Relationships Between Somatic Cell Counts and Milk Production

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ABSTRACT

The relationship between Dairy Herd Improvement program test-day milk yield and somatic cell counts in milk was analyzed in 34 dairy herds over 3 yr. Estimates of this relationship were more accurate when somatic cell counts were transformed to natural logarithms rather than actual. For 67,707 observations, test-day milk yield decreased with increasing somatic cell count. The decrease of milk yield for second and later lactations, as somatic cell count increased, was greater than for first lactations. When herds were partitioned according to herd milk production (>7700, 6500 to 7700, and <6500 kg/yr), decrease of milk yield was linear with increasing somatic cell counts for herds averaging below 7700 kg milk. Regressions were linear, quadratic, and cubic for both parity groups in herds with high production, over 7700 kg/yr. Quarter samples were composited for each cow and cultured. Percentage of infected cows increased as somatic cell counts increased with greater infection rates above 400×10^3.

INTRODUCTION

Mastitis generally is recognized as the costliest disease of the dairy industry. Reduced milk yield has been estimated to be 69 to 80% of total mastitis cost (6, 9, 13).

Numerous studies have attempted to measure the relationship between milk yield and mastitis or somatic cell concentrations (3, 5, 8, 10, 11, 14, 17, 18, 19, 21, 22, 23). Cows with clinical mastitis suffered daily milk yield losses of .5 kg when compared with healthy cows (5). Daily milk yield decrease was 4.5 to 12.7 kg for the 24 h preceding development of clinical symptoms (10). Infected quarters produced 15 to 17% less milk than apparently healthy opposite quarters (14, 17). The California Mastitis Test (CMT) has been used in some Dairy Herd Improvement (DHI) programs as a monthly mastitis screening test. By using DHI records from 10 or 16 herds, two studies estimated that losses ranged from 5 to 6, 10 to 11, 16, and 21 to 25% for CMT scores of trace, 1, 2, and 3 as compared to negative CMT scores (8, 11). Daily losses were estimated at .4, 1.0, 2.2, and 3.1 kg for corresponding CMT scores in six herds (3). For quarter milk samples, milk yield was decreased 8, 15, and 27% for somatic cell counts (SCC) of 1×10^6, 2×10^6, and 4×10^6 (18, 23). Earlier milk yield was decreased by 3, 4, and 10% at SCC of 100, 200, and 300×10^3 compared to 50×10^3 (22). Recently, SCC above 500×10^3 have been used as an indication of significant mastitis incidence in a herd (19) or nonspecific mastitis if pathogens have not been isolated (21).

In the 1970's, development of electronic measurement of SCC provided the dairy industry with an excellent mastitis management and research tool. A highly repeatable, quantitative estimate of SCC became available at low cost. Subsequent studies found that as SCC increased, agreement between DHI supervisor CMT scores and electronic SCC on the same samples decreased, raising some question as to the accuracy of estimates of milk loss (12).

Objectives of this study were: 1) to develop a statistical model describing the relationship between milk yield and increased SCC; 2) to determine if there was an effect of truncating SCC on the relationship between SCC and test-day yield; 3) to determine if the relationship

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between SCC and test-day milk yield varied with production of the herd and with lactation number of the cow; 4) to measure the relationship between means of natural log of previous test day and second, fifth, and eighth test-day milk yield; 5) to establish the relationship between bacterial status of the udder and SCC.

EXPERIMENTAL PROCEDURE

Thirty Virginia dairy herds enrolled in DHI testing program were selected in 1976 so that 10 herds had DHI rolling yearly herd averages of less than 6350, 10 herds averaged between 6350 and 7258 kg, and 10 herds exceeded 7258 kg. Herds were enrolled in the DHI monthly somatic cell counting program. One low producing herd discontinued DHI, and its records were not used. Records from four correction center herds and the university herd were added to the data set. Monthly production data were collected for each cow in 33 herds from June 1977 through June 1980 plus one lower producing herd that discontinued DHIA testing in May 1978. This provided data from 34 herds.

Milk samples and milk weights were collected by DHI supervisors at monthly herd visits. Somatic cell counts (Fossomatic[2] or Coulter[3] electronic counters) were by the DHI central laboratory located on campus. Counts were reported to the nearest 1,000 SCC/ml milk.

Statistical Analysis

The data set was constructed to determine relationships between test-day SCC and test-day milk yield. Lactation was divided into 10 increments of 30 days. Parity or lactation number consisted of lactations 1 to 9, with any lactation over 9 considered in a 10th group.

Somatic cell counts were treated as continuous or classification variables. Models expressing SCC as a continuous variable used somatic cells both as actual counts and natural logarithms of the count. All analyses were by General Linear Model procedure in SAS (4).

Model A (continuous variable) is:

$$Y_{ijklmn} = \mu + H_i + C_{ij} + St_k + M_l + P_m + B_1(SCC) + B_2(SCC^2) + B_3(SCC^3) + E_{ijklmn}$$

where:

Y_{ijklmn} = Test-day milk yield,
μ = overall mean,
H_i = effect of i^{th} herd,
C_{ij} = effect of j^{th} cow within i^{th} herd,
St_k = effect of k^{th} stage of lactation,
M_l = effect of l^{th} month of calving,
P_m = effect of m^{th} parity,
$B_1(SCC)$ = regression coefficient for natural log or actual somatic cell count,
$B_2(SCC^2)$ = regression coefficient for natural log or actual somatic cell count squared,
$B_3(SCC^3)$ = regression coefficient for natural log or actual somatic cell count cubed, and
E_{ijklmn} = residual.

As a classification variable, somatic cell counts were partitioned as follows: 50,000 ranges for under 400,000 cells, and 100,000 ranges from 401,000 to 1,200,000 SCC.

Model B (discrete variable) is:

$$Y_{ijklmn} = \mu + H_i + C_{ij} + St_k + M_l + P_m + SCC_n + E_{ijklmn}$$

where SCC_n = Effect of n^{th} class of somatic cell count. Other elements are defined as in Model A.

The Southern Dairy Records Processing Center expresses somatic cell counts to nearest 10^5 cells/ml. To determine if these measures predict milk losses as effectively as our data set, SCC ($\times 10^3$) were truncated to the nearest 10^5. Before taking the natural log of the truncated SCC, we set SCC of 0 equal to .0001. Model A was used to analyze these data.

Effect of herd average milk yield upon the relationship between estimated milk yield and SCC was examined. Herds were separated according to 1980 DHI rolling herd average for milk with 12 herds averaging more than 7,700 kg, 17 herds between 6,500 and 7,700 kg, and 5 herds below 6,500 kg. Data were analyzed as natural logarithms of SCC in Model A.

[2] Fossomatic, Foss Electric, Hillerod, Denmark.
[3] Milk Cell Counter, Coulter Electronics, Hialeah, FL.

The relationship between test-day milk yield for 2nd, 5th, and 8th test days and average SCC for all previous test-days during the lactation was examined for a variation of Model A. Differences between cows within herd were not included as a source of variation because there was only one observation per cow for most cows. Means of the natural logarithms of SCC for previous test days were used. Stage of lactation was refined by fixed 10-day intervals for early (days 20 to 119), mid (days 110 to 209), or late lactations (days 200 to 299 in milk), corresponding to 2nd, 5th, and 8th test-day periods.

Pathogenic Bacteria Identification of Milk Samples

Beginning in October 1978, herds were visited every 3 mo for 2 yr with 10 herd visits per mo. Milk samples were collected at milking time from every cow in milk. Teats were washed and dried throughly with single-service paper towels. Several streams of milk from each teat were discarded. The teat end was scrubbed with alcohol and allowed to dry for 1 min before sampling. Composite samples were collected into sterile plastic bags and stored in an insulated chest cooled with ice. In the laboratory, samples were stored in the refrigerator and then cultured as soon as possible with blood agar (7). Culture data were available from 29 of the 34 herds. Five commercial herds chose not to participate in this phase. Milk production and SCC data were from these herds for the 3 yr.

RESULTS

There were 67,707 observations in this data set with 23,598 observations from first lactation and 44,109 from cows in second or later lactation. For animals in first lactation, SCC were higher during the first test after calving

TABLE 1. Frequency distribution of somatic cell counts for first lactation or older animals in different stages of lactation.

Stage of lactation	n	Percent of somatic cell counts (× 10^3) Below 50	50–100	100–200	200–400	400–800	Over 800
First lactation							
1	1,960	25.0	26.8	20.0	13.1	7.0	8.1
2	2,728	37.1	24.5	18.0	9.7	5.5	5.2
3	2,610	36.9	25.1	17.0	9.9	6.0	5.1
4	2,669	33.8	26.1	18.7	11.2	6.0	4.2
5	2,595	32.5	25.5	19.6	11.5	6.5	4.4
6	2,646	30.3	26.8	20.3	11.8	6.2	4.6
7	2,372	30.0	24.7	21.7	11.3	6.7	5.6
8	2,309	27.6	26.3	21.6	13.8	6.4	4.3
9	2,050	27.1	25.7	22.2	13.9	6.6	4.5
10	1,659	26.5	24.2	23.1	14.8	6.8	4.6
Mean		31.2	25.6	20.0	11.9	6.3	5.0
Second and later lactation							
1	3,915	25.7	19.4	17.1	13.7	10.8	13.3
2	5,385	29.2	18.8	16.5	14.0	10.0	11.5
3	5,014	27.3	20.4	17.6	13.3	9.8	11.6
4	5,103	22.8	22.3	19.5	14.3	9.4	11.7
5	4,652	19.2	22.4	20.8	16.0	10.5	11.1
6	4,612	15.6	21.3	24.2	16.8	11.1	11.0
7	4,340	13.0	20.7	24.5	18.7	11.6	11.5
8	4,276	10.8	19.9	25.6	20.2	11.7	11.8
9	3,721	8.4	18.9	26.5	21.7	12.8	11.7
10	3,091	6.4	16.1	24.9	24.0	15.4	13.2
Mean		18.7	20.2	21.4	16.9	11.0	11.8

compared to the second and subsequent tests during this lactation (Table 1). A greater proportion of samples exceeded 100 × 10^3 SCC (48%), with 28% over 200 × 10^3 SCC at the first test. After the 1st mo, 74 to 80% of the counts were below 200 × 10^3, and 51 to 62% were below 100 × 10^3, regardless of stage of lactation. Somatic cell counts tended to increase after the third test. As lactation progressed, there was a gradual decrease of percentage samples under 50 × 10^3 SCC. The proportion of samples ranging from 100 to 200 × 10^3 SCC and from 200 to 400 × 10^3 increased with stage after the third test. The average somatic cell count during the first lactation was 231 ± 617 × 10^3 (arithmetic mean ± SD).

Somatic cell counts during second and later lactations averaged 409 ± 953 × 10^3. As lactation progressed there was a gradual increase of the proportion of cows with SCC over 200 × 10^3. This ranged from a low of 35% during the 3rd mo to a high of 53% at the 10th mo. Also, there was an increase of the percentage of counts ranging between 100 to 400 × 10^3 SCC and a decrease of counts below 50 × 10^3.

Predicting Milk Yield from Somatic Cell Counts

Three distinct models were used to examine the relationship between test day SCC and test day milk: 1) a third degree polynomial for actual SCC (Model A'); 2) a third degree polynomial for the natural log of SCC (Model A); and 3) classes of SCC (Model B). All three regression coefficients from analyses 1 and 2 were significant as were classes of SCC in analysis 3. Predicted milk yield, measured as a deviation from the average prediction for 390 × 10^3 SCC, differed greatly between analysis 1 and the other two analyses (Figure 1). Although quadratic and cubic coefficients were significant for actual somatic cell count, the drop of yield associated with increasing cell count was more nearly linear than for analyses 2 and 3. A distinct curvilinear relationship was detected when natural logarithms were in the continuous model or when classes of SCC were used. Predicted milk yield decreased at a decreasing rate as SCC increased. In the original classes used, lowest classes included SCC from 10 to 50 × 10^3. Because 45.4% of the samples were below 100 × 10^3, curvilinearity was tested further by our including classes with 10 × 10^3 ranges below 100 × 10^3 SCC. These 10 classes were associated with predicted milk yields of 3.0, 2.8, 2.6, 2.3, 2.1, 1.9, 1.7, 1.4, 1.3, and 1.3 kg above the predicted yield for mean SCC.

The frequency distribution indicated a heavily skewed population with 81.2% of the observations below the mean of 390 × 10^3 (Table 1). The distribution was skewed similar to that in (20). A natural log (Ln) transformation was used to normalize SCC distribution. Linear, quadratic, and cubic effects were highly significant ($P<.01$). The cubic model, with transformed data, significantly described the curvilinear relationship (R^2=.744). With Ln SCC, the decrease of milk yield was not as great at SCC below 100 × 10^3 as losses predicted by the model using SCC classes (Figure 1). Decreases of milk yield predicted by Ln SCC were greater than decreases estimated by actual SCC when SCC were less than 400 × 10^3.

Many DHI computing centers report SCC to the nearest 100,000 cells/ml. We truncated our data to represent current DHI SCC ranges reported by the Southern Dairy Records Processing Center (<50, 51 to 150, 151 to 250 × 10^3, etc.) and reanalyzed the data with Ln truncated SCC in Model A. The transformation of data resulted in a curvilinear relationship that was similar to the curve predicted by the cubic model generated by logarithmic transformation of the data (Figure 1).

Daily Milk Yield, Somatic Cell Count, and Lactation Number

The relationship between daily milk yield and somatic cell counts for first calf heifers is in

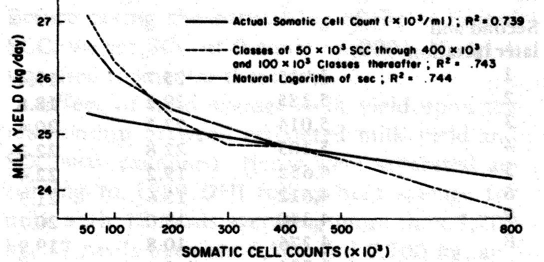

Figure 1. Relationship between predicted milk yield and milk somatic cell counts (SCC), for actual SCC, natural log of SCC, or the classification model.

TABLE 2. Relationship between predicted milk or fat yield and somatic cell count during first or later lactations.

Somatic cell count (000's/ml)	DHI score	First lactation Milk (kg)	First lactation ΔMean[a]	First lactation ΔDHI[b]	Older lactations Milk (kg)	Older lactations ΔMean[a]	Older lactations ΔDHI[b]	Fat yield (kg/d) First lactation	Fat yield (kg/d) Older lactations
12.5	0	23.1[c]	+1.05		29.2[d]	+3.02		.78[e]	.98[f]
25	1	22.9	+.82	.23	28.6	+2.39	.63	.79	.98
50	2	22.6	+.55	.27	28.0	+1.83	.56	.79	.98
100	3	22.4	+.32	.23	27.4	+1.25	.58	.79	.96
200	4	22.1	+.05	.27	26.9	+.65	.60	.79	.95
300		21.9	−.13		26.5	+.28		.79	.94
400	5	21.8	−.27	.32	26.2	0	.65	.79	.93
500		21.6	−.40		26.0	−.23		.78	.92
800	6	21.4	−.72	.45	25.4	−.73	.73	.78	.91
1,600	7	20.7	−1.38	.66	24.6	−1.61	.88	.77	.89
3,200	8	20.0	−2.13	.75	23.6	−2.60	.99	.76	.87
6,400	9	19.0	−3.09	.96	22.5	−3.78	1.18	.74	.84
R^2		.81			.78			.68	.65

[a]ΔMean = Difference in daily milk yield compared to the average somatic cell count.

[b]ΔDHI = Difference in daily milk yield compared to the next lowest DHI somatic cell count score.

[c]Predicted daily yield equation: Y = 22.07 kg milk + −1.0189 LN SCC (natural log somatic cell count) + .1834 $(\text{LN SCC})^2$ − .0162 $(\text{LN SCC})^3$.

[d]Predicted daily yield equation: Y = 26.20 kg milk + −1.6477 LN SCC + .1968 $(\text{LN SCC})^2$ − .0158 $(\text{LN SCC})^3$.

[e]Predicted daily yield equation: Y = .79 kg fat + −.0105 LN SCC + .0037 $(\text{LN SCC})^2$ − .0004 $(\text{LN SCC})^3$.

[f]Predicted daily yield equation: Y = .93 kg fat + .0429 LN SCC + .0098 $(\text{LN SCC})^2$ + .0004 $(\text{LN SCC})^3$.

Table 2. The linear, quadratic, and cubic effects were highly significant ($P<.01$). The 30.7% of first lactation animals with less than 50 × 10^3 SCC produced .55 to 1.05 kg more milk/day than the average animal (231 × 10^3 SCC), whereas 25.6% of those animals ranged from 51 to 100 × 10^3 SCC and produced .32 to .55 kg more milk than average cows.

For second and later lactations, linear, quadratic, and cubic effects were highly significant ($P<.01$). In contrast to first lactation animals, only 19 and 20% of the older cows had SCC below 50 × 10^3 or between 51 and 100 × 10^3. However, these cows produced 1.18 to 2.37 kg or .59 to 1.18 kg more milk than cows with 200 × 10^3 SCC and 1.83 to 3.02 or 1.25 to 1.83 kg more milk than cows with average SCC (409 × 10^3). Table 2 shows that elevation of SCC had a greater detrimental relation with milk production in older cows than in first lactation animals.

During first lactation, increasing SCC had little relation to fat yield until SCC exceeded several million. With a mean SCC of 231 ± 617 × 10^3, only 2.5% of the samples would be expected to exceed 1465 × 10^3 and .5% would exceed 2082 × 10^3. A closer relation of SCC to fat production was observed in older cows ($\bar{x}$ = 409 ± 953 × 10^3 SCC). Approximately 17% of these cows had SCC above 1000 × 10^3. For those cows, loss in fat yield exceeded .07 to .33 kg daily. An explanation for this loss is not apparent.

Relationship Between Milk Yield and Somatic Cell Counts for Different Herd Production

There were 30,514 cow test day observations in the high producing herds (rolling yearly herd average above 7,700 kg milk). These cows averaged 26.7 kg milk per day and 300 ± 704 × 10^3 SCC. In these herds, linear, quadratic, and cubic effects were significant in both first lactation animals and cows in second or later lactations ($P<.01$). Milk yield was plotted against the new DHI SCC scoring system instituted in January 1984. During first lactation, a dramatic decrease of milk yield occurred after cell counts exceeded 400,000. In older animals, a marked response occurred at 25,000 cells but not at the higher SCC for first lactation (Figure 2).

For medium producing herds, 27,565 cow observations averaged 23.6 kg milk daily and 354 ± 814 × 10^3 SCC. The 6,781 cow observations in low producing herds averaged 19.7 kg milk and 598 ± 1,475 × 10^3 SCC. In both groups of herds, averaging less than 7,700 kg milk per lactation, only the linear effect was significant ($P<.01$). As the SCC doubled (DHI scores), milk production reduced by .36 and .72 kg per day in first lactation and older cows. The linear regression coefficients for high, medium, and low producing herds were −.43, −.52, and −.39 for first lactation and −.85, −1.03, and −1.03 for second and later lactations. This similarity of regression coefficients between the three groups of first lactation animals and again for older cows suggests that differences in milk yields with increasing SCC were not from differences among herd production.

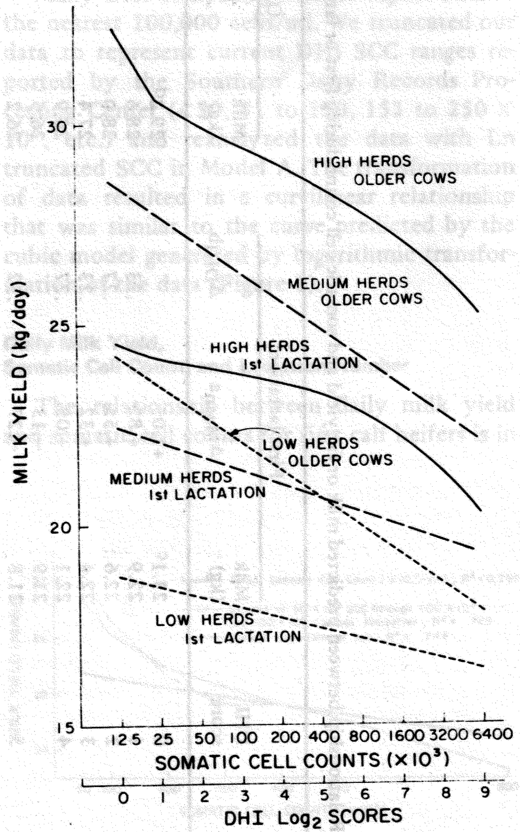

Figure 2. Predicted milk yield according to somatic cell counts for first lactation and older cows in herds of differing milk production.

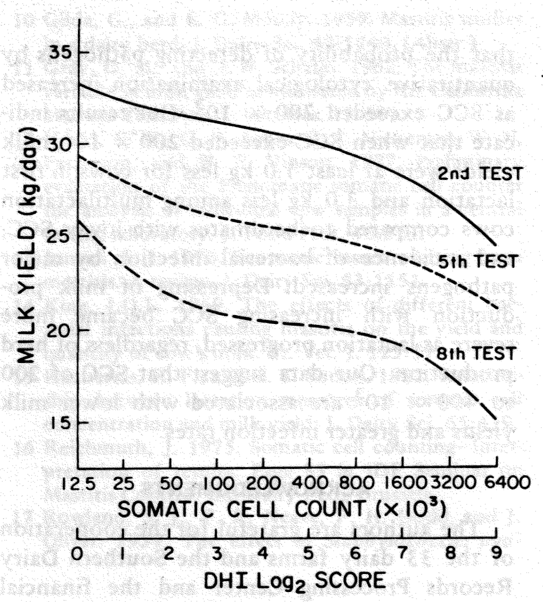

Figure 3. Relationship between lactation somatic cell count and milk yield at either early, mid, or late lactation.

Accumulative Relationship of Lactation Average Somatic Cell Counts

Linear, quadratic, and cubic effects were significant between milk production at 2nd, 5th, or 8th test days of lactation and accumulative average SCC ($P<.01$). Interaction of stage of lactation × parity was significant ($P<.05$) only for the fifth test. The relationship between SCC and milk yield supports the results with test-day data except that the curvilinear response was more evident for the eighth test (Figure 3).

Bacterial Infections and Somatic Cell Counts

Of the 26,739 milk samples cultured on a blood agar plate, 12,206 samples or 46% were free of major or minor (*Corynebacterium bovis* and *Staphylococcus epidermidis*) pathogens usually associated with mastitis. The most prevalent organisms were other streptococci (*Strep. uberis* and *Strep. dysgalactiae*) at 6.6% of samples. Percentages of samples containing *Staph. aureus* and *Strep. agalactiae* were 5.3 and .6%. *Staphylococcus aureus* was isolated from every herd. Over the 2-yr culturing, *Strep. agalactiae* was never found in 11 herds, and only one isolate was in 6 herds. In this study, *Escherichia coli* and *Klebsiella pneumoniae* infections represented 1.0% of all milk samples. *Escherichia coli* accounted for 54% of these infections. *Staph. epidermidis* and *C. bovis* were isolated from 23.4 and 14.4% of the samples.

Only 5.9% of the samples with less than 100 × 10^3 SCC contained major pathogens normally associated with mastitis (Table 3). As SCC increased, percentage of major pathogens increased to 11.7% between 100 to 200 × 10^3 SCC, 17 to 19% between 200 and 400 × 10^3 SCC, and 23% in milk samples exceeding 400 × 10^3 SCC.

The relationship between bacterial infection rate and somatic cell counts was similar to the

TABLE 3. Relationship between somatic cell counts and bacterial infection status.[a]

Somatic cell counts in foremilk (000's/ml)	% of Samples	Percent of samples within cell count range					
		Negative	STN	SA	STA	Coli	Other
Below 100	36.9	62.2	3.2	2.1	.1	.5	31.8
100 to 200	20.1	39.0	6.0	4.4	.4	.9	49.2
200 to 300	12.0	33.4	8.1	7.2	.7	1.3	49.3
300 to 400	7.7	31.0	9.0	7.8	1.0	1.0	50.3
400 to 500	5.5	26.2	10.9	9.3	1.1	2.2	50.2
500 to 800	9.3	26.3	12.0	9.9	1.6	1.7	48.5
Over 800	8.5	51.3	8.9	8.2	1.2	1.2	29.1

[a]STN = *Streptococcus uberis* and *Streptococcus dysgalactiae*; SA = *Staphylococcus aureus*; STA = *Streptococcus agalactiae*; Coli = *Escherichia coli* and *Klebsiella pneumoniae*; other includes *Staphylococcus epidermidis* and *Corynebacterium bovis*.

relationship between milk yield and somatic cell counts. As somatic cell count exceeded 100,000 cells, milk production was less and infection rates were higher than for cows with lower SCC. The relationship was even stronger when somatic cell counts exceeded 200,000. However, neither somatic cell count nor bacterial culture results alone gave a true picture of an individual cow's status. Only 50 and 68% of negative samples were milk samples below 100 and 200 × 10^3 SCC. Ten percent of the negative samples exceeded 800 × 10^3 SCC. Of the samples exceeding 800 × 10^3 SCC, 51% were free of major or minor pathogens. This high percentage of negative cultures may reflect the wide range of SCC within this group (800 to 20,000 × 10^3). For other streptococci and *Staph. aureus*, 36 and 32% were in milk samples with less than 200 × 10^3 SCC, whereas 38 and 40% occurred in samples above 400 × 10^3 SCC. In other words, either many cows had low grade infections or pathogens had invaded the mammary gland but did not maintain an infection that would have been characterized by increased SCC.

DISCUSSION

Our data support Ali and Shook (1), who suggested that DHI SCC data should undergo logarithmic transformation before analysis. Recently, National Dairy Herd Improvement Association decided that all Dairy Records Processing Centers should store SCC reported to either 10^3 SCC or Log_2 and report results to dairy farmers in a linear score, as recommended by Shook (20). Many DHI truncate SCC. Truncation of such data in our study indicated that the same curvilinear relationship existed between SCC and milk loss, although precision was lost between classes. For research, Ln SCC had higher repeatability of tests within lactation, provided more consistent results from test to test within cow, and resulted in smaller error variance than SCC (2).

The trend for decreased milk yield in relation to SCC was similar to (15), a curvilinear relationship with greater losses at low SCC. Both their study and ours found that losses in first lactation animals associated with specific SCC were about 50% of losses in older cows. Bacteriological examination of milk samples every 3 mo suggested increasing infection, especially major pathogens, when SCC exceeded 100 × 10^3. Reichmuth (16) suggested that the probability of detecting pathogens by quantitative cytological examination increased as SCC exceeded 200 × 10^3. Our results indicate that when SCC exceeded 200 × 10^3, milk yields were at least 1.0 kg less for cows in first lactation and 3.0 kg less among multilactation cows compared to herdmates with lower SCC, and incidence of bacterial infection by major pathogens increased. Depressing of milk production with increasing SCC became more severe as lactation progressed, regardless of herd production. Our data suggest that SCC of 200 to 400 × 10^3 are associated with lower milk yields and greater infection rates.

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