentage of herd scoring less than 5 on linear SCC score constant.

Minimum expected differences occurred with herds that were fed high amounts of grain, had low days open, and were healthy and genetically strong. At \$.30/kg of FCM, maximum annual value of a decrease in average herd days open, occurring with high grain feeding, long days open, and poor health and genetics, was \$1.05 per cow. This figure is the expected difference in profit between two herds with identical genetics, herd health, grain DMI, and differing in average days open by 1.

At the same milk price of \$.30/kg of FCM, a 1-unit increase in percentage of cows testing less than 5 on the linear SCC score translated to an annual difference of 6.72 to \$8.97 per cow. Minimum response occurred in herds at high levels of grain feeding, low days open, and poor genetics, whereas maximum FCM difference was seen in herds with high grain feeding, high days open, and strong genetics. In a 100-cow herd, 1 cow/mo less testing 5 or more on linear SCC score would translate to 672 to \$897/yr in additional milk revenues with no increase in feed cost.

Some conclusions regarding lost milk production due to mastitis can be derived from the results. On average, 26.5% of cows in the sample data herds were considered infected. At average management levels, expected difference in herd FCM due to a 1% difference in cows infected was 25 kg per cow. This would imply that reducing mastitis infection to 0% in the average herd would increase annual FCM production per cow by 638 kg, a figure somewhat higher than Blosser's 1979 figure of 448 kg (2). However, this discrepancy could easily be attributed to production differences between the two time periods.

Expected annual difference across herds due to a 1-unit difference in PTA\$ varied from \$2.28 per cow with high levels of grain feeding, short days open, and poor health to a high of \$4.17 per cow with high levels of grain feeding, long days open, and relatively healthy herds. In a 100-cow herd, the expected effect of culling a cow and replacing her with a cow genetically superior by 100 PTA\$ would range from 228 to \$417 annually.

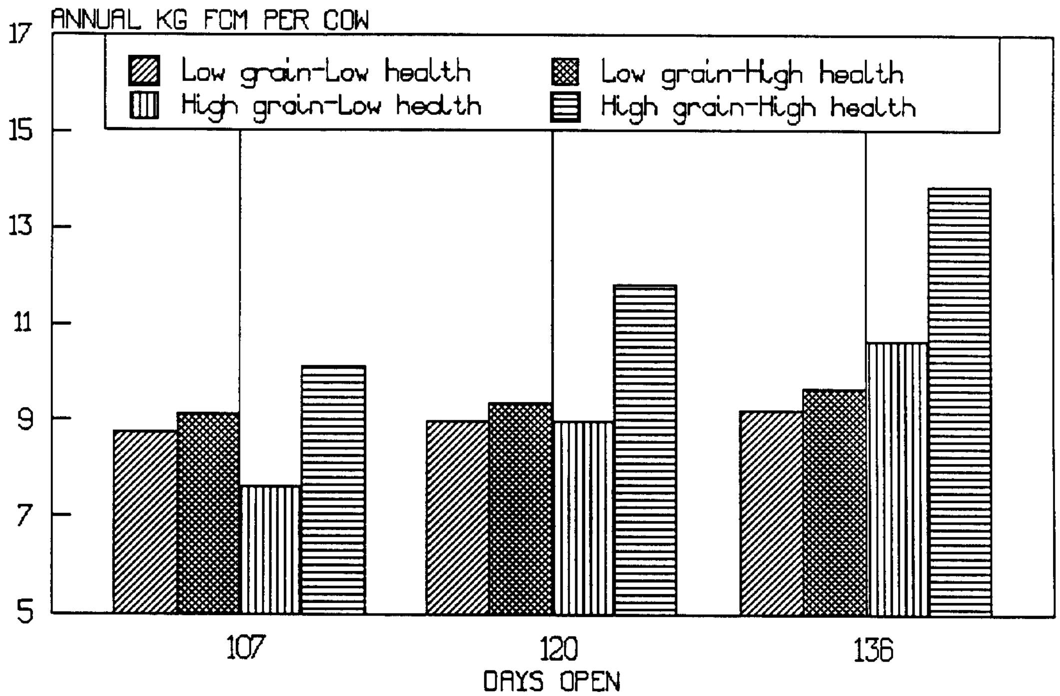

Figure 3. Expected difference in herd 4% FCM per cow per year due to 1 additional average herd PTA dollar while holding herd average grain DMI, days open, and percentage of herd scoring less than 5 on linear SCC score constant.

The importance of interrelationships can be displayed by examining the grain column in Table 4. High levels of grain feeding are associated with both minimum and maximum FCM differences for the other categories. The determining factor for high or low response was the level of genetics, days open, and herd lactational health. Minimum FCM differences are associated with high management levels in all categories, such as the expected difference with a 1-d decrease in average days open, or low management levels in all categories, such as response to additional grain. Perhaps more important is to examine herd levels at maximum herd FCM differences. In all cases, maximum response to a change occurs with long days open. Maximum mastitis effect takes place with high genetics, whereas maximum genetic effect is associated with high herd lactational health. For all situations, marginal return is always highest in a setting with long days open, indicating at least one weakness and at least one herd strength, increasing potential for improvement.

CONCLUSIONS

Results indicate the cost of mastitis problems to be considerable. With milk price of $.30/kg of FCM, 1 less infected cow/mo in a 100-cow herd was associated with 672 to $897/yr extra milk revenues with no increase in feed cost. In addition, herds with higher infection rates appear to be less responsive to genetic and nutritional improvements. Herds with higher infection rates are, however, more responsive to decreases in days open, particularly in herds that are genetically weak as well. This suggests that mastitis problems and poor genetics aggravate the problem of long days open.

The interrelationships among and within environmental and genetic categories were important in estimating expected differences in FCM due to a 1-unit difference in a herd characteristic. Minimum responses were generally associated with either poor herd health or high herd characteristics and the associated diminishing marginal returns. A decline in re-

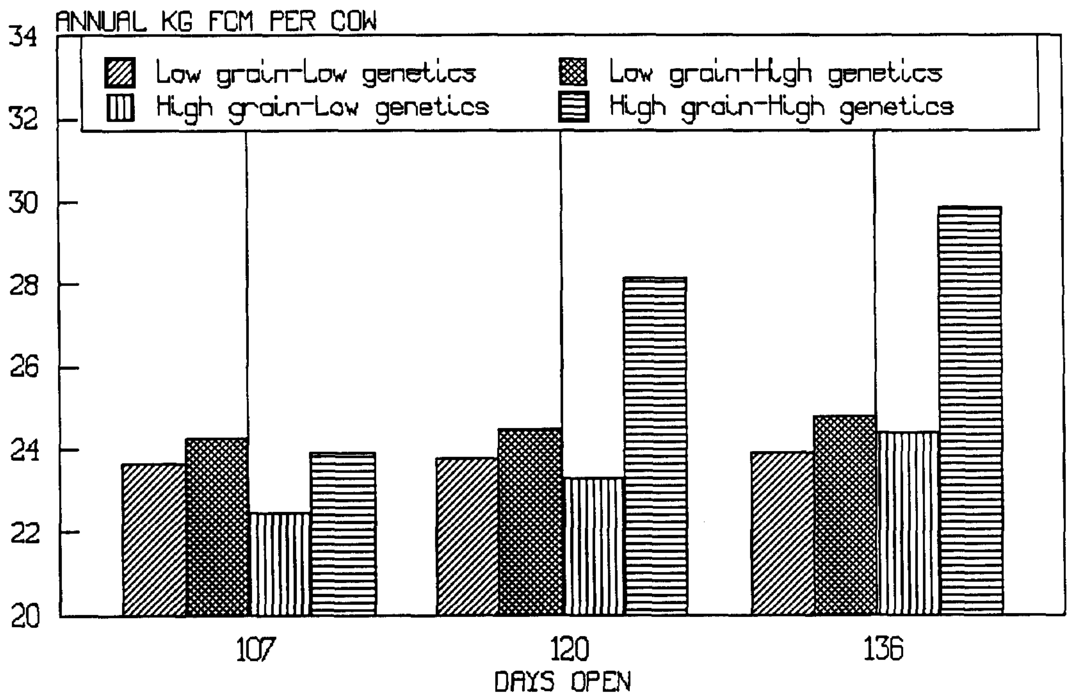

Figure 4. Expected difference in herd 4% FCM per cow per year due to additional 1% of herd scoring less than 5 on linear SCC score while holding herd PTA dollars, days open, and grain DMI constant.

TABLE 4. Response extremes and corresponding herd characteristics.

		Herd characteristic level[1]					
Responding variable	Response level	Grain	Days open	Mastitis	PTA$	FCM[2]	
						(kg)	($)
Grain	Lowest	A	L	L	L	.418	.13
Grain	Highest	A	L	H	H	.579	.17
Days open	Lowest	H	H	H	H	−1.9	−.57
Days open	Highest	H	L	L	L	3.5	1.05
Mastitis	Lowest	H	H	A	L	22.4	6.72
Mastitis	Highest	H	L	A	H	29.9	8.97
PTA$	Lowest	H	H	L	A	7.6	2.28
PTA$	Highest	H	L	H	A	13.9	4.17

[1]A = All management rating or levels, L = 25th percentile, low management ratings or levels, H = 75th percentile, high management ratings or levels; PTA$ = PTA dollars.

[2]Assumes 4% FCM price $.30/kg; data are on a per cow basis.

sponse to mastitis improvements could likely be attributed to a diminishing response to practices designed to correct health problems. For example, a herd with 50% of its cows infected has the potential for a more drastic improvement than a herd with 5% of its cows infected.

Maximum herd FCM differences were associated with a combination of herd strengths and weaknesses that left both the potential and room for improvement. Although the economic importance of herd health is significant, potential benefits and cost of health improvements need to be regarded when evaluating this category. Interrelationships among and within genetic and environmental factors also need to be considered when establishing priorities for herd improvement in other categories.

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