Relationship Between Test-day Measures of Somatic Cell Count and Milk Production in California Dairy Cows

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ABSTRACT

The relationship between test-day measures of milk somatic cell count and milk yield was evaluated using the November 1985 test data from 8352 Holstein cattle (2923 primiparous and 5429 multiparous cows) located in ten Tulare County, California dairies. Following correction for herd and stage of lactation effects, design variable regression was used to create separate models for primiparous and multiparous cows predicting the changes in milk production associated with milk somatic cell count class. Cell counts were stratified by ½ $\log_e$ cell count (x1000 cells/mL) units, permitting comparisons with previous studies.

Cell counts less than 148,000/mL were not found to be associated with significant reductions in milk yield when compared to the reference class (cell counts < 20,000/mL). Consistent incremental decreases in milk production were not noted with increasing cell count strata, even following the natural log transformation. The most dramatic production losses were noted in the range of 148,000 to 665,000 cells/mL. Primiparous cattle in the 403,000 to 665,000 cell count strata experienced a 5.22 kg (19.72%) decrease in test-day milk yield. Multiparous cattle in the same class experienced 3.01 kg (7.82%) reductions in milk production. Primiparous and multiparous cows had similar production losses.

The study population differed from previous studies on the basis of herd size, milk production and the level of udder health, measured by milk somatic cell count. These differences and the choice of experimental design may in part explain differences in study results and conclusions.

RÉSUMÉ

Cette étude portait sur 8352 vaches Holstein, dont 2923 primipares et 5429 multipares, qui appartenaient à dix troupeaux laitiers du comité de Tulare, en Californie. Elle consistait à utiliser les résultats du jour du test de novembre 1985, dans le but d'évaluer le rapport entre le nombre de cellules somatiques du lait et la production lactée. Après les corrections pour les effets reliés aux troupeaux et au stade de la lactation, les auteurs utilisèrent la régression linéaire multiple pour former des modèles différents entre les primipares et les multipares, modèles susceptibles de prédire les changements de la production lactée associés à la classe des numérations des cellules somatiques retrouvées dans le lait. Ils stratifièrent ensuite les numérations précités par unités de ½ $\log_e$, c'est-à-dire X1000 cellules/mL, ce qui leur permit de comparer leurs résultats avec ceux d'études antérieures.

Les numérations inférieures à 148,000 cellules somatiques/mL ne s'avérèrent pas associées à des réductions significatives de la production lactée, lorsqu'on les compara à la classe de référence, c'est-à-dire moins de 20,000 cellules/mL. L'augmentation des strates de numérations cellulaires ne s'accompagna pas de diminutions graduelles constantes de la production lactée, même après la transformation du logarithme naturel. On enregistra les baisses de production les plus dramatiques dans la gamme de 148,000 à 665,000 cellules/mL. Les primipares qui se situaient dans le strate de 403,000 à 665,000 cellules/mL affichèrent une diminution de leur production lactée de 5,22 kg, c'est-à-dire 19,72%, le jour du test, comparativement à 3,01 kg, c'est-à-dire 7,82%, pour les multipares. En somme, les unes et les autres affichèrent des baisses de production semblables.

Les vaches de cette expérience différaient de celles des précédentes, de par l'importance des troupeaux, la production lactée et le degré de santé du pis, tel que déterminé par le nombre de cellules somatiques du lait. Ces différences et le choix du plan expérimental peuvent expliquer une partie des différences des résultats et des conclusions de cette étude.

INTRODUCTION

Mastitis is an important cause of impaired economic productivity in the dairy industry. A variety of costs may be either directly or indirectly attributed to intramammary inflammation.

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Included are culling and replacement of infected individuals, medication and veterinary services, diagnostic microbiology and additional labor or management inputs. Less visible is the reduced milk yield associated with subclinical intramammary infection, the single largest cost associated with mastitis (1-8).

The relationship between mammary gland inflammation and milk production has been investigated in studies (9-10) using qualitative measures of inflammation such as the California Mastitis Test (CMT), and more recently (11-17) continuous measures of somatic cell count (SCC). These studies have demonstrated that as milk SCC increases, lower milk production can be expected. Estimates of reduced production predicted by SCC have been useful in compiling costs related to mastitis and in increasing the knowledge of mastitis pathogenesis (18-20).

Recently, studies examining production and SCC measures from large data bases have offered an improved understanding of the relationship between SCC and milk production. A one unit increase in the natural logarithm (SCC (x 1000 cells/mL) (LSCC) was found to be associated with a 0.65 to 1.44 kg reduction in daily milk production (11,16). Over a 305 day lactation, a unit increase in LSCC was associated with a 135 kg and 270 kg loss for primiparous and multiparous cows, respectively (16).

Many such studies have attempted to discover the optimally descriptive and clinically relevant relationship between increased milk somatic cell counts and the attendant reductions in milk yield. Models have become progressively more complex with introduction of logarithmic transformations (21), quadratic and cubic components (13); all seeking to present a mathematical description of production losses accurate across the broad range of observed somatic cell counts.

Although these studies employed large data bases and rigorous statistical analyses, the design and geographic location of these studies may preclude the extrapolation of their results to other production units, particularly the large intensively managed dairies of the arid southwestern United States.

In some cases data sets were restricted to cattle with completed lactations, potentially biasing results by excluding cows culled for mastitis and/or low milk production before completing a lactation. The same bias may exist for studies in which production and SCC were measured repeatedly for individual cows over the course of a lactation (11,16). In such a design, cows with high SCC and/or low production would likely be removed at a higher rate and, therefore, be represented by fewer records. Additionally, interpretation of these results is complicated because serial observations for an individual cow are not strictly independent; production and SCC for a test day being related to those of previous test days.

This study sought to examine the relationship between milk production and SCC for cows in the San Joaquin Valley of California. The design permitted a prediction of milk production from SCC that was free from confounding influences of lactation number, herd-effect and stage of lactation and from bias associated with use of complete lactation records.

MATERIALS AND METHODS

SOURCE OF RECORDS

The association between SCC and milk production was examined using Dairy Herd improvement (DHIA) records (AgriTech Analytics, Tulare, California) for ten dairies in Tulare County, California tested during November 1985. Each herd contained only Holstein cattle and managed cattle in a manner representative of feedlot dairies in the San Joaquin Valley. A summary description of herds, relative to size, lactation number, production, somatic cell count and calving interval is provided in Table I.

Somatic cell counts were performed using a Fossomatic Cell Counter (Foss Electric, Hillerod, Denmark). Information was extracted from DHIA cow records for the test day. Only data from records containing complete information on SCC, lactation number, days-in-lactation (DIL) and milk production were used in analyses.

ANALYSIS

The general analytic approach used in this study was to construct models predicting milk production from SCC that adjusted for possible effects of herd and DIL. The form of the general model before adjustment was:

$$Y = U + S + H + DIL + e$$

Where:

Y = Estimated test-day milk production
U = Mean production (kg)
S = Effect common to milk somatic cell count (x1000 cells/mL) strata
H = Effect common to herd
DIL = Effect common to days in lactation strata
e = Unexplained variation

TABLE I. Descriptions of Ten Dairies in Tulare County, California, November 1985[a]

	Number of Cows Tested				Mean 305 Day Mature Equivalent Production			
		Lactation Number			Mean SCC[b] (x1000			Calving Interval
Herd	Total	1	2	>= 3	cells/mL)	kg milk	kg fat	(mo)
1	1562	531	371	660	203	9986	353	14.01
4	622	202	144	276	150	9568	378	13.32
6	224	69	57	98	173	9951	352	14.53
7	722	239	187	296	140	8422	310	13.38
8	1362	391	316	655	105	8840	310	12.32
9	941	270	240	431	143	8807	302	14.27
10	304	101	23	180	166	8437	300	12.39
11	799	252	39	508	175	9067	334	14.09
13	1922	907	547	468	325	8677	302	13.24
15	427	128	105	194	155	9078	318	13.59

[a]Herd descriptions were drawn from Dairy Herd Improvement Association monthly herd total reports and do not incorporate data editing prior to analysis
[b]Mean milk somatic cell count was computed by the records processing company as the arithmetic mean of SCC weighted by test-day milk production

TABLE II. Correction Factors (kg) Used to Adjust Test-day Milk Production for Days-in-lactation Effect for Cows Tested from Ten Dairies in Tulare County, California

Days-in-lactation			
Lower Class Limit	Upper Class Limit	Primiparous Cows	Multiparous Cows
0	30	a	a
31	60	-3.0	-1.7
61	90	-2.6	-0.7
91	120	-2.5	+2.2
121	150	-2.4	+3.8
151	180	-2.4	+5.9
181	210	-5.0	+8.1
221	240	+0.2	+11.1
241	270	+1.5	+13.0
271	300	+1.5	+15.9
301	360	+4.3	+17.3

[a]Production was corrected using cattle in the first month of lactation as the reference for days-in-lactation

The $\log_e$ transformation of somatic cell count (LSCC) was used to permit comparisons with previous studies and to explore the possibility of a linear relationship between $\log_e$SCC and production. Log_e somatic cell count (x1000) cells/mL was stratified by ½ $\log_e$ units ranging from = < 3 to > = 8 and treated as a categorical design variable with 12 levels. Herd was treated as a categorical design variable using herd number 1 as the reference herd. Days-in-lactation was also considered as a design variable with 11 levels because we did not anticipate a linear relationship with test-day milk production. The inherent strength of the categorical design was that it removed the initial assumption that an inherently linear relationship existed between dependent and independent variables (22). The size of the data set (5429 multiparous and 2923 primiparous cows) permitted the stratification of independent variables into large numbers of relatively narrow categorical design variables. Herd and DIL strata descriptions are presented in Tables II and III. Cattle exceeding 360 days-in-lactation were excluded from all subsequent analyses. Separate models were constructed for primiparous and multiparous cattle.

Initially, regression was performed using the statistical software package BMDP 2R (23). Adjustments for possible effects of herd and DIL were made by adding or subtracting from the dependent variable, production, herd and DIL strata coefficients generated in a previous regression. This adjustment procedure was repeated until no strata of DIL or herd had an F-value > 0.001 or a coefficient differing by more than 0.005 kg from the mean production estimated for the reference class, cows in herd number 1 with LSCC < = 3.0 and in their first month of lactation. Adjustment factors for each stratum are presented in Tables II and III. The adjusted models were of the general form:

$$Y^* = U^* + B\,(S) + e$$

Where:

- Y^* = Estimated production adjusted to the first month of lactation in the reference herd
- U^* = Estimated adjusted production
- B = Production change (coefficient) associated with a given SCC stratum
- S = Presence or absence within a given SCC stratum
- e = Unexplained variation

A final regression analysis was perfomed using BMDP 1R (24) on adjusted models to provide estimates of production changes associated only with changes in LSCC class and the probability of production for cattle within a given stratum differing from the reference class (SCC < 20,000 cells/mL).

TABLE III. Correction Factors (kg) Used to Adjust Test-day Milk Production for Herd Effect in a Study Performed in Ten Herds in Tulare County, California

Herd Number	Primiparous Cows	Multiparous Cows
1	a	a
4	+2.3	+2.8
6	-1.6	0
7	+5.5	+5.3
8	+3.9	+4.3
9	+3.0	+4.0
10	+2.5	+2.3
11	+2.5	+3.1
12	+1.7	+1.8
15	+1.8	+2.5

[a]Herd number 1 was the reference herd

RESULTS

Of the 8352 cow records that had complete information for the DHIA test of November 1985, 2923 were for cows in their first lactation and 5429 were for cows in their second or higher lactation. Distribution of cows according to LSCC class showed that cows studied generally had low SCC (Fig. 1, Tables I and II). The mean values of SCC, lactation number, DIL and production are given in Table IV. The daily milk production for cows in the reference classes, herd 1 and the first month of lactation, were 26.47 kg for first lactation cows and 38.49 kg for multiple lactation cows (Table V).

Results of regression analyses of milk production as a function of LSCC are presented in Table V. The coefficients reported are estimated changes in production associated with changes in LSCC relative to the reference class. Negative coefficients indicate production losses associated with respective LSCC strata. Coefficients for LSCC classes = < 5.0 (SCC 148,000 cells/mL) were not statistically significant for either primiparous or multiparous cows. Production loss for all LSCC classes > 5.0 (148,000 cells/mL) was significant, with the exception of LSCC classes 7.0-7.5 and 7.5-8.0 for first lactation cows (Table V). The absolute magnitude of reduced production was similar for first and multiple lactation cows. The

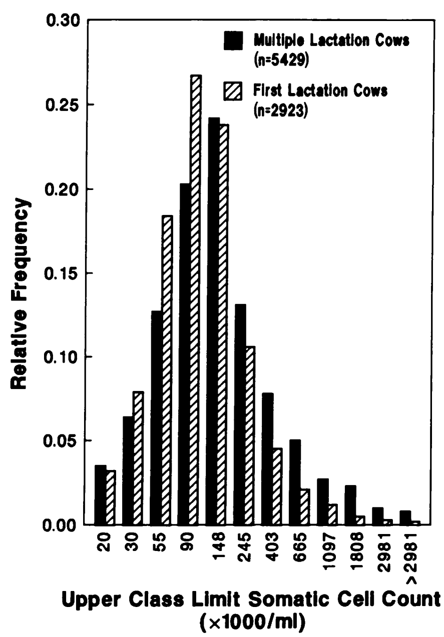

Fig. 1. Relative frequency of primiparous and multiparous cattle within strata of $\log_e$ somatic cell count (x1000 cells/mL) for ten dairies tested through Dairy Herd Improvement in November 1985, in the San Joaquin Valley of California.

TABLE IV. Descriptive Statistics for Cows Tested in November 1985, in Ten Herds Located in Tulare County, California

	Lactation No. 1 Mean	(SE)	Lactation > = 2 Mean	(SE)
Milk somatic cell count (x 1000 cells/mL)	137	(314)	242	(534)
Log_e somatic cell count	4.43	(0.84)	4.74	(1.07)
Lactation number	1	(a)	3.44	(1.56)
Days-in-lactation	159	(90)	157	(93)
Test-day milk production (kg)	24.2	(5.7)	28.8	(9.3)
n	2923		5429	

[a]Only first lactation cattle are included in the group

reduction ranged from 1.72 kg/day for cows in all lactations with a LSCC of 5.0-5.5 (148,000-245,000 cells/mL) to 5.08 kg/day for first lactation cows and 5.86 kg/day for multiple lactation cows with a LSCC > 8.0 (2,981,000 cells/mL).

Production loss expressed as a percentage of reference class production was higher for first lactation cows than for multiple lactation cows. Percentage loss for first lactation cows in LSCC classes with significant coefficients ranged from 6.5% (1.72/26.47) for LSCC 5.0-5.5 to 19.7% (5.22/26.47) for LSCC class 6.0-6.5. Production loss for multiple lactation cows ranged from 4.5% (1.72/38.49) for LSCC of 5.0-5.5 to 15.2% (5.86/38.49) for LSCC of > 8.0. Production losses, expressed both in actual production lost and as a percentage of reference class production are graphically depicted in Fig. 2.

Consistent incremental production losses of increasing magnitude were only observed across a narrow range of LSCC, between LSCC 5.0 and 6.5 (148,000 to 665,000 cells/mL) (Fig. 2, Table V). The reduced milk yield per unit change in LSCC for LSCC classes showing a linear relationship with production loss (LSCC 4.5-5.0 to 6.0-6.5) was estimated to be 1.78 kg [(3.01 kg-0.34 kg)/1.5 units] or 4.62% of the reference class for multiple lactation cows and 3.21 kg [(5.22 kg-0.40 kg)/1.5 units] or 12.13% of the reference class for first lactation cows.

DISCUSSION

This study suggests SCC exceeding 148,000 cells/mL are associated with reduced milk production. This estimate is considerably lower than that of 500,000 cells/mL by Reichmuth *et al* (19). A level of 148,000 cells/mL is also lower than, but in close agreement with, the threshold of 228,000 cells/mL suggested to indicate intramammary infection (25). A study of Canadian multiple lactation cows, however, found a significant reduction in test day milk yield of 1.81 kg for SCC = < 148,000 cells/mL (11).

Production losses associated with cell counts exceeding this threshold did not consistently increase in absolute magnitude with increasing cell counts, suggesting the relationship between LSCC and production losses may not be strictly linear. Coefficients failed to demonstrate consistently increasing production losses with higher LSCC classes (> 5.0) in both primiparous and multiparous cattle. Models for both age groups actually demonstrated smaller production loss coefficients for LSCC scores between 6.5 and 7.5 (403,000 < SCC = < 1,808,000). Furthermore, the production loss experienced by primiparous cattle with LSCC scores > 7.0 and = < 7.5 was not significantly different from the reference LSCC class (SCC < 20,000 cells/mL).

Previous studies have suggested the existence of more complex relationships between somatic cell count and reduced milk production that resist linear interpretation even following logarithmic transformations (11,13, 14). Of the two LSCC ranges that appeared to be responsible for the deviations from linearity, the increased production relative to lower LSCC classes for cows with LSCC between 6.5 and 7.5 was unexpected and unexplained. It is unlikely that the elevated

TABLE V. Summary of Regression Results for Models Predicting Production Losses Associated with Varying Concentrations of Milk Somatic Cells in a Study Performed on Ten Dairy Herds Located in Tulare County, California

Upper Class Limit SCC	Log_e SCC	Multiparous Cows n	Relative Frequency	Production Loss (kg)	S.E.	%	p[a]	Primiparous Cows n	Relative Frequency	Production Loss (kg)	S.E.	%	p[a]
20	3.0	194	0.035	*	*	*	*	95	0.032	*	*	*	*
30	3.5	349	0.064	+0.18	0.56	+0.47	0.747	233	0.079	-0.43	0.61	-1.62	0.479
55	4.0	677	0.124	+0.38	0.51	+0.99	0.458	538	0.184	-0.35	0.55	-1.32	0.529
90	4.5	1103	0.203	+0.02	0.49	+0.05	0.975	783	0.267	-0.89	0.54	-3.36	0.101
148	5.0	1314	0.242	-0.34	0.48	-0.88	0.492	698	0.238	-0.40	0.54	-1.51	0.464
245	5.5	714	0.131	-1.72	0.51	-4.47	<0.001	312	0.106	-1.72	0.58	-6.50	0.003
403	6.0	428	0.078	-2.61	0.54	-6.78	<0.001	134	0.045	-2.90	0.67	-10.96	<0.001
665	6.5	273	0.050	-3.01	0.59	-7.82	<0.001	63	0.021	-5.22	0.81	-19.72	<0.001
1097	7.0	148	0.027	-3.02	0.69	-7.85	<0.001	36	0.012	-2.81	0.98	-10.62	0.004
1808	7.5	125	0.023	-2.74	0.72	-7.12	<0.001	16	0.005	-1.05	1.35	-3.97	0.437
2981	8.0	56	0.010	-4.79	0.96	-12.44	<0.001	9	0.003	-3.15	1.74	-11.90	0.071
>2981	>8.0	48	0.008	-5.86	1.02	-15.22	<0.001	6	0.002	-5.08	2.11	-19.19	0.016
Total		5429						2923					
Coefficient (kg)		38.49						26.47					
r^2		0.0398						0.0352					

*Cows with milk somatic cell counts <20,000/mL were used as the reference level
[a]p refers to the probability production did not differ from the reference class

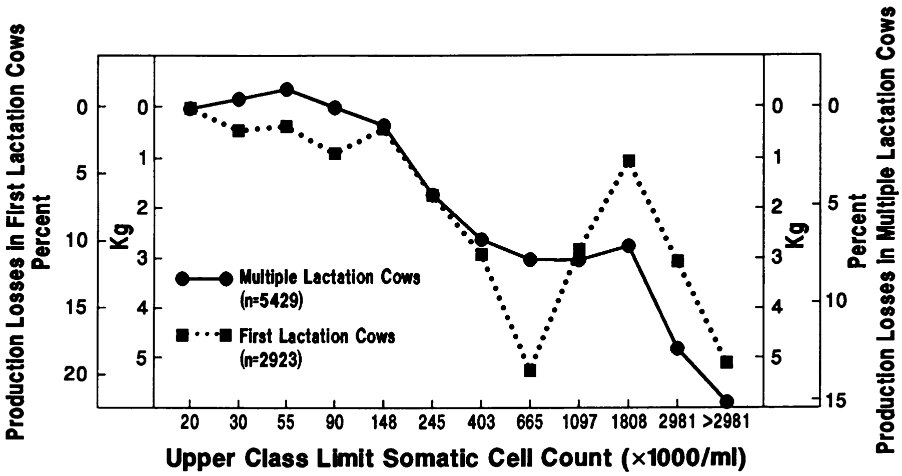

Fig. 2. Absolute and percentage losses in milk yield associated with varying concentrations of milk somatic cells in a study performed in ten dairy herds located in Tulare County, California.

production in high SCC cows was observed by chance because the phenomenon was present in both first and multiple lactation cows and because a pattern of first increasing then decreasing production was apparent from several coefficients. Moreover, other studies hint that this phenomenon may not be unique to the cows studied here. Presence of a significant quadratic and cubic component in the relationship of production, and SCC, estimated by Jones *et al.* would be compatible with a curvilinear relationship similar to that observed in the present study (13). Data presented by Meijerling *et al* also suggested a similar phenomenon for LSCC > 1,500,000 cells/mL, although the suggestion was subtle and apparent only for primiparous cows (14). Similarly, the reduced incremental production loss found by Dohoo for LSCC > = 6.0 and the curvilinear appearance of production data reported by Jones *et al* for cows in highly productive herds suggests that a similar relationship may have existed for production at high SCC (11,13). The finding of a narrow range of consistently increasing production losses indicates that, at least for cows similar to those studied here, it would be unreasonable to assume production loss is a linear function of LSCC, except between LSCC of 5.0 and 6.5 (148,000 and 665,000 cells/mL).

The estimated production loss associated with a unit change in LSCC for the linear segment between LSCC 4.5-5.0 and 6.0-6.5 of 3.21 kg and 1.78 kg for first and multiple lactation cows was substantially higher than losses previously reported. In two studies Dohoo *et al* and Salsberg found respective decreases of only 1.44 kg and 0.65 kg milk associated with a unit increase in LSCC (11,17). Both studies estimated production change for SCC ranging from lowest to highest values, which likely included SCC levels not related to production loss and, therefore, could have accounted for the small estimates of loss per unit LSCC.

The dramatic changes in daily milk yield observed in the middle range of SCC strata far exceed those predicted by previous studies employing linear modelling techniques, even those employing logarithmic transformations of milk somatic cell count. Were cattle from low, middle and high somatic cell count strata included in a single linear model, even following the $\log_e$ transformation, the net result would be a least squares regression line producing consistent incremental production losses with increases in milk somatic cell count. Because we observed no significant decreases in milk production to be associated with somatic cell counts less than 148,000, inclusion of these observations in a linear model would be expected to flatten the slope of a regression line, producing an erroneously low estimate of incremental production losses. Preliminary linear regression models following the $\log_e$ transformation were also performed, but not reported. These analyses revealed production losses of 0.89 and 1.11 kg milk yield per unit increase in LSCC, for primiparous and multiparous cows respectively; both substantially less than losses suggested by categorical models.

Percentage losses reported by Dohoo *et al* and Salsberg *et al*, 6.1 and 3.19% respectively (11,17), were considerably lower than our estimate of 12.13% for first lactation cows, but similar to our estimate of 4.62% for multiple lactation cows. Differences in methods of calculating percentages would not account for differences in results. In previous studies percentages were based on mean production, which likely would be lower than the reference level we used for herd 1 cows with a SCC = < 20,000 and in their first month of lactation, resulting in a higher, not lower, percentage.

In contrast to results of previous studies, first lactation cows had losses similar to those multiple lactation cows (13,16). The lack of appreciable difference in loss between first and multiple lactation cows may relate to the general high level of production in the study population and the relatively high production achieved by primiparous cows (24.2 kg) in this study. Plots of data from a study examining milk yield for herds with various levels of production suggested that the difference in loss between first and multiple lactation cows diminished as the level of milk production for the herd increased (17). Based on the results of this study, the thumb rule of a twofold loss in production per lactation for multiple lactation cows compared to first lactation cows should not be applied to the intensively managed dairies of the arid southwestern United States.

Results of the present study suggest that the loss of milk production related to increased SCC may be greater than previously expected, at least for California cows. Production was 1.72 kg less than the reference level at SCC as low as 148,000-245,000, and at high SCC production was reduced by as much as 19.7% for first lactation cows and by 15.2% for multiple lactation cows. Further research is needed to confirm the findings of this study and to identify possible factors that may explain why cows raised in large, highly productive herds under systems of intensive feedlot management would experience such high losses, compared to cows investigated in other studies.

A different relationship and magnitude of milk production loss associated with SCC found in the present study also may be a reflection of the higher level of milk production and different degree of udder health observed for the California herds. Average milk production for first and multiple lactation cows (24.2 kg and 28.8 kg) was considerably higher than that of 19.7, 23.6 and 26.7 kg for all lactations of low, medium and high producing herds estimated by Jones (13). Salsberg *et al* found an average milk yield of only 20.34 kg (17). In contrast to the average SCC for first and multiple lactation cows found here (137,000 and 242,000), the average for cows in low, medium and high producing Virginia dairies was 598,000, 354,000 and 300,000 (13); whereas the average SCC in a study involving Canadian Holsteins was only 177,560 (17). The distribution of SCC observed in the present study, however, tended to have a higher proportion of cows with low SCC than that for another group of Canadian cows (11).

The difference between the relationships of milk loss and SCC described here and by Salsburg *et al* may be explained additionally by the difference in stage of lactation for cows in the studies. The present study was restricted to cattle less than 361 days in lactation. The average DIL for first and multiple lactation cows (157 and 159) reflects this constraint. If the SCC can be expected to increased by the time cows reached 300 DIL (17), a study examining cows with extended lactations would be expected to find production to be low and SCC to be high, compared to cows of more typical lactation length (18).

In conclusion, we believe our observations, and hence interpretations, are not artifacts resulting from our choice of analytic methods. The variable herd, which was subsequently removed from the models presented, might have been classified a random effect. We chose to treat herd as a fixed variable for two reasons. First, the sample population was restricted to ten herds and extrapolation to all possible herds must be made with a degree of caution. This admission in no way diminishes the importance or relevance of the study. Second, treating herd as a fixed effect is certainly not without precedent in the field of animal health research. It is unlikely that alternative categorical models would have produced substantially dissimilar results. The use of a fixed effect model would not have biased estimates of production losses, but may have effected the level of statistical significance reported. Given that coefficients estimating production losses were in most cases highly significant, this was not troubling.

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REFERENCES

1. **DOBBINS CN Jr.** Mastitis losses. J Am Vet Med Assoc 1977; 170: 1129-1132.
2. **FETROW J.** Subclinical mastitis: Biology and economics. Compend Contin Educ 1983; 2: S223-S233.
3. **HALE HH, PLASTRIDGE WN, WILLIAM LF.** The effect of *Streptococcus agalactia* infection on milk yield. Cornell Vet 1956; 46: 201-206.
4. **JANZEN JJ.** Economics losses resulting from mastitis: A review. J Dairy Sci 1970; 53: 1151-1161.21.
5. **KITCHEN BJ.** Review of the progress of dairy science: bovine mastitis: milk compositional changes and related diagnostic tests. J Dairy Res 1981; 48: 167-188.
6. **SCHULTZ LH.** Somatic cell counting of milk in production testing programs as a mastitis control technique. J Am Vet Med Assoc 1977; 170: 1244-1246.
7. **SHAW AD, BEAN AL.** The effect of mastitis upon milk production. J Dairy Sci 1935; 18: 353-357.
8. **WHEELOCK JV, ROOK JAF, NEAVE FK, DODD FH.** The effect of bacterial infection of the udder on the yield and composition of cow's milk. J Dairy Res 1966; 33: 199-215.
9. **APPLEMAN RD, ROWE GA, FORKER OD.** Relationship between milk production and incidence of low level mastitis as indicated by California Mastitis Test. (Abstract E20) J Dairy Sci 1965; 48: 829.
10. **FORSTER TL, ASHWORTH US, LEUDECKE LO.** Relationships between California Mastitis Test reaction and production and composition of milk from opposite quarters. J Dairy Sci 1967; 50: 675-682.
11. **DOHOO IR, MEEK AH, MARTIN SW.** Somatic cell counts in bovine milk: Relationships to production and clinical episodes of mastitis. Can J Comp Med 1984; 48: 130-135.
12. **FOX LK, SHOOK GE, SCHULTZ LH.** Factors related to milk loss in quarters with low somatic cell counts. J Dairy Sci 1985; 68: 2100-2107.
13. **JONES CM, PEARSON RE, CLABAUGH GA, HEALD CW.** Relationships between somatic cell counts and milk production. J Dairy Sci 1984; 67: 1823-1831.11.
14. **MEIJERLING A, JAARTSVELD FJH, VERSTEGEN MWJ, TIELEN MJM.** The cell count of milk in relation to milk yield. J Dairy Res 1978; 45: 4-14.
15. **PEARSON JKL, GREER DO.** Relationship between somatic cell counts and bacterial infections of the udder. Vet Rec 1974; 95: 252-257.
16. **RAUBERTAS RF, SHOOK GE.** Relationship between lactation measures of somatic cell concentration and milk yield. J Dairy Sci 1982; 65: 419-425.
17. **SALSBURG E, MEEK AH, MARTIN SW.** Somatic cell counts: Associated factors and relationship to production. Can J Comp Med 1984; 48: 251-257.
18. **LESLIE KE, DOHOO IR, MEEK AH.** Somatic cell count in bovine milk. Compend Contin Educ 1983; 2: S601-S610.
19. **REICHMUTH J.** Somatic cell counting — Interpretation of results. Proc Seminar Mastitis Control. Int Dairy Fed Doc 1975; 85: 93-109.
20. **SHOOK GE.** Approaches to summarizing somatic cell count which improve interpretability. Proc 21st Annu Meet National Mastitis Council, 1982: 150-166.
21. **ALI AKA, SHOOK GE.** An optimum transformation for somatic cell concentration in milk. J Dairy Sci 1980; 63: 487-490.
22. **AFIFI AA, CLARK V.** Computer Aided Multivariate Analysis. Belmont: Lifetime Learning Publications, 1984: 221-228.
23. **DIXON WJ, JENNRICH R.** P2R: Stepwise regression. In: BMDP Statistical Software. Berkeley: University of California Press, 1983: 251-263.
24. **DIXON WJ, BROWN MB, ENGLEMAN L, FRANE JW, HILL MA, JENRICH RI, ROPOREK JD.** PIR: multiple linear regression. In: BMDP Statistical Software. Berkeley: University of California Press, 1983: 237-250.
25. **DOHOO I, MEEK AH, MARTIN SW, BARNUM DA.** Use of total and differential somatic cell counts from composite milk samples to detect mastitis in individual cows. Can J Comp Med 1981; 45:8-14.