RELATIONSHIPS BETWEEN SOMATIC CELL COUNTS AND MILK PRODUCTION IN DAIRY CATTLE

by

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INTRODUCTION

Mastitis is generally recognized as one of the costliest diseases confronting the dairy industry today. Of all costs related to mastitis, reduction in milk yield represents the greatest loss, and has been estimated at 69.3 to 80.4 percent of the total cost (5,9,19).

Numerous research studies have attempted to predict milk production losses associated with mastitis. Much of this research has been based on results using diagnostic or screening tests which were developed to monitor the extent of subclinical mastitis through changes in leukocyte or somatic cell concentrations.

The California Mastitis Test (CMT), Wisconsin Mastitis Test (WMT), and Direct Microscopic Somatic Cell Count (DMSCC) have all been used in mastitis research. In practical application these tests perform adequately for their designed purposes. The WMT is utilized under laboratory conditions for evaluating large numbers of milk samples. The DMSCC is the officially approved test used by milk regulatory agencies. It is a more tedious test, and consequently is used for smaller numbers of samples. The CMT is a subjective test and is best utilized as a cowside evaluation for mastitis.

The above tests have limited capacities when used in research designed to evaluate milk yield reductions due to mastitis. Both CMT and WMT measure ranges of somatic cell concentrations rather than a quantitative value. Variability between individual CMT scores and actual somatic cell counts can be high (18,37). Variability can

also be high between CMT scores assigned to identical, split samples by different technicians, indicating variation between individuals assigning CMT scores (16). The DMSCC is limited to small sample numbers due to time required in preparing and tedious microscopy in reading samples. Additionally, variability between technicians can be high when reading samples microscopically (16). Repeatability of the DMSCC may be low depending upon age of milk sample, and adequacy of sample preparation (17).

Development of electronic somatic cell counting has provided the dairy industry with an excellent mastitis management and research tool. A highly repeatable, quantitative value representing somatic cell concentration is obtained at low cost (17). Operational speed permits large sample numbers to be analyzed quickly and efficiently.

This project was initiated in 1977 when formal, long-term research using electronic somatic cell counting had not yet been conducted. Electronic somatic cell counters had been in use only for a limited time. The objective of the project was to more accurately determine milk yields accompanying a wide range of somatic cell counts, over a three year period.

REVIEW OF LITERATURE

Economic Considerations of Mastitis

Many nutritional, physiological, and infectious diseases are known to cause economic losses to dairymen. Of all diseases, mastitis is the single, costliest disorder confronting the dairy industry. Losses from mastitis are compounded due to decreased milk yield, discarded milk, veterinary and medicine fees, increased labor, decreased sale value, increased replacement costs, and loss of genetic potential when a cow is culled (9).

Appleman *et al.* (2) have estimated that milk from CMT-negative cows increased milk income by 2.2, 11.3, 23.7, and 32.6 cents per cow per day compared to milk from CMT-trace, 1, 2, and 3 cows, respectively. Estimates were determined following a systematic sampling of 2,296 monthly DHIA records, representing 234 cows in six herds.

In 1970, Janzen (19), citing University of Georgia Veterinary Extension Service data, indicated that total economic losses due to mastitis were $154.38 per cow per year. Losses were estimated from data collected before and after mastitis control programs were implemented in various herds. It was determined that total loss was due 80.4% to milk production loss, 15.1% to increased replacement cost, 2.6% to discarded milk, 1.2% to drug costs, 0.4% to veterinary fees, and 0.4% to extra labor. In later Georgia results total mastitis costs per cow per year were calculated to be $147.23 (9). Percentages of each

category contributing to total loss were similar to those reported by Janzen; 80.4% was due to milk yield loss, 13.2% to increased replacement cost, 2.6% to discarded milk, 2.4% to veterinary fees, 0.7% to drug costs, and 0.5% to extra labor. Additionally, Dobbins (9) suggested that culling of mastitic cows resulted in lost genetic potential of from one-sixth to one-fourth of genetic gain normally expected.

Blosser (5) estimated national, annual losses due to mastitis to be $1.3 billion. A questionnaire was sent to one person from each of the fifty states. Usable responses were received from 33 states representing 9.5 million cows, or 86% of the U.S. dairy cow population. Based on estimates provided by the respondents, $897 million (69.3%) of the total $1.3 billion was due to decreased milk yield, $142 million (11.0%) to discarded milk, $22 million (1.7%) to veterinary fees, $42 million (3.2%) to drug costs, $25 million (1.9%) to increased labor, $63 million (4.9%) to decreased sale value, and $103 million (8.0%) to increased replacement costs. Total dollar losses represented 11% of gross receipts for sale of fluid raw milk from farms.

Current estimates of $2.0 billion in annual losses due to mastitis appear reasonable. Application of inflation factors to Blosser's $1.3 billion loss estimate, and consideration of lost genetic potential may actually suggest a loss exceeding $2.0 billion.

Production Losses Due to Mastitis

Research With Clinical Mastitis and Early Diagnostic Tests

In studies relating dollar losses to mastitis, reduced milk yield has continually appeared as the major contributor. In certain

instances, decreased milk production contributed five to six times more toward economic loss than the second most important factor (5,9,19).

Concern about decreased milk yield associated with increased mastitis severity has prompted much research. Early research utilized bacteriological cultures, physical appearance of milk, and the Whiteside Test as indicators of mastitis. Crossman *et al.* (7) presented data from eleven cows involved in a two year study. Mastitis infection was determined by bacteriological procedures and Whiteside Test. Variable results were obtained. Estimates of milk yield losses for subclinically infected cows ranged from no noticeable loss to a 47% reduction over five months. One cow, subclinically infected during the dry period, freshened yielding five percent below expected, and later dropped 45% in milk yield over seven months. Clinical cases of mastitis showed an abrupt and severe decrease in milk yield, often exceeding losses suffered from long-term, subclinical infections. Findings by Gilda and Moody (14) later supported this observation. A study of 254 separate incidents of clinical mastitis in 87 cows revealed an immediate daily loss of 4.5 kg of milk per cow.

Other researchers have calculated milk losses accompanying clinical cases of mastitis. Abnormal appearance of milk was used to define a clinical case of mastitis. Seventy five clinical cases in 26 cows over a 4 year period were studied by Bishop and Compaan (4). They estimated an average reduction in milk yield of 13.83 kg per 28 days; or 0.49 kg per day. King (22) examined 65 heifers which had recovered from their first case of mastitis. Immediately after the infected quarter appeared normal, it's milk yield was compared to that of the

opposite, healthy quarter. At 10-60 days, 79-160 days, and 200-290 days postpartum, infected quarters produced 0.21 kg, 1.26 kg, and 0.64 kg less milk per quarter per milking compared to opposite, healthy quarters. This reduction in milk yield by infected quarters persisted. At 28 days after sampling, infected quarters produced 0.06 kg, 0.18 kg, and 0.44 kg less milk per quarter per milking than non-infected, opposite quarters at 10-60, 79-160, and 200-290 days postpartum, respectively.

In a later investigation, King (23) determined that infected quarters produced 17.3% less milk on an overall, weighted average as compared to opposite, normal quarters. These findings supported an earlier observation by Rowland *et al.* (31) that infections decreased milk yield by an average 15.3% when compared to normal, opposite quarters. Their data was based on 92 comparisons involving 72 lactations. In the same study, it was found that 53% of the 92 comparisons had milk yield decreases between 10 and 50%. Differences may have been due to the stage of lactation in which a cow became infected. Similar results were obtained by Wheelock *et al.* (42). Randomly selected, healthy quarters were infused with a bacterial suspension. Subsequent milk yield was compared to milk yield from randomly assigned control quarters. Apparent depression in milk yield ranged from 20 to 70%. In this study, stage of lactation in which infusion of the bacterial suspension took place may explain the wide range of milk yield reduction.

In a study comparing milk yield of healthy quarters to opposite infected quarters Rako *et al.* (30) classified a total of 181 infections as: Positive bacteriological readings but no clinical symptoms; abnormal secretion usually accompanied by clinical symptoms; and partial or

complete atrophy of a quarter. Losses in milk yield for the three categories amounted to 15.2, 21.5, and 83.9% of the healthy quarters, respectively. For quarters responding to treatment, milk losses were 23.3% before treatment, 14.4% one month after treatment, 10.7% at two months after treatment, and 2.3% after the next calving. For quarters not responding to treatment, losses amounted to 27.8, 30.1, 26.4, and 42.2%, respectively.

Effect of mastitis on 305 day milk yield by 83 Simmental cows, averaging 4,000 kg milk per year was studied by Car (6). A cow was considered infected if at least one quarter had been diagnosed clinical. Milk loss was determined by comparing expected milk yield of infected cows to actual 305 day production of healthy cows. The difference in 305 day milk yield between mastitic cows and healthy cows was estimated to be 870 kg per head. In some individual cases, losses exceeded 1,500 kg. Again, differences may have been due to stage of lactation when mastitis developed.

Car's results did not support earlier work by O'Donovan *et al.* (28). They compared milk yield by 50 cows who became infected during a lactation to the previous, infection-free lactation of those cows, and to 54 similar cows who had two subsequent infection-free lactations. Lactational milk yield loss was determined by subtracting second lactation production from first in both infected and control groups. Control group difference was then subtracted from infected group difference to yield an average lactational milk production loss of 298 kg or 10%. Dissimilarity between Car's findings and those of O'Donovan *et al.* may be partly explained by the latter's approach. Comparisons involving

two or more lactations introduce variation such as weather differences, age differences, feeding differences, and differences in other management factors which could substantially alter results.

Research Using the California Mastitis Test (CMT)

During the early 1960's, the Modified Whiteside Test or California Mastitis Test (CMT) gained support as a rapid, and inexpensive cowside test for detecting subclinical mastitis in varying degress of severity. Availability of this inexpensive, screening test, which could be performed on many cows, prompted considerable research.

Using DHI records from 10 Holstein herds, Gray and Schalm (15) estimated decreases in milk production for trace, 1, 2, and 3 CMT scores of 6, 10, 16, and 25.5%, respectively, when compared to milk yield with a corresponding CMT-negative. Comparisons were based on complete lactation milk yield, or records of 305 days or over. Milk production losses ranged from a low 0.2% (between a CMT-negative and CMT-trace value) to a high 32.6% (between a CMT-negative and CMT-3 value). California Mastitis Test was run by DHI supervisors, on DHI samples collected for butterfat determination. The authors also noted a greater decline in milk yield over the course of a lactation for cows who were consistently CMT-3 when compared to cows who were consistently CMT-negative (i.e. persistency was not as good). They calculated a reduction in test day milk yield of 60.8% from month 1 to month 10 of lactation, as compared to a milk production drop of 50% for CMT-negative cows.

Later work by Daniel *et al.* (8) supported the findings of Gray

and Schalm. Data collected on cows from 16 herds for three years yielded milk production losses of 5.3, 10.6, 15.9, and 21.2% for CMT-trace, 1, 2, and 3 scores, respectively when compared to milk production from CMT-negative cows. The losses closely paralleled those obtained by Gray and Schalm.

Some researchers have noted larger milk production losses associated with an increasing CMT score. Philpot (29) calculated percentage of milk loss in a study involving 178 Jersey cows. The CMT was conducted on foremilk samples from individual quarters to determine the presence and severity of subclinical mastitis. All milk appeared normal by strip cup evaluation. Cows were milked with quarter milkers, and milk loss was estimated to be 2.8, 11.4, 25.6, and 45.5% for CMT-trace, 1, 2, and 3 scores, respectively, when compared to milk yield from healthy, opposite quarters.

Analysis of data collected on private dairy herds from December, 1962 through March, 1965 by Forster *et al.* (13) yielded similar results. Comparisons were made between CMT-positive quarters and opposite CMT-negative, trace, or 1 quarters. Correction factors were used to bring comparisons between positive and trace or 1 quarters back to a positive-negative comparison. Using the correction factors, and the positive-negative comparisons, CMT-trace, 1, 2, and 3 quarters averaged 9.0, 19.5, 31.8, and 43.4% less milk compared to their negative, opposite quarters. The findings of Philpot (29) and Forster *et al.* (13) indicate that milk loss by CMT-2 and 3 cows was about twice that reported by Gray and Schalm (15), and Daniel *et al.* (8).

Several researchers have calculated milk loss for CMT-positive

reactions in terms of milk weight rather than percentage. In a study previously cited, Daniel *et al.* (8) calculated actual milk weight loss as well as percentage. The average decrease in monthly milk production per increase of one CMT value was 22.22 kg milk per cow, with a range of 0.34 kg to 73.26 kg. This is consistent with the findings of Appleman *et al.* (2) who evaluated 2,296 monthly DHI samples, representing 234 cows in six herds. They found that cows with a CMT-negative score produced 0.4, 1.0, 2.2, and 3.1 kg more milk per day compared to cows with CMT reactions of trace, 1, 2, and 3, respectively. Using the factors obtained by Daniel *et al.* (8), monthly milk loss for CMT-3 score would total 88.9 kg. A monthly milk loss of 92.5 kg would be realized if values estimated by Appleman *et al.* (2) are used.

Forster (11) calculated decreases in milk yield associated with each CMT reaction for 277 cows. Cows were milked once with a quarter milker and CMT score determined for each quarter. Production from opposite quarters which differed in CMT reaction was compared. Average daily decreases in milk production per quarter were 0.34, 1.02, 1.85, and 2.66 kg for CMT-trace, 1, 2, and 3 scores, respectively. On a monthly basis, the losses would translate to 41.4, 123.0, 221.5, and 319.0 kg for CMT-trace, 1, 2, and 3 scores, respectively, if all 4 quarters of a cow were so infected. At about the same time, Forster *et al.* (12) conducted a similar study involving 115 cows. Average decreases in milk yield per quarter per milking for negative-trace, negative-one, and trace-one comparisons were 0.16, 0.42, and 0.38 kg, respectively. For the first two comparisons, monthly losses would be 38.1 and 100.2 kg if all four quarters were CMT-trace, and 1, respectively.

Data from two days of quarter sampling in six trials with eight cows per trial were collected and analyzed by Natzke *et al.* (27). CMT-negative, and trace scores were classified as CMT-0. Results were based on opposite quarter comparisons. Milk losses per quarter per milking were estimated to be 0.18, 0.31, and 0.67 kg for CMT 0-1, CMT 0-2, and CMT 0-3 comparisons, respectively. This would translate to 44.9, 75.0, and 161.1 kg per month, assuming all four quarters had a CMT-1, 2, and 3 score, respectively. The lower values obtained by Natzke *et al.* (27) can be partially explained by the fact that CMT-trace scores were combined with CMT-negative scores, and considered to be negative. Other researchers (2,8,11,12,13,15,29) have found that milk loss occurs at CMT-trace. The loss in CMT-trace quarters was not considered, and hence reduced estimated losses due to CMT-1, 2, and 3 scores.

Calculating monthly milk losses from the literature previously cited yields ranges of 12.2 to 41.4 kg for CMT-trace scores, 29.9 to 123.0 kg for CMT-1 scores, 65.3 to 221.5 kg for CMT-2 scores, and 88.9 to 319.0 kg for CMT-3 scores. It is apparent that wide variation occurs between studies. Explanations for this variation exist and will be discussed later.

Research Using Direct Microscopic Somatic Cell Count (DMSCC)

Several researchers have calculated milk loss due to various concentrations of somatic cells as determined by direct microscopic analysis. Waite and Blackburn (40) slaughtered one cow having positive bacteriological culture for hemolytic Staphylococcus, and a high somatic cell count (>1-2 X 10^6 cells per ml). Histological examination of the

udder revealed many abscesses and extensive involution in all quarters except the right rear quarter. Milk from the udder never appeared clinical. Prior to slaughter, quarter milk production was measured at weekly intervals during the first 84 days of lactation. Assuming 30% of total milk production comes from each rear quarter, and that the right rear quarter was normal, the authors calculated loss in milk yield. During the first 42 days of lactation, they estimated milk loss to be about 254 kg, or about 6 kg per day. Over the 80 day period, total probable loss was about 345 kg, or 4 kg per day.

Sendelbach *et al.* (35) studied 3,277 complete lactations which had at least four microscopic somatic cell counts conducted during the lactation. Two methods were employed to determine the effect of somatic cell count on milk production. One method placed greater emphasis on high cell counts occurring in early lactation than those occurring in late lactation. Cows who never exceeded 500,000 cells per ml were compared to: 1) cows who exceeded one million cells per ml for only one test in early lactation, 2) cows who exceeded one million cells per ml twice in a lactation (one count had to be in early lactation), and 3) cows who exceeded one million cells per ml at all tests. Lactation milk loss for the three comparisons was 158 to 191 kg, 370 to 446 kg, and 475 to 573 kg, respectively. In the second method, the 3,277 lactations were grouped into four categories: Two tests over one million cells per ml; two tests over 750,000 cells per ml; two tests over 500,000 cells per ml; and no more than one test over 500,000 cells per ml. Each of the three high groups (>500,000 cells per ml) was compared to the low group (>500,000 cells per ml), and lactation milk loss was calculated.

The authors listed milk loss by parity, however average milk loss over all lactations was 339, 291, and 14 kg for the three high groups, respectively.

Reduced milk yield as somatic cell count increased was observed by Waite and Blackburn (39) in an early study. Decreases of 2.8, 3.5, 9.8, and 15.5% occurred as cell counts rose from 50 X 10^3 to 100 X 10^3 cells per ml, 50 X 10^3 to 200 X 10^3 cells per ml, 50 X 10^3 to 300 X 10^3 cells per ml, and 50 X 10^3 to 350 X 10^3 cells per ml, respectively. Using 812 quarter samples, Ward and Schultz (41) have shown milk losses of 8, 15, 22, 27, and 31% at 1, 2, 3, 4, and 5 million cells per ml. Based on 874 quarter samples, Schultz (34) later estimated quarter milk loss to be 7.5, 15, and 30% at 1, 2, and 5 million cells per ml. He suggested that losses could be calculated at lower somatic cell count levels when a composite milk sample was counted due to dilution of somatic cell count from normal quarters. He also suggested that lactation milk production losses estimated by Sendelbach *et al.* (35) were conservative because the estimates assumed that no production loss occurred below 500,000 cells per ml. The milk yield losses approximated by Schultz (34) parallel those reported by Waite and Blackburn (39), although the latter observed milk losses at somatic cell counts below 300,000 cells per ml. The fact that Schultz (34) observed similar milk losses, but at much higher somatic cell counts may be due to his use of quarter samples rather than composite milk samples to determine somatic cell count.

Findings by Miller (26) were consistent with other estimates (34,40,41). In 108 complete lactations, cows were classified as healthy, subclinically, or clinically infected if somatic cell counts

were less than 200 X 10^3, 200 X 10^3 to 500 X 10^3, or greater than 500 X 10 cells per ml, respectively. Subclinical, second-lactation cows produced 12.6 percent less milk compared to healthy cows of the same parity. Cows who remained healthy in both first and second lactations produced 9.7 percent more milk during their second over their first lactation. However, cows subclinically infected during their second lactation produced 1.5 percent less milk during that lactation than during their first, infection-free lactation. Additionally, cows infected subclinically for both lactations produced 9.7% less milk during their second lactation. In all cases, clinically infected cows suffered higher losses.

Problems Associated with CMT, Opposite Quarter Comparisons or DMSCC

Disadvantages of the CMT

The CMT provided an important tool toward understanding milk losses associated with subclinical mastitis in its varying severities (2,8,11,12,13,15,27,29). For the first time, substantial milk losses caused by subclinical mastitis were established. However, the CMT was designed as a cowside test to aid dairymen, and not necessarily as a research tool. Several researchers have tested the CMT for accuracy and dependability. Rude (32) obtained 567 bacteriological quarter samples. In 230 bacteriologically negative samples, there were false positive CMT reactions. In eleven bacteriologically positive samples, there were false negative CMT reactions. With 241 false CMT readings, the CMT showed only a 57% success ratio. In terms of the various levels of subclinical mastitis, misreading either a CMT-1, 2, or 3 could further lower the success ratio.

Spencer and Simon (37) compared the CMT to catalase or direct microscopic methods of somatic cell counting. They found numerous discrepancies between CMT and direct miscroscopic cell counts with a correlation coefficient of .71. Large numbers of doubtful traces and ones indicated that individuals reading the CMT experienced difficulty in deciding what category to place reactions. Additionally, CMT reactive substances were found in milk from which somatic cells had been removed by centrifugation. The authors suggested the reactive substances may be produced by body cells, and therefore the CMT may not be a reliable indicator of infected and non-infected cows.

Laboratory bacteriological and cytological tests were compared to the CMT by Heever and Giesecke (18). In one experiment, laboratory results showed 661 samples to be completely normal, and 454 samples to be heavily infected with mastitis. CMT reactions on the same samples showed positive in 59 of the normal samples and negative in 51 of the infected samples. In another experiment, CMT reactions yielded positive results on 101 of 947 normal samples, and 60 negative results on 442 heavily infected quarters. Accuracy of the CMT was 90 and 88%, respectively in the two experiments. Although the findings by Heever and Giesecke (18) dispute those by Spencer and Simon (37), number of different technicians reading CMT reactions directly affects CMT accuracy (16). Discrepancies between the studies may be explained by variability between technicians reading CMT reactions, as well as milk sample age at time of reading CMT reactions (16,17).

Disadvantages of Using Opposite Quarter Comparisons

In many studies milk loss was calculated by comparing milk yield

of infected quarters to milk yield by opposite, healthy quarters (11,12, 13,22,23,24,27,29,34,40,41). However, considerable evidence is available which indicates that healthy, opposite quarters compensate for infected or injured quarters by producing more milk. In 1938, Swett *et al.* (38) established compensatory nature of healthy udder quarters by dissecting the udder of a dead Jersey cow. The cow had freshened as a heifer with the left rear quarter non-secreting. She died shortly after calving a second time. Soon after having her first calf, the right rear quarter dried-up as well. Udder dissection revealed that milk secreting tissue in both fore quarters had pushed backward, and displaced a large part of the space normally occupied by the rear quarters. Expansion of healthy, milk secreting tissue indicated compensatory action by the udder. Some researchers have reported compensatory action while conducting studies utilizing opposite quarter comparisons (7,13,25,29).

Variation of milk yield between udder sides was shown to exist by King (21). Variation in milk yield between udder sides of up to 29.9% in fore quarters, and 26.8% in rear quarters was found. The variation was not caused by mastitis as all 44 cows had clinically healthy udders. Natzke *et al.* (27) have reported large differences in milk production between opposite quarters with identical CMT scores, demonstrating variability in udder quarters.

Disadvantages of the Direct Miscroscopic Somatic Cell Count (DMSCC)

Direct microscopic somatic cell counting (DMSCC) offers a satisfactory method for measuring the presence of somatic cells in milk. Variability between individuals reading samples is considerably lower

than with the CMT, but can be high (16). Unfortunately, time required for sample preparation, and time and drudgery of microscopically reading prepared samples lowers number of samples read per hour to a relatively few. These limitations prohibit studies involving large numbers of samples. Many studies using DMSCC had sample sizes of less than 1,000 (7,26,34,41). Without large sample sizes, population statistics may be inaccurately estimated due to sampling error. Direct microscopic somatic cell counting therefore cannot be considered as a total evaluation tool for determining somatic cell count in mastitis research.

Electronic Somatic Cell Counters - A Practical Technological Development that Benefits Mastitis Research

Electronic somatic cell counters are a new method of measuring somatic cell concentration in milk. Preliminary tests conducted to determine accuracy and repeatability of the instruments and procedures have yielded promising results. Heald *et al.* (17) found high correlation between DMSCC and electronically-measured somatic cell counts. Correlation ranged from .97 to .92 from day one to day seven on 160 milk samples. Of 929 quarters, 96.1% of quarters free of organisms had electronic somatic cell counts below 300 X 10^3 cells per ml. Agreement between electronic somatic cell counts and CMT was also studied. As somatic cell counts rose, agreement between CMT and electronic counts decreased. Agreement of CMT with electronic somatic cell counts was 68, 49, 55, 36 and 16% with CMT-negative, trace, 1, 2, and 3 scores respectively. According to electronic somatic cell counts, DHI supervisors reading CMT results were hesitant to classify CMT scores of 2 and 3. This further demonstrated the inadequacies of the CMT

in research. In the study, electronic somatic cell counting resulted in a coefficient of variation near 3.3%, indicating good repeatability in the electronic somatic cell counter.

Repeatability, speed, and lower cost indicate that electronic somatic cell counting can be adequately used in both mastitis research, and dairy management. This study attempted to demonstrate the value of electronic somatic cell counting in mastitis research by analyzing relationships between subclinical mastitis and milk yield, using the electronic somatic cell count as an indicator of subclinical mastitis. It was hoped that a stronger relationship could be established by increasing sample numbers to levels unobtainable when DMSCC was used, and by reducing variability which was reported when CMT was used.

MATERIALS AND METHODS

Herd Selection

Thirty Virginia dairy herds were selected in 1976 to be cooperators. Herds were enrolled in Dairy Herd Improvement (DHI) testing. Herds were also required to be enrolled in the monthly somatic cell counting program offered by DHI. Equal numbers of herds were selected from three production levels. Ten herds had herd averages exceeding 7,257 kg milk. Ten herds were selected with herd averages ranging from 6,350 kg to 7,257 kg milk. Herd averages of the remaining ten herds were below 6,350 kg milk.

Shortly after commencement of the study, one of the lower producing herds discontinued DHI testing. This herd was subsequently removed from the study. No records from this herd were included in analysis of the data. In May, 1978, a second herd from the lower production group discontinued DHI testing and was removed from the project. Records obtained from that herd through the date of discontinuance were included in data analysis.

During May, 1978, five Virginia institution herds were added to the project. Records collected from these herds were included in statistical analysis of the data.

Source of Data

Monthly production data were collected from individual cows in

the thirty herds from June, 1977 through June, 1980. Monthly data were obtained from DHI supervisors' barn sheets. Calculated data were obtained from the Southern Region Dairy Records Processing Center, Raleigh, North Carolina.

Somatic cell counts were determined by the DHI central laboratory located at Virginia Polytechnic Institute and State University (VPI & SU). Milk samples collected by DHI supervisors at regular monthly visits were used for both butterfat and somatic cell count determinations. Somatic cells were counted on either a Fossomatic[1] or a Coulter[2] electronic somatic cell counter. Somatic cell counts were obtained immediately after butterfat determination and were recorded to the nearest 1,000 cells per ml.

Statistical Analysis

Three Data Sets were created to analyze relationships between somatic cell counts and milk production from different approaches. Multiple regression analysis was utilized to analyze the data (3).

Data Set I

Data Set I was constructed to determine relationships between test day somatic cell count, and test day milk yield. The following multiple regression models were used to explain the data.

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[1]A/S N. Foss Electric, Hillerod, Denmark.

[2]Coulter Electronics, Inc., Hialeah, Florida.

Model A:

$$Y_{ijklmn} = \mu + H_i + C/H_{ij} + St_k + Se_l + P_m + \beta_1(SCC) + \beta_2(SCC^2) + \beta_3(SCC^3) + E_{ijklmn}$$

where: Y_{ijklmn} = Test day milk yield

μ = Overall mean

H_i = Effect of i^{th} herd

C/H_{ij} = Effect of j^{th} cow within the i^{th} herd

St_k = Effect of k^{th} stage of lactation

Se_l = Effect of l^{th} season of year

P_m = Effect of m^{th} parity

$\beta_1(SCC)$ = Regression coefficient of somatic cell count

$\beta_2(SCC^2)$ = Regression coefficient of somatic cell count squared

$\beta_3(SCC^3)$ = Regression coefficient of somatic cell count cubed

E_{ijklmn} = Residual error term

Model B:

$$Y_{ijklmno} = \mu + H_i + C/H_{ij} + St_k + Se_l + P_m + SCC_n + E_{ijklmno}$$

where: $Y_{ijklmno}$ = Test day milk yield

μ = Overall mean

H_i = Effect of i^{th} herd

C/H_{ij} = Effect of j^{th} cow within the i^{th} herd

St_k = Effect of k^{th} stage of lactation

Se_l = Effect of l^{th} season of year

P_m = Effect of m^{th} parity

SCC_n = Effect of n^{th} somatic cell count

$E_{ijklmno}$ = Residual error term

Model C:

$$Y_{ijklmn} = \mu + H_i + C/H_{ij} = St_k + Se_l + P_m + \beta_1(LN) + \beta_2(LN^2) + \beta_3(LN^3) + E_{ijklmn}$$

where: Y_{ijklmn} = Test day milk yield

μ = Overall mean

H_k = Effect of i^{th} herd

C/H_{ij} = Effect of j^{th} cow within the i^{th} herd

St_k = Effect of k^{th} stage of lactation

Se_l = Effect of l^{th} season of year

P_m = Effect of m^{th} parity

$\beta_1(LN)$ = Regression coefficient of natural log of somatic cell count

$\beta_2(LN^2)$ = Regression coefficient of natural log of somatic count squared

$\beta_3(LN^3)$ = Regression coefficient of natural log of somatic cell count cubed

E_{ijklmn} = Residual error term

In the three models, stage of lactation was divided into thirty-day increments, thus allowing each month of lactation to be considered as a stage. Similarly, each month of the year was considered as a season. Stage of lactation, and season of year were incremented in

this manner as an attempt to minimize variation encountered when the two are defined to contain several months.

Parity, or lactation number in all three models consisted of lactations one through nine, with any lactation exceeding nine considered in a tenth group. Few lactations above nine were encountered.

Somatic cell count was treated as a discrete variable in Model B, as opposed to a continuous variable as in Models A and C. In Model B, ranges of somatic cell count were partitioned into levels to allow consideration of somatic cell count as a discrete variable in analysis of variance. Partitioning of somatic cell count ranges are presented in Table 1.

Data Set II

Models in Data Set II were designed to analyze relationships between test day milk yield, and cumulative effects of somatic cell count. The continual effect of somatic cell levels on milk yield was of concern.

Arithmetic and geometric means for somatic cell counts were calculated from first DHI test day through test day being considered. One of the two means was incorporated into otherwise identical models. Geometric mean was used due to it's nature of weighting one abnormally high or low somatic cell count in relation to many moderate counts. Arithmetic mean gave equal weighting to all somatic cell counts.

Five models similar to those used in Data Set I were employed in Data Set II. Components were identical with the exception that regression coefficients were calculated for geometric or arithmetic mean

Table 1. Partition Assignments of Somatic Cell Count.

Somatic Cell Count (X 1000)	Class
> 50	1
51 - 100	2
101 - 150	3
151 - 200	4
201 - 250	5
251 - 300	6
301 - 350	7
351 - 400	8
401 - 500	9
501 - 600	10
601 - 700	11
701 - 800	12
801 - 900	13
901 - 1,000	14
1,001 - 1,100	15
1,101 - 1,200	16
> 1,200	17

of somatic cell count. Two of the five models treated geometric or arithmetic mean somatic cell count as discrete variables. Partitioning was identical to that utilized in Data Set I, with geometric or arithmetic mean somatic cell count replacing raw somatic cell count.

Data Set III

Data Set III was developed to determine relationships between lactational somatic cell count, and 305-day M.E. milk yield. Monthly somatic cell count was multiplied by percent days in milk remaining. The individual products were then summed to produce a lactational somatic cell count. In this manner higher somatic cell counts occurring in late lactation when monthly milk yield is normally lowest were given much less weighting. In the model used to evaluate data obtained from Data Set III, calving date was defined into twelve months to correct for variation of lactational milk yield associated with calving at different seasons of a year. Parity effects were also corrected for, and defined in the same manner as in the previous data sets. Lactational somatic cell count classes were also identical to those used in the previous data sets. The following model was selected for use in Data Set III:

$$Y_{ijklm} = \mu + H_i + C_j + P_k + W_l + E_{ijklmn}$$

where;

Y_{ijklm} = 305-day mature equivalent (M.E.) milk yield

μ = Overall mean

H_i = Effect of i^{th} herd

C_j = Effect of j^{th} calving date

P_k = Effect of k^{th} parity

W_l = Effect of l^{th} lactational somatic cell count class

E_{ijklm} = Residual error term

RESULTS AND DISCUSSION

Data Set I

Data Set I contained 67,707 observations with a mean somatic cell count of 390,000 cells per ml. As previously discussed, the first model in the data set analyzed relationships between daily milk yield, and linear, quadratic, and cubic effects of somatic cell count (SCC). Figure 1 illustrates the relationship. Cows with somatic cell counts of 50 X 10^3, 100 X 10^3, 200 X 10^3, and 300 X 10^3 cells per ml produced 0.55, 0.47, 0.31, and 0.15 kg more milk per day, respectively, compared to cows with somatic cell counts of 400 X 10^3 cells per ml. Conversely, cows with somatic cell counts of 500 X 10^3, 800 X 10^3, and 1,200 X 10^3 cells per ml produced 0.15, 0.60, and 1.17 kg less milk per day, respectively.

Although a cubic model was used, and linear, quadratic, and cubic effects were significant ($P<.01$), plotting the regression coefficients as in Figure 1 yielded results expected only in a linear model (analysis of variance (ANOVA) is presented in Appendix Table 1). A straight-line relationship appeared to describe the data, with an R^2 of .739. This did not support findings by Gray and Schalm (15), or Daniel *et al.* (8) who earlier reported a curvilinear relationship between CMT and decreased milk production.

Attempts to discover the presence of a curvilinear relationship resulted in development of the classification model previously outlined. Incrementing somatic cell count into classes demonstrated a likelihood

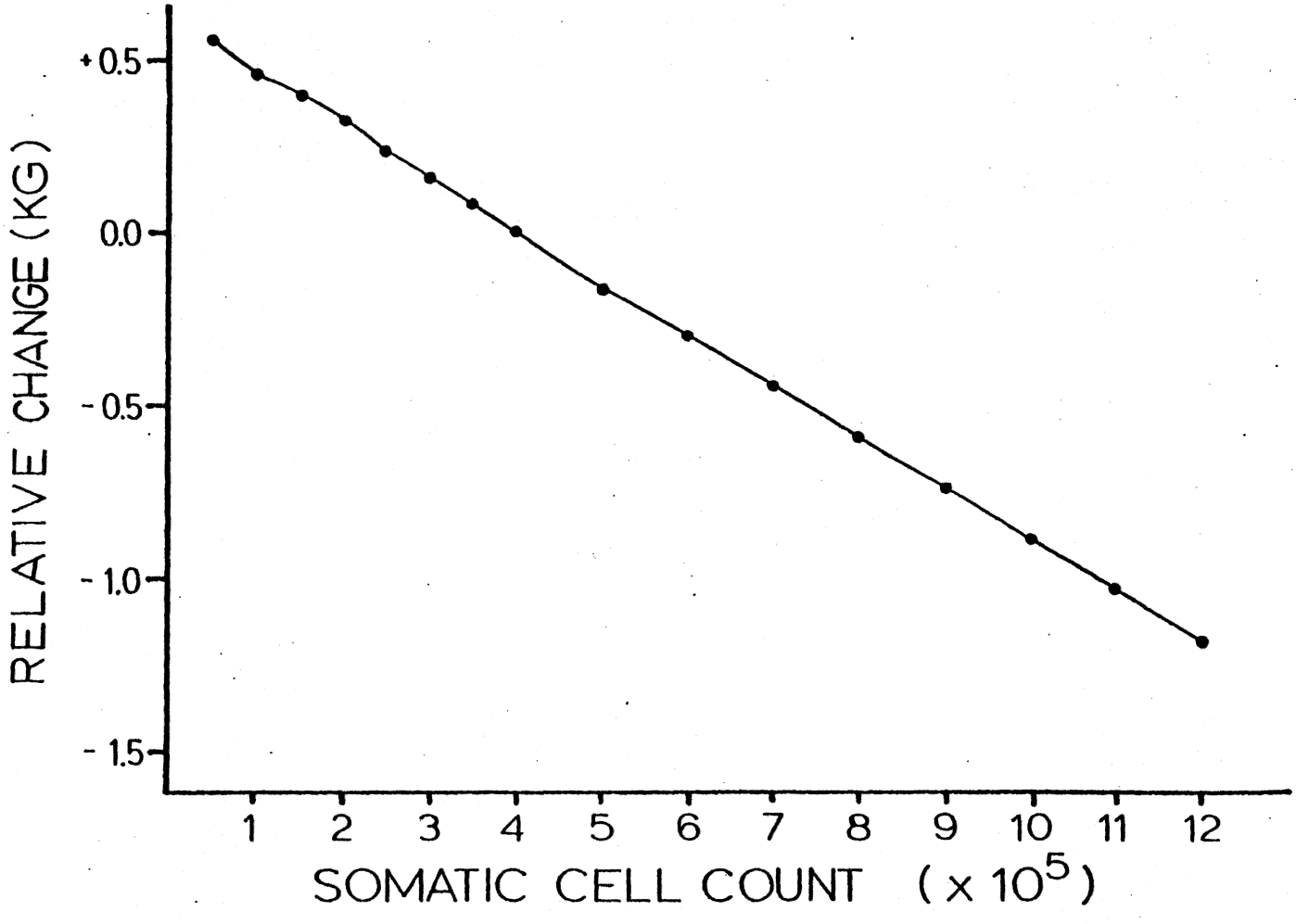

Figure 1. Relationship between test day milk yield and test day SCC.

that curvilinear relationships existed as the histogram presented in Figure 2 indicates. As somatic cell count increased from 50 X 10^3 to 300 X 10^3 cells per ml, milk yield decreased at a more rapid rate compared to milk yield decline as somatic cell count rose from 300 X 10^3 1,200 X 10^3 cells per ml. Milk loss declined at a more rapid rate through the lower somatic cell levels than that observed in the previous model. At somatic cell counts of 50 X 10^3, 100 X 10^3, 200 X 10^3, and 300 X 10^3 cells per ml, cows produced 2.33, 1.49, 0.49, and 0 kg more milk per day, respectively compared to cows with a somatic cell count of 400 X 10^3 cells per ml. Through the higher somatic cell counts, milk loss was not appreciably different than that observed in the first model. At somatic cell counts of 500 X 10^3, 800 X 10^3, and 1,200 X 10^3 cells per ml, cows produced 0.15, 0.73, and 1.08 kg less milk per day, respectively compared to cows with a somatic cell count of 400 X 10^3 cells per ml. The classification model resulted in a slightly higher R^2 of .743 (ANOVA presented in Appendix Table 2).

Greater milk losses through the lower ranges of somatic cell count observed in the second model can be attributed to the classification of a continuous variable into discrete categories. The class considered as 50 X 10^3 cells per ml actually contained cell counts ranging from 10 X 10^3 to 50 X 10^3 cells per ml. Similarly, the class designated as being greater than 1,200 X 10^3 cells per ml contained a wide range of somatic cell counts from 1,201 X 10^3 to the maximum count observed of 23,000 X 10^3 cells per ml.

There was concern that a classification model could not adequately describe a relationship between milk production, and the

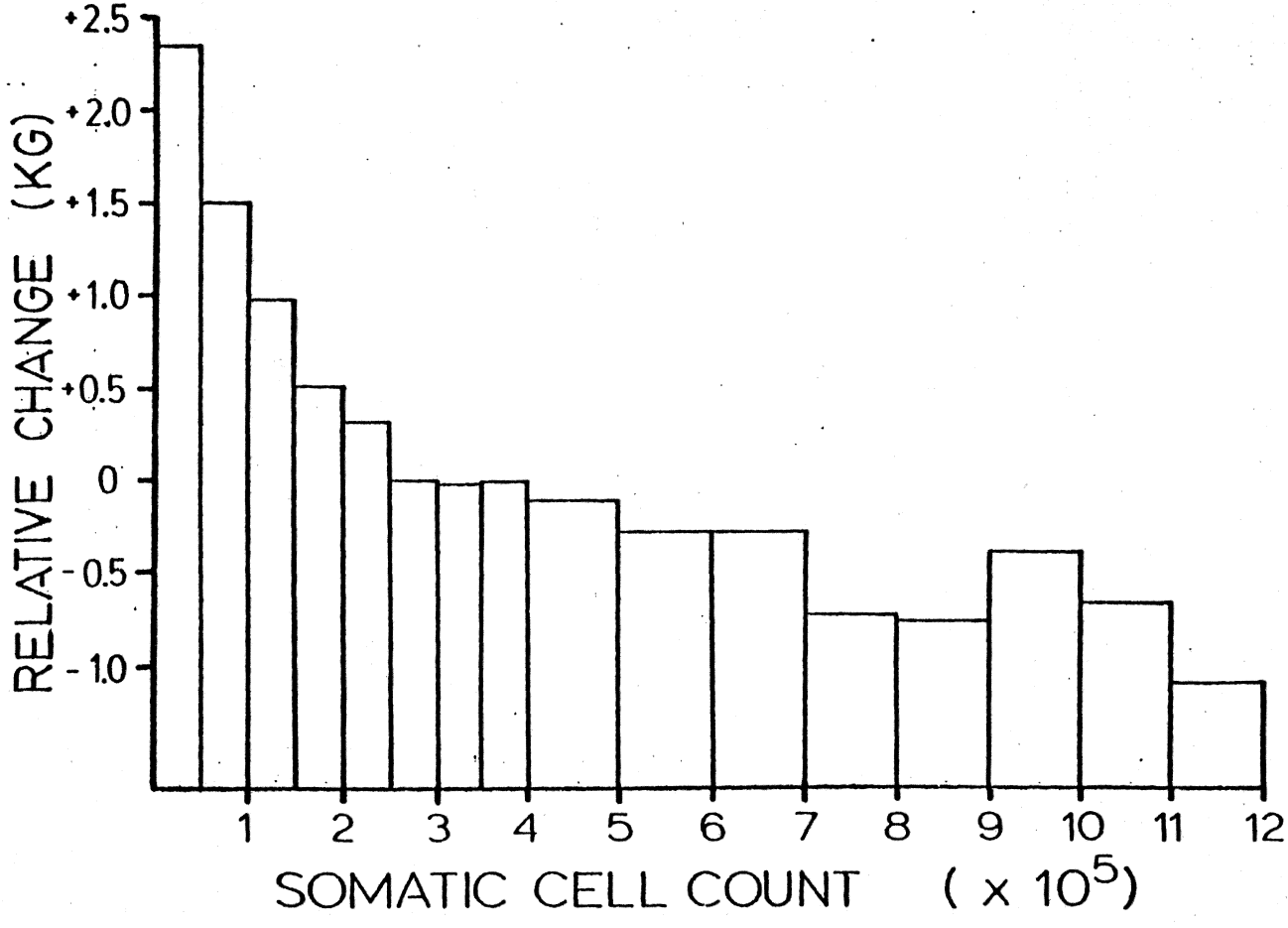

Figure 2. Relationship between test day milk yield and test day SCC. SCC classified.

continuous variable, somatic cell count. This viewpoint was supported by further incrementing the lowest two somatic cell count classes (50 and 100 X 10^3 cells per ml) into increments of 10,000 cells per ml. A clear trend within each 50,000 cell count class was observed. Figure 3 illustrates this strong trend for decreasing milk production from lower to upper range within each 50,000 somatic cell count class. The dotted lines represent values given for each 50,000 cells per ml class. Classification models are designed to describe data of a discrete nature. In the above situation, the classification model failed to give sufficient consideration of within-class trends, therefore the relationship between milk yield and somatic cell count was inadequately described.

As previously mentioned, a curvilinear relationship between milk production, and somatic cell count should be sufficiently described by a model such as the first model employed in Data Set I. However, regression models like the one used assume that data being analyzed is normally distributed, and they give erroneous conclusions or interpretations in cases of non-normal distribution (36). A frequency distribution of the observations indicated a heavily skewed population. The frequency distribution, shown in Figure 4, revealed that 81.2% of all observations were at or below 400 X 10^3 cells per ml. The skewed distribution of somatic cell counts was similar to that reported by Ali and Shook (1).

A log transformation was utilized to normalize somatic cell count distribution. A model using linear, quadratic, and cubic effects of natural log (ln) of somatic cell count was then used. A significant, curvilinear relationship was shown to exist (ANOVA presented in Appendix

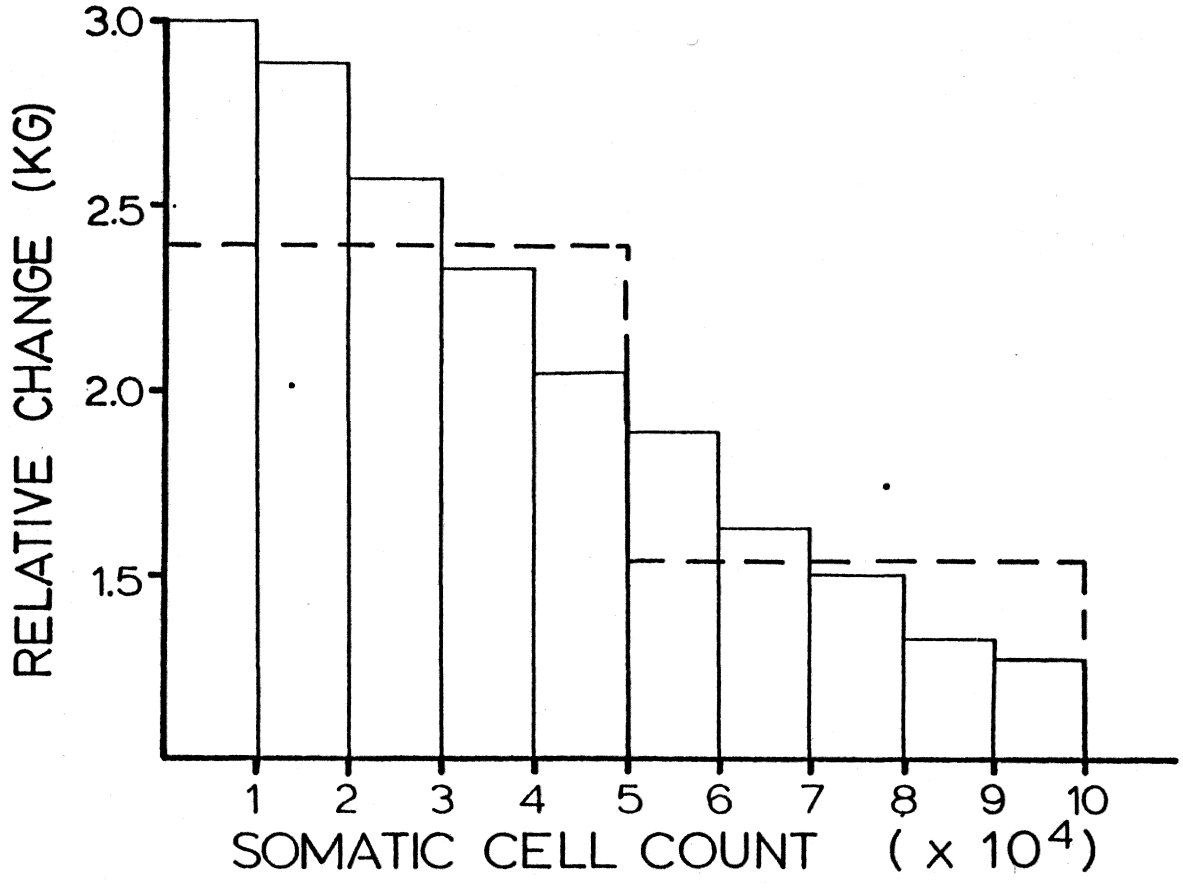

Figure 3. Within-class trends of somatic cell count.

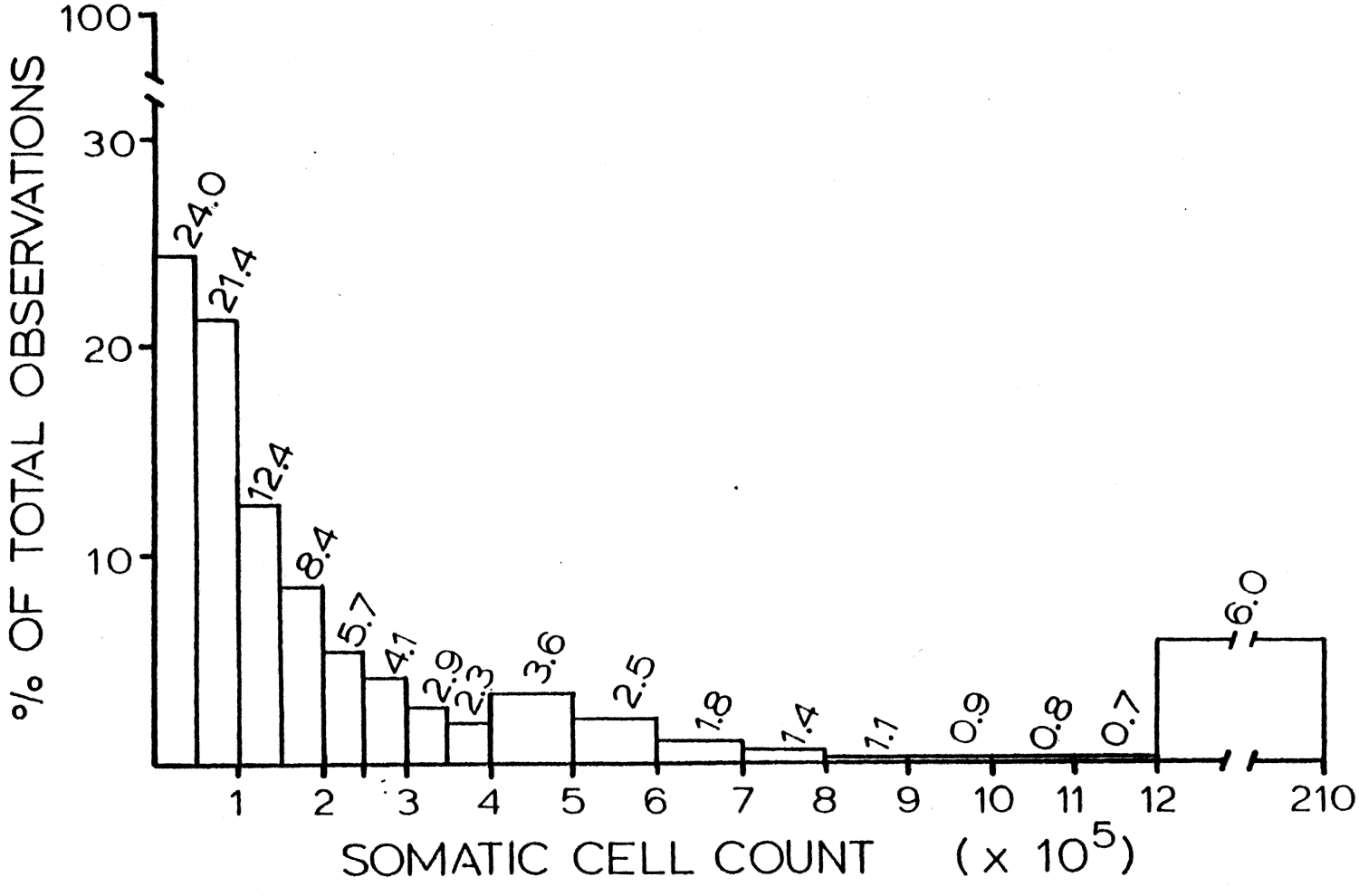

Figure 4. Distribution of somatic cell counts.

Table 3) linear, quadratic and cubic effects were all highly significant ($P<.05$). The relationship illustrated in Figure 5 is similar to the relationship described by the classification model. In both instances, milk yield reduction was dramatic as equivalent somatic cell count increased from 300 X 10^3 cells per ml. As equivalent somatic cell count increased from 300 X 10^3 to 1,200 X 10^3 cells per ml, declines in milk yield continued but less dramatically. However, for reasons previously proposed, the cubic model, using transformed data, better described this relationship. Cows with somatic cell counts equivalent to 50 X 10^3, 100 X 10^3, 200 X 10^3, and 300 X 10^3 cells per ml produced 1.88, 1.27, 0.65, and 0.28 kg more milk per day, respectively, compared to cows with somatic cell equivalent to 400 X 10^3 cells per ml. Meanwhile cows with somatic cell counts equivalent to 500 X 10^3, 800 X 10^3, and 1,200 X 10^3 cells per ml produced 0.22, 0.71, and 1.16 kg less milk per day, respectively.

These results indicate that substantial milk loss occurred at somatic cell levels well below 400 X 10^3 cells per ml. Comparing milk production of cows at somatic cell counts equivalent to 1,200 X 10^3 cells per ml to milk production by cows with somatic cell counts equivalent to 50 X 10^3 cells per ml, 40.4, 52.6, and 61.8% of the total difference had occurred at somatic cell counts equivalent to 200 X 10^3, 300 X 10^3, and 400 X 10^3 cells per ml, respectively. An R^2 value of .744 with the log model was the highest yet obtained.

A similar trend was noted in results of Ward and Schultz (41), who reported that 26, 48, and 71% of the milk yield loss noted at 5 million cells per ml occurred at somatic cell counts of one, two, and three million cells per ml, respectively. They used only foremilk from infected quarters to obtain somatic cell counts, and dilution of somatic

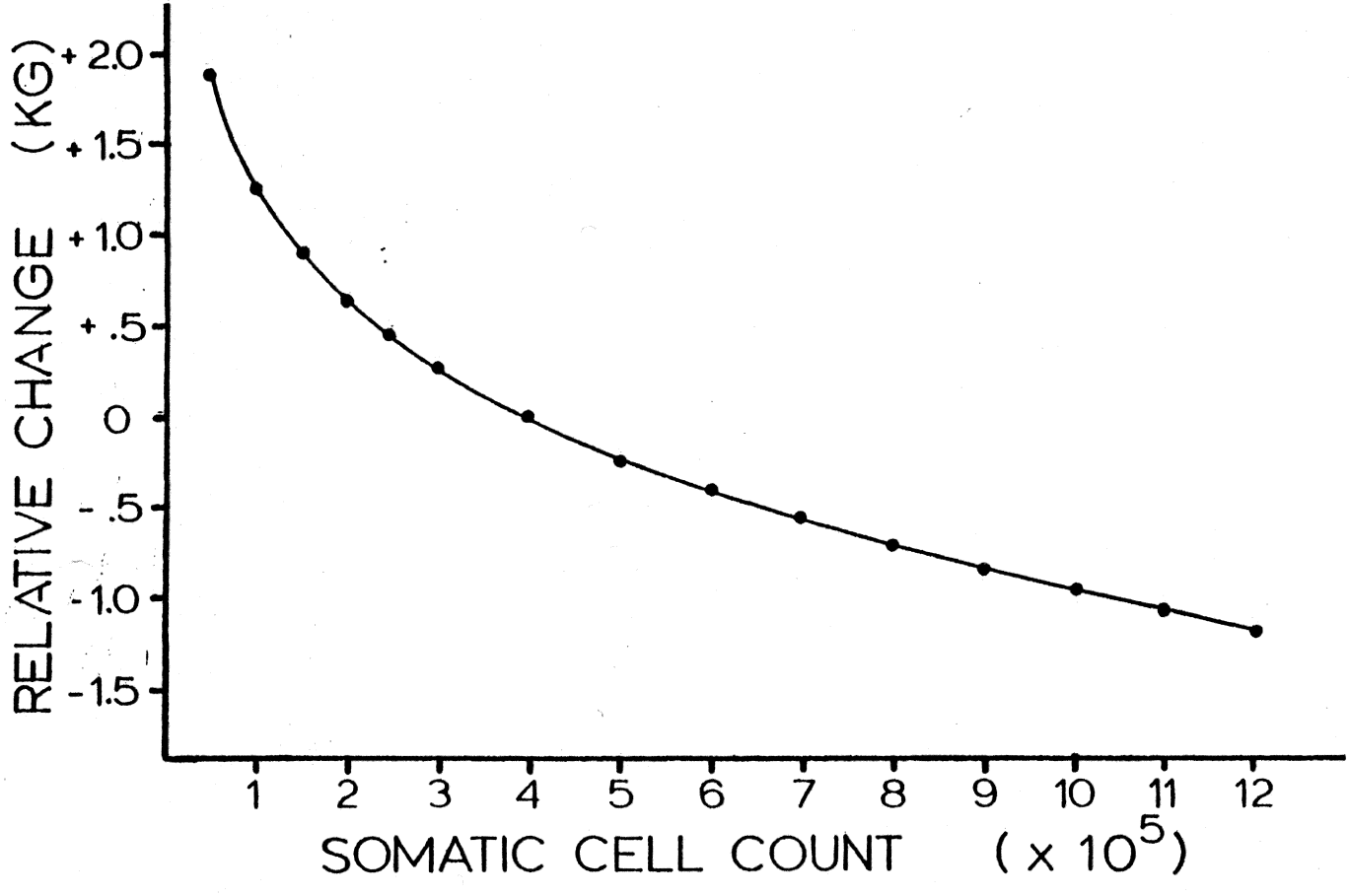

Figure 5. Relationship between test day milk yield and log(n) SCC.

cell count from milk of normal quarters would considerably lower somatic cell counts in a composite milk sample. Use of composite milk samples, representing the entire amount of milk produced during two milkings may explain why a similar trend was observed with the log model, but at much lower somatic cell counts.

Data Set II

Results of Data Set I supported the presence of a strong relationship between milk yield and somatic cell count, particularly at lower somatic cell counts. However, design of the data set permitted comparison of only test-day milk yield to test-day somatic cell count. Researchers have found that udder infections reduce milk yield in subsequent months, and that milk production during the lactation never recovers to 100% of preinfection levels after elimination of the infection (22,30,31). Of interest was the possibility of cumulative effects of somatic cell count on test day milk production. Models were developed to consider all prior somatic cell counts in the current lactation, and their combined effect on current test day milk production. Both arithmetic and geometric means of somatic cell counts were used. To be considered in the statistical analysis, a cow had to have a reported somatic cell count in each month of test including the current month. Data Set II consisted of 43,677 observations with a mean somatic count of 390 X 10^3 cells per ml.

Identical models to those used in Data Set I were employed in Data Set II. The only exception to the model was a substitution of arithmetic or geometric mean of somatic cell count for actual test day

somatic cell count. Figure 6 shows results similar to those obtained by using the first model in Data Set I. Once again, a straight-line relationship appeared to exist, this time between arithmetic and geometric mean somatic cell count and test day milk yield. Although linear, quadratic, and cubic trends were all significant ($P<.01$), no curvilinear relationship was evidenced by plotting the results (ANOVA's for arithmetic and geometric mean models are presented in Appendix Tables 4 and 5, respectively).

Two important differences were observable in Figure 6. Milk yield declined at a greater rate compared to decline of milk yield in Figure 1. This indicated a strong influence of the continued effect of somatic cell count on milk production. Cows with arithmetic mean somatic cell counts of 50×10^3, 100×10^3, 200×10^3, and 300×10^3 cells per ml produced 1.04, 0.89, 0.59, and 0.29 kg more milk, respectively, on test day compared to cows with an arithmetic mean somatic cell count of 400×10^3 cells per ml. These milk yield differences were 0.49, 0.42, 0.28, and 0.14 kg more, respectively, compared to milk yield differences calculated for cows at the same somatic cell counts, using the first model in Data Set I. This suggested that as cumulative somatic cell count rose, test day milk yield declined more rapidly causing wider margins in milk yield at arithmetic mean somatic cell count 400×10^3 cells per ml, and the lower arithmetic mean somatic cell counts.

A sharper rate of decline in milk yield resulted by using geometric mean somatic cell count. This was the second important characteristic discernable in Figure 6. At geometric mean somatic cell counts of 50×10^3, 100×10^3, 200×10^3, and 300×10^3 cells per ml, cows produced 1.24, 1.06, 0.69, and 0.35 kg more milk, respectively, on test day compared

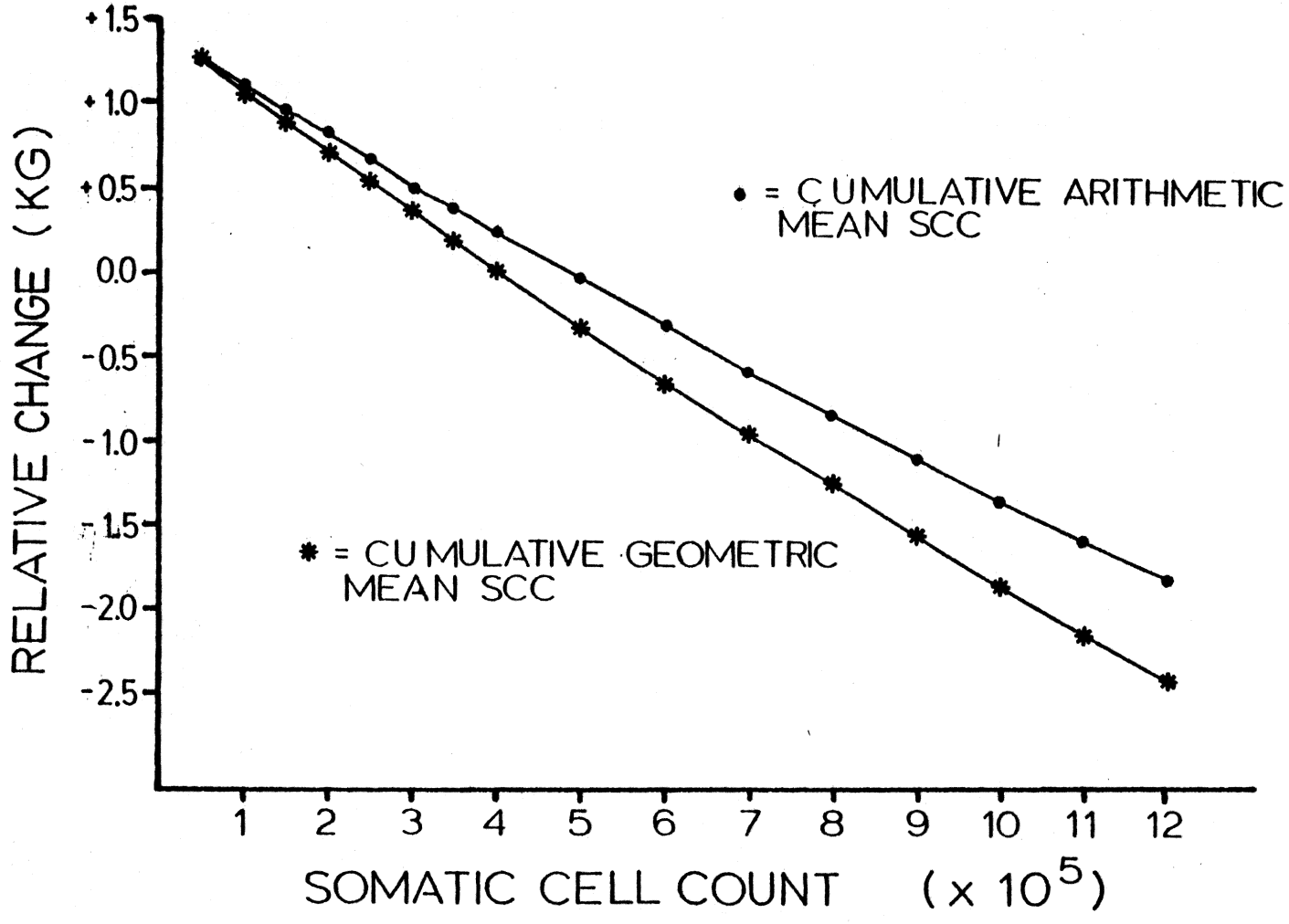

Figure 6. Relationship between mean SCC and test day milk production.

to cows with geometric mean somatic cell count of 400 X 10^3 cells per ml. These milk yield differences were 0.20, 0.17, 0.10 and 0.06 kg more per day, respectively, compared to milk yield differences calculated when arithmetic mean somatic cell count was used. A sharper rate of decline in milk production resulted from using geometric mean somatic cell count. R^2 values of arithmetic and geometric mean models were both .768. This was slightly higher than R^2 values of models in Data Set I, indicating a better fit of Data Set II models.

Variation between arithmetic and geometric mean results can be explained. Arithmetic mean gave equal weighting to all somatic cell counts under consideration. Therefore, one high somatic cell count in a group of predominantly low counts received equal attention. The same was true for a low somatic cell count in a group of predominantly high counts. Geometric mean weighted extreme somatic cell counts less. Therefore, a single high somatic cell count was given less weighting while many low somatic cell counts were given considerably more emphasis. In view of the extreme range of somatic cell counts, and the skewed nature of the population, the geometric mean was probably the better method for calculating cumulative effect of somatic cell count on test day milk yield.

Classification of arithmetic and geometric mean somatic cell counts produced results similar to those obtained for the classification model used in Data Set I (ANOVA's for arithmetic and geometric mean classification models presented in Appendix Tables 6 and 7, respectively). Figure 7 illustrates that, as in Data Set I rapid decreases in milk yield were noted at lower somatic cell levels from 50 X 10^3 through

300 X 10^3 cells per ml. However, Figure 7 shows that the rate at which milk production declined was greater, indicating an influence of continual effect of somatic cell count on milk yield. Cows with geometric mean somatic cell counts of 50 X 10^3, 100 X 10^3, 200 X 10^3, and 300 X 10^3 cells per ml produced 3.50, 2.06, 0.69, and 0.22 kg more milk per day, respectively, compared to cows with geometric mean somatic cell count of 400 X 10^3 cells per ml. Compared to milk yield declines calculated in Data Set I using a similar classification model, declines in milk yield calculated by considering geometric mean somatic cell count were 1.16, 0.57, 0.20, and 0.22 kg greater per day, respectively.

Variability between arithmetic and geometric mean was again apparent, as illustrated in Figure 7. With geometric mean somatic cell count providing a preferable method of determining cumulative effect of somatic cell count on daily milk yield, the effect of arithmetic mean somatic cell count was no longer considered. All statistical analysis in Data Set II after the classification model included only geometric mean somatic cell count.

As previously mentioned, the population in Data Set II was skewed. Figure 8 shows that 51% of all observations had a geometric mean somatic cell count of 100 X 10^3 cells per ml or less. This indicated that a higher degree of skewness existed in Data Set II. Once again, a logarithmic transformation of the data was suggested.

Statistical analyses of the relationship between natural log of geometric mean somatic cell count and test day milk yield resulted in a curvilinear relationship similar to that observed when natural log of

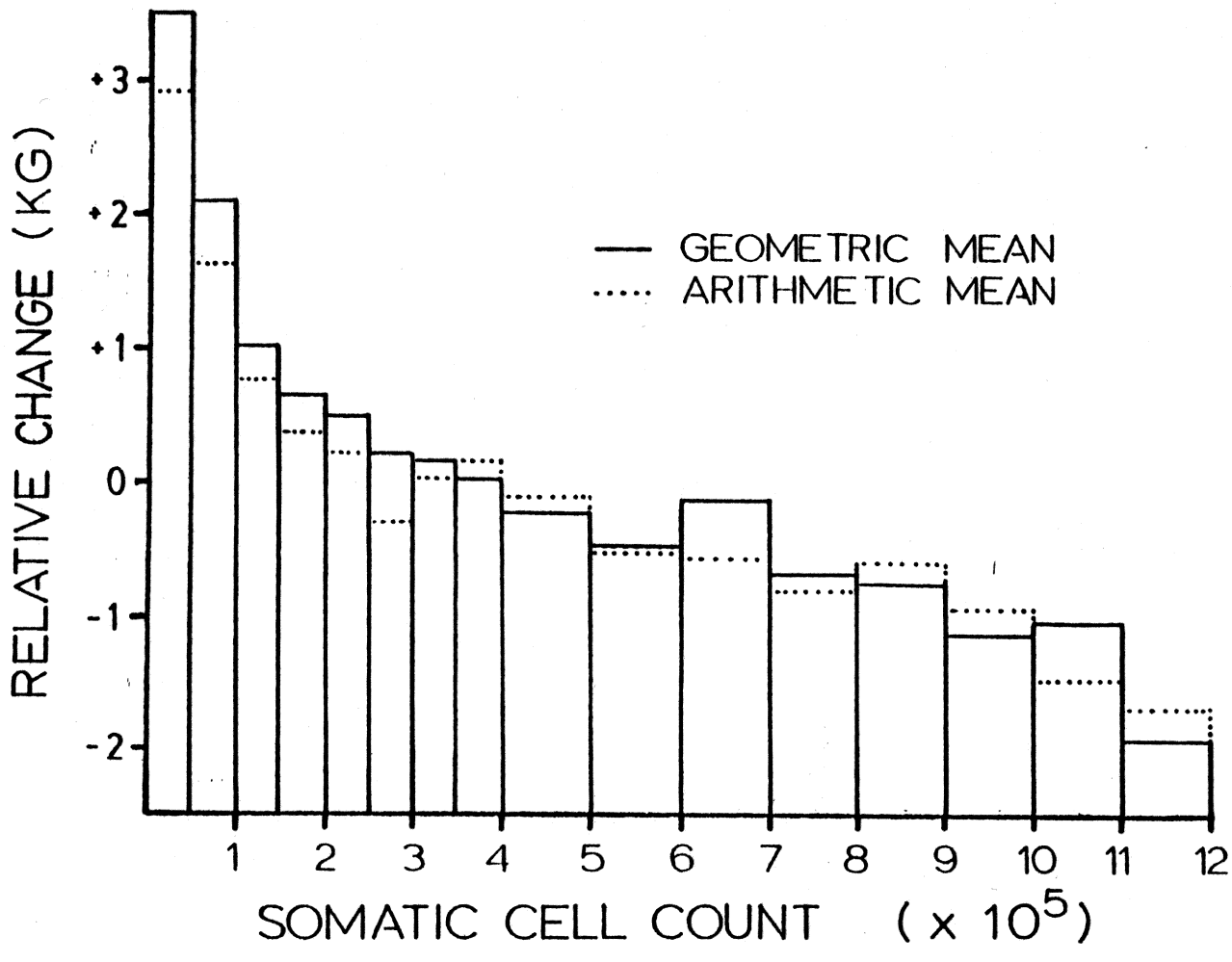

Figure 7. Relationship between mean SCC and test day milk yield. Mean SCC classified.

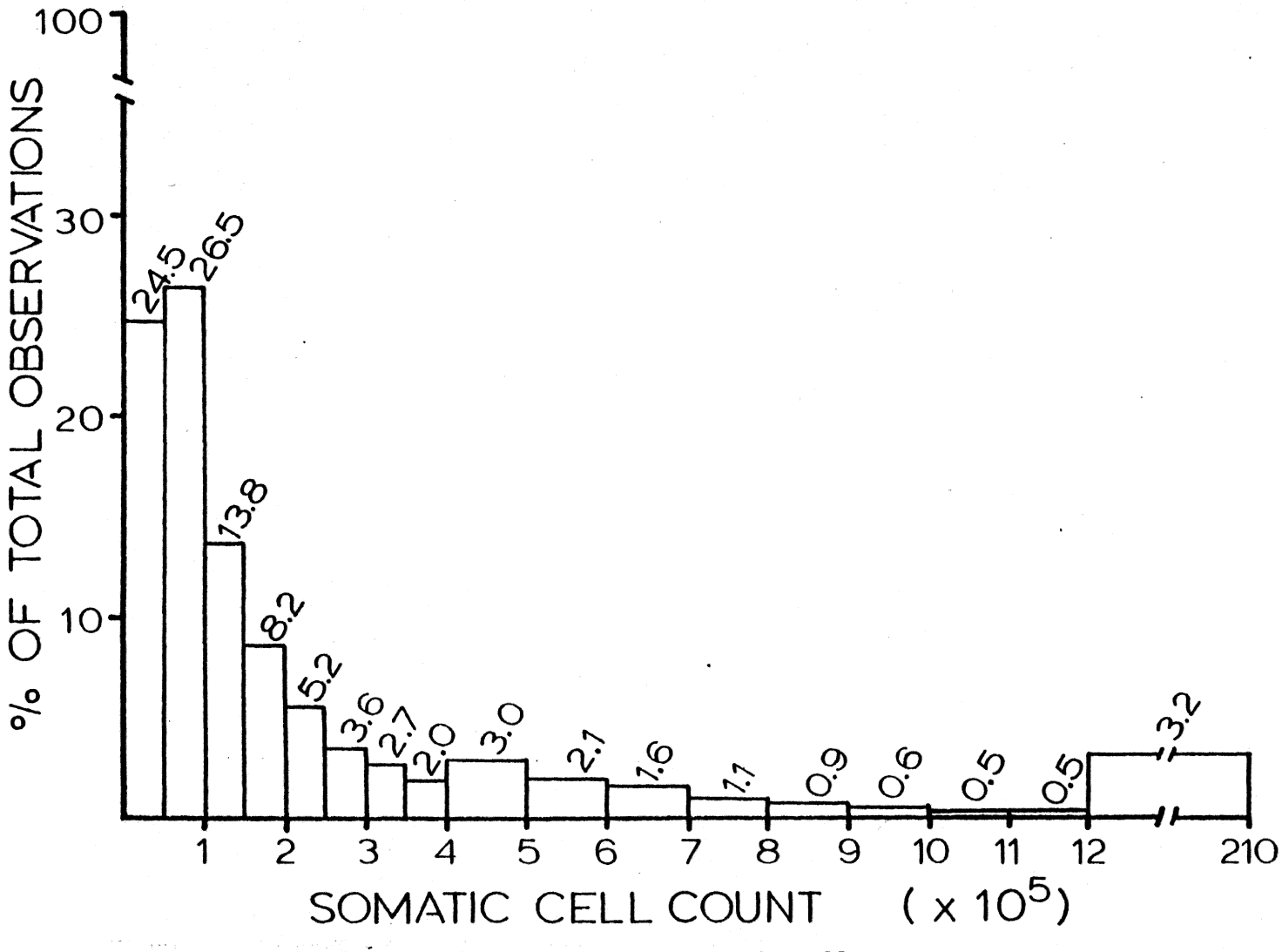

Figure 8. Distribution of geometric mean somatic cell count.

somatic cell count was used (ANOVA for log of geometric mean somatic cell count is presented in Appendix Table 8). Figure 9 shows a sharp decline in test day milk yield from 50 X 10^3 through 400 X 10^3 cells per ml. The rate of decline was much greater, compared to rate of milk yield decline presented in Figure 5. A strong, continual effect of somatic cell count was implied. Cows with geometric mean somatic cell counts equivalent to 50 X 10^3, 100 X 10^3, 200 X 10^3, and 300 X 10^3 cells per ml produced 2.97, 1.83, 0.87, and 0.36 kg more milk per day, respectively, compared to cows with geometric mean somatic cell count equivalent to 400 X 10^3 cells per ml. At geometric mean cell counts equivalent to 500 X 10^3, 800 X 10^3, and 1,200 X 10^3 cells per ml, cows produced 0.28, 0.90, and 1.48 kg less milk per day, respectively, compared to cows with geometric mean somatic cell count equivalent to 400 X 10^3 cells per ml. Differences between milk yield at lower somatic cell counts and milk yield at 400 X 10^3 cells per ml were much greater using natural log of geometric mean somatic cell count compared to natural log of test-day somatic cell count. Differences in milk yield at somatic cell counts equivalent to 50 X 10^3, 100 X 10^3, 200 X 10^3, and 300 X 10^3 cells per ml compared to milk yield at somatic cell count equivalent to 400 X 10^3 cells per ml was 2.42, 1.36, 0.56, and 0.21 kg more per day, respectively, when cumulative effects of somatic cell count were considered. These wider margins reflected a sharper decline in daily milk yield.

The curve presented in Figure 9 best described the relationship between daily milk yield and lactation average somatic cell count through current test day. It considered a continual effect of somatic cell count

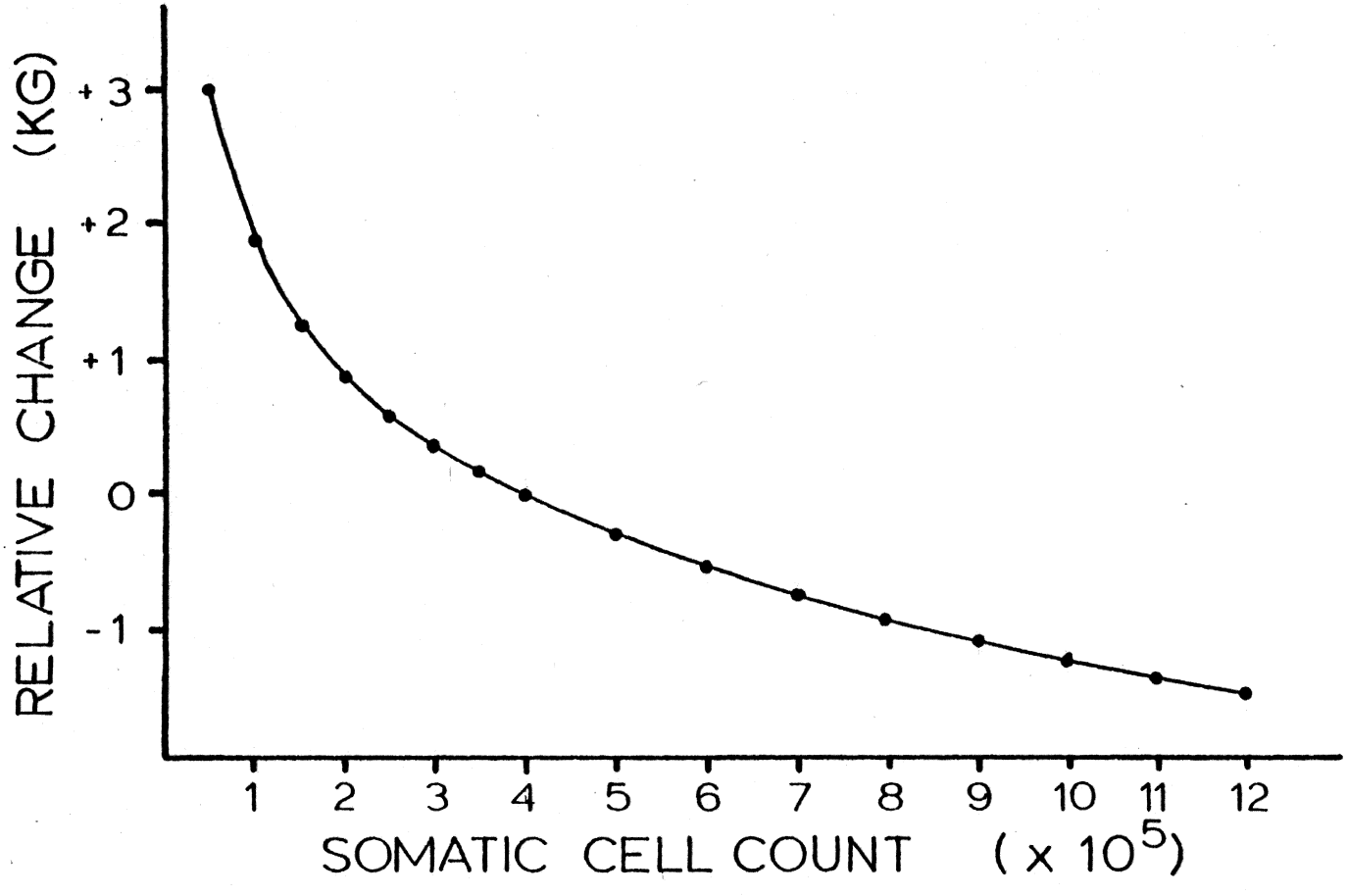

Figure 9. Relationship between geometric mean SCC and test day milk yield.

on milk secreting, epithelial cells. The model used to develop the curve utilized a transformation which normalized a non-normal distribution. Further confirmation was an R^2 value of .769, the highest obtained in any model of Data Set I or Data Set II.

The relationship shown in Figure 9 strongly suggests that much milk is being lost per day after a cow's somatic cell count exceeds 100 X 10^3 cells per ml. To date, dairymen have been advised that second or higher lactation cows with somatic cell counts of 400 X 10^3 cells per ml or less were safe or normal (20). However, these recommendations are based on research which used less precise methods of determining milk loss associated with somatic cell count, previously described in Review of the Literature. Figure 9 suggests that by an average somatic cell count of 200 X 10^3 cells per ml, 47.2% of total milk lost at average somatic cell count of 1,200 X 10^3 cells per ml has been realized. At 300 X 10^3, and 400 X 10^3 cells per ml, the percentages are 58.6, and 66.7, respectively.

Occurrence of large milk losses at somatic cell counts below 400 X 10^3 cells per ml has never been documented. However, suggestions and theories to the possibility have been advocated. Schultz (33) postulated that milk production losses would occur at somatic cell counts well below 500 X 10^3 cells per ml if the somatic cell counts were taken from bucket samples representing an entire milking of all four quarters. In the current study, milk samples represented an entire day's milk production by all producing quarters. Miller (26) proposed that cows with somatic cell counts of 150 X 10^3 to 500 X 10^3 cells per ml should

be classified as having subclinical mastitis. Eberhart *et al.* (10) found that cows with somatic cell counts of less than 100 X 10^3 cells per ml had a 54% chance of having some type of major or minor infection. In 1957, Waite and Blackburn (39) stated that a somatic cell count of less than 10,000 cells per ml, with a complete absence of polymorphonuclear leukocytes appears to be characteristic of milk from a healthy udder. They further stated that, generally, milk from a full milking having less than 100 X 10^3 cells per ml could be considered free of subclinical mastitis. It is possible that 27 years later, research using electronic somatic cell counting is documenting these earlier hypotheses.

Perhaps the greatest indication of normal somatic cell count levels can be found in the distribution of somatic cell counts. Referring again to Figure 8, 51% of all geometric mean somatic cell counts were 100 X 10^3 cells per ml or less. At 200 X 10^3 cells per ml, 73% of all observations had been noted. This heavy preponderance of observations at such low somatic cell counts strongly indicates normalcy for somatic cell counts of less than 100 X 10^3 to 200 X 10^3 cells per ml.

Data Set III

Relationships between lactational somatic cell count, and 305-day M.E. milk yield were analyzed. Lactational somatic cell count was calculated by multiplying monthly somatic cell count by percent days in milk remaining as of that month. The weighted monthly somatic cell counts were then summed to yield lactational somatic cell count. In this way, somatic cell counts in early lactation were given heavier

emphasis than those in late lactation. It was assumed that somatic cell counts occurring during peak milk production months of early lactation would exert greater influence on total 305-day milk yield compared to somatic cell counts occurring near end of lactation, when milk production is normally lowest.

Based on 2,193 observations, results obtained differed from expected results (ANOVA presented in Appendix Table 9). Using the log model in Data Set II, it was determined that cows with somatic cell counts of 50 X 10^3, 100 X 10^3, 200 X 10^3, and 300 X 10^3 cells per ml produced 2.97, 1.83, 0.87, and 0.36 kg more milk per day, respectively, compared to cows with somatic cell counts of 400 X 10^3 cells per ml. If one multiples these values by 305, an expected lactational milk yield difference of 906, 558, 265, and 110 kg, respectively, could be expected. Figure 10 illustrates that the expected differences did not occur. Cows with lactational somatic cell counts of <50 X 10^3 cells per ml produced a 305-day M.E. record with only 250 kg more milk compared to cows whose lactational somatic cell counts were 301 X 10^3 to 400 X 10^3 cells per ml. Similarly, at 51 X 10^3 to 100 X 10^3, 151 X 10^3 to 200 X 10^3, and 251 X 10^3 to 300 X 10^3 cells per ml, 305-day M.E. records were only 142, 51, and 23 kg more, respectively, compared to 305-day M.E. production at 301 X 10^3 to 400 X 10^3 cells per ml. A large difference existed between expected and actual results.

Figure 10 also shows a sharper rate of decline in 305-day M.E. milk production at higher somatic cell counts compared to lower somatic cell counts. This was in direct contrast to results obtained in both

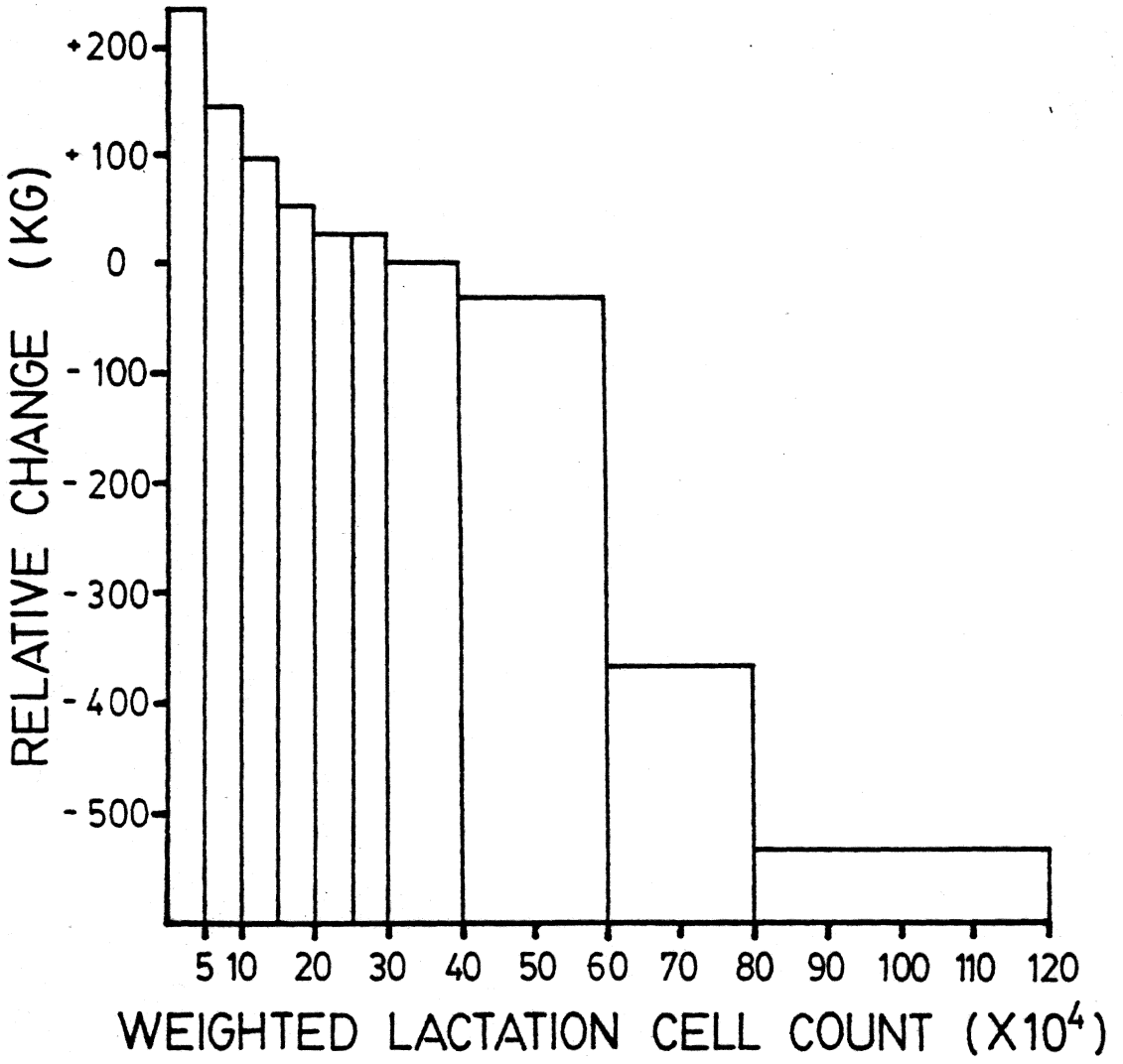

Figure 10. Relationship between 305 day M.E. milk production and lactational SCC.

Data Sets I and II, which showed much sharper rates of decline at lower somatic cell counts, leveling off as higher ranges were approached.

Discrepencies in the results of Data Set III, and those of the prior two data sets can be explained. In calculating 305-day M.E. milk production, adjustments are made for season of calving and age effects. However, the model used in Data Set III corrected for these effects also. Therefore, these effects were corrected for on both sides of the equation. This could have significantly affected the results, although any exact effect is not known. Additionally, numerous other variables besides somatic cell count enter into determining a cow's 305-day M.E. milk record. Factors such as feed changes, and weather changes during the course of a lactation are only a few. Failure to correct for these factors could have masked the true effect of lactational somatic cell count on 305-day M.E. milk production. The fact that the model did not account for much of the variation in 305-day M.E. milk production was documented by an R^2 value of only .33. This compared to R^2 values of at least .74 for all models in Data Set I and II. Disagreement of results obtained from Data Set III compared to prior data sets clearly indicates further refinement is necessary to adequately utilize models in which an entire lactation is being considered. Effects of lactational somatic cell count on 305-day M.E. milk production cannot be accurately measured until methods are devised to correct for other within-lactation variables.

SUMMARY AND CONCLUSIONS

In this study no cause and effect relationship between somatic cell count and milk production has been proven, absolutely. However, a strong indication has been demonstrated that cows with somatic cell counts below 100 X 10^3 cells per ml produce much greater milk yields. Furthermore, this study demonstrated that apparent losses of milk production occur most rapidly as somatic cell counts increase through levels well below the currently accepted normal level of 400 X 10^3 cells per ml. In previously cited literature from numerous sources authors have continually hinted that such relationships could exist at lower somatic cell counts. Unfortunately, until recently somatic cell counting techniques had not advanced to a point of allowing rapid and consistent determination of quantitative values. Only since development of electronic somatic cell counting could such relationships at lower somatic cell concentrations be determined.

Further research should support conclusions reached from this study. Refinement and improvement of models utilizing 305-day milk production records could yield results nearer those expected when daily milk losses are extended to 305 days. Cause and effect relationships could be established by incorporating fore-milk bacteriological sampling with somatic cell counts taken from composite milk samples of the same milking, or a milking within a few days of the bacteriological sampling. Comparison of fore-milk somatic cell counts to composite somatic cell

counts representing the entire milking would also be of interest.

Support of the findings in this study is likely through future research. However, practical application of the findings can be ongoing during the interim. Through DHIA, dairymen can continue receiving individual, monthly somatic cell counts for each cow. Until now research has suggested that dairymen should pay close attention to cows whose somatic cell counts exceed 400 X 10^3 cells per ml. The results of this study indicate that dairymen should start paying strict attention to cows whose somatic cell counts exceed 150 X 10^3 to 200 X 10^3 cells per ml. This is particularly true for first calf heifers. Results obtained from this study indicate that by keeping somatic cell counts below 200 X 10^3 cells per ml, dairymen can increase income through higher milk yields while providing a better product to consumers.

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APPENDIX

Appendix Table 1. Analysis of Variance for Somatic Cell Count with Herd and Cow Absorbed.

Source	df	SS	F	Probability
Season	11	29209.40	151.42	.0001
Stage	9	1130321.15	7161.76	.0001
Parity	9	71249.26	451.44	.0001
SCC	1	22172.50	1264.37	.0001
SCC^2	1	4890.89	278.90	.0001
SCC^3	1	3041.49	173.44	.0001
Error	60542	1061686.04		
Total	66694	4077947.45		
R^2		.739		

Source	Regression Coefficient	T	Probability
SCC	-0.00161	-35.56	.0001
SCC^2	9.58266×10^{-8}	16.70	.0001
SCC^3	-1.10430×10^{-12}	-13.17	.0001

Appendix Table 2. Analysis of Variance for Incremented Somatic Cell Count with Herd and Cow Absorbed.

Source	df	SS	F	Probability
Season	11	25494.82	133.98	.0001
Stage	9	1053129.54	6764.15	.0001
Parity	9	71692.09	460.47	.0001
SCC	16	47011.16	169.85	.0001
Error	60529	1047103.69		
Total	66694	4077947.45		
R^2		.743		

SCC Partition	Regression Coefficient	T	Probability
1	4.21	44.98	.0001
2	3.37	36.75	.0001
3	2.83	29.65	.0001
4	2.37	23.61	.0001
5	2.14	19.90	.0001
6	1.88	16.20	.0001
7	1.90	14.91	.0001
8	1.88	13.74	.0001
9	1.74	14.63	.0001
10	1.61	12.23	.0001
11	1.59	10.84	.0001
12	1.15	7.02	.0001
13	1.13	6.38	.0001
14	1.47	7.46	.0001
15	1.19	5.69	.0001
16	0.80	3.61	.0003
17	0.00	.	.

Appendix Table 3. Analysis of Variance for Natural Log Somatic Cell Count with Herd and Cow Absorbed.

Source	df	SS	F	Probability
Season	11	25105.84	132.56	.0001
Stage	9	1052283.08	6790.71	.0001
Parity	9	71936.91	464.23	.0001
Log SCC	1	387.89	22.53	.0001
$(\text{Log SCC})^2$	1	95.05	5.52	.0188
$(\text{Log SCC})^3$	1	153.94	8.94	.0028
Error	60542	1042393.91		
Total	66694	4077947.45		
R^2		.744		

Source	Regression Coefficient	T	Probability
Log SCC	-1.4656	-4.75	.0001
$(\text{Log SCC})^2$	0.1410	2.35	.0188
$(\text{Log SCC})^3$	-0.0112	-2.99	.0028

Appendix Table 4. Analysis of Variance for Arithmetic Mean SCC with Herd and Cow Absorbed.

Source	df	SS	F	Probability
Stage	9	698435.94	4844.54	.0001
Parity	9	41307.60	286.52	.0001
Season	11	21033.19	119.37	.0001
Mean SCC	1	11645.33	726.98	.0001
$(\text{Mean SCC})^2$	1	2625.34	163.89	.0001
$(\text{Mean SCC})^3$	1	1691.04	105.57	.0001
Error	38464	616149.53		
Total	43096	2624192.46		
R^2		.765		

Source	Regression Coefficient	T	Probability
Mean SCC	-0.003136	-26.96	.0001
$(\text{Mean SCC})^2$	3.743958×10^{-7}	12.80	.0001
$(\text{Mean SCC})^3$	$-1.411471 \times 10^{-11}$	-10.27	.0001

Appendix Table 5. Analysis of Variance for Geometric Mean SCC with Herd and Cow Absorbed.

Source	df	SS	F	Probability
Stage	9	714818.23	4937.62	.0001
Parity	9	40614.76	280.55	.0001
Season	11	21000.08	118.68	.0001
G. Mean SCC	1	11575.47	719.62	.0001
(G. Mean SCC)^2	1	3945.29	245.27	.0001
(G. Mean SCC)^3	1	2710.98	168.54	.0001
Error	38464	618713.85		
Total	43096	2624192.46		
R^2		.764		

Source	Regression Coefficient	T	Probability
G. Mean SCC	-0.003785	-26.83	.0001
(G. Mean SCC)^2	5.179920×10^{-7}	15.66	.0001
(G. Mean SCC)^3	$-1.966231 \times 10^{-11}$	-12.98	.0001

Appendix Table 6. Analysis of Variance for Incremented Arithmetic Mean SCC with Herd and Cow Absorbed.

Source	df	SS	F	Probability
Stage	9	631207.40	4428.11	.0001
Parity	9	38085.95	267.18	.0001
Season	11	20120.42	115.49	.0001
Mean SCC	16	25491.01	100.59	.0001
Error	38451	609002.35		
Total	43096	2624192.46		
R^2		.768		

Mean SCC Partition	Regression Coefficient	T	Probability
1	5.54024	35.47	.0001
2	4.27122	28.45	.0001
3	3.39908	22.18	.0001
4	3.01073	19.14	.0001
5	2.87325	17.46	.0001
6	2.34284	13.74	.0001
7	2.64606	14.69	.0001
8	2.79388	14.81	.0001
9	2.53446	14.78	.0001
10	2.11018	11.85	.0001
11	2.06074	10.83	.0001
12	1.84200	9.31	.0001
13	2.01193	9.30	.0001
14	1.65649	7.06	.0001
15	1.13648	4.64	.0001
16	0.94377	3.68	.0002
17	0.00000	.	.

Appendix Table 7. Analysis of Variance for Incremented Geometric Mean SCC with Herd and Cow Absorbed.

Source	df	SS	F	Probability
Stage	9	675786.11	4750.83	.0001
Season	11	20102.89	115.63	.0001
Parity	9	37793.98	265.69	.0001
G. Mean SCC	16	26771.88	105.87	.0001
Error	38451	607721.47		
Total	43096	2624192.46		
R^2		.768		

G. Mean SCC Partition	Regression Coefficient	T	Probability
1	6.14074	32.38	.0001
2	4.70046	25.37	.0001
3	3.65269	19.49	.0001
4	3.33018	17.38	.0001
5	3.13313	15.82	.0001
6	2.86302	14.00	.0001
7	2.82684	13.36	.0001
8	2.63493	11.82	.0001
9	2.38124	11.55	.0001
10	2.15185	9.97	.0001
11	2.45339	10.61	.0001
12	1.93831	7.73	.0001
13	1.86171	6.90	.0001
14	1.48202	4.97	.0001
15	1.56317	4.84	.0001
16	0.73799	2.24	.0249
17	0.00000	.	.

Appendix Table 8. Analysis of Variance for Natural Log of Geometric Mean SCC with Herd and Cow Absorbed.

Source	df	SS	F	Probability
Stage	9	654343.32	4627.84	.0001
Parity	9	38082.41	269.34	.0001
Season	11	19560.59	113.19	.0001
Log G. Mean SCC	1	1341.80	85.41	.0001
(Log G. Mean SCC)^2	1	722.04	45.96	.0001
(Log G. Mean SCC)^3	1	612.97	39.02	.0001
Error	38464	604281.11		
Total	43096	2624192.46		
R^2		.770		

Source	Regression Coefficient	T	Probability
Log G Mean SCC	-6.97815	-9.24	.0001
(Log G Mean SCC)^2	0.98815	6.78	.0001
(Log G Mean SCC)^3	-0.05678	-6.25	.0001

Appendix Table 9. Analysis of Variance for Lactational Somatic Cell Count with Herd Absorbed.

Source	df	SS	F	Probability
Calving date	11	301,375,090.15	2.53	.0037
Parity	9	384,571,636.42	3.94	.0001
SCC	10	437,713,107.94	4.04	.0001
Error	2128	23,076,798,384.39		
Total	2192	34,559,433,001.57		
R^2		.332		

SCC Class	Regression Coefficient	T	Probability
1	1929.505	4.65	.0001
2	1726.142	4.52	.0001
3	1628.412	4.13	.0001
4	1526.693	3.72	.0002
5	1460.206	3.29	.0010
6	1464.816	3.15	.0017
7	1414.322	3.15	.0017
8	1343.963	3.12	.0018
9	608.749	1.30	NS
10	234.828	0.47	NS
11	0.000	.	.

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RELATIONSHIPS BETWEEN SOMATIC CELL COUNTS AND MILK PRODUCTION IN DAIRY CATTLE

by

Gregory Arthur Clabaugh

(ABSTRACT)

Monthly milk production data collected by DHI supervisors in 28 Virginia dairy herds over a three year period were analyzed. Relationships between somatic cell count and milk production were determined.

A curvilinear relationship between somatic cell count and daily milk yield was shown to exist. The relationship indicated daily milk yield declined more rapidly as somatic cell counts increased from 50×10^3 through 300×10^3 cells per ml compared to daily milk decline as somatic cell counts rose from 400×10^3 through $1{,}200 \times 10^3$ cells per ml. Daily milk yield declined at a slower rate at somatic cell levels above 400×10^3 cells per ml.

There was an apparent cumulative or continual relationship between somatic cell count and daily milk yield. Losses and declines in test day milk production were greater when cumulative somatic cell count was considered.

Complete lactation records of 305-day, mature equivalent milk production were compared to weighted, lactational somatic cell counts. Lactational milk production losses were not as great as daily milk production losses, extended to full lactation, indicated. Design

difficulties and inadequacies of models used in complete lactation evaluation may explain the discrepancies.

A maximum somatic cell count of 150 X 10^3 to 200 X 10^3 cells per ml was indicated as an optimum level for somatic cell count. Above this level milk losses were excessive.

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