# The Relationship of Milk Somatic Cell Count to Milk Yields for Holstein Heifers After First Calving

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## ABSTRACT

The contribution of a dilution effect to the relationship between milk yield and milk SCC was investigated using data from 24 Holsteins during the first 75 d after first calving. Bucket and quarter milk SCC were collected at weekly intervals. Individual milk weights were obtained at milking, and samples were obtained for determination of SCC. The milk weights at the corresponding a.m. milking on the following day were also obtained. A dilution effect was assumed to cause the regression of milk yield on milk SCC to diminish when adjustment was made for milk yield on the day following sampling for SCC. Regressions of milk yield on various functions of SCC decreased by about one-half when adjustment was made for the next day's milk yield, but the regressions remained significant. The observed negative relationship between milk yield and SCC may partly reflect both the true biological effects of udder inflammation and a dilution effect. The carry-over effect of SCC on milk yields measured 1 wk after cell counting was investigated, but no effect was significant.
(**Key words**: somatic cell counts, epithelial cells, mastitis)

## INTRODUCTION

The negative phenotypic correlation between milk yield and milk SCC per unit milk volume is well established (4, 5, 11, 17, 18). This relationship exists for lactation yields (4, 5, 7, 17) and for daily yields (11). The yield to SCC relationship is nonlinear on the scale of actual SCC; the milk decline accompanying increased SCC is greater at low than at high SCC (11, 20). Ali and Shook (1) and Raubertas and Shook (17) proposed expressing SCC on a log scale to linearize the relationship with milk yield, thus providing a simpler way to demonstrate and to communicate the milk loss that occurs when SCC increases. Dentine and McDaniel (5) showed that the relationship for total lactation is not completely linear even on a log scale; they reported that the rate of decline in lactation milk yield was greater for geometric mean SCC above 837,000 cells/ml than for lower SCC. Emanuelson and Persson (7) found a significant quadratic regression of lactation milk yield on log SCC.

Most authors have ascribed the milk yield to SCC relationship to the presence of mastitis infections. Bartlett et al. (2) reported that reduced milk yield persisted for as long as 60 d after a clinical mastitis infection. However, the existence of a negative relationship between milk yield and SCC at very low SCC has been puzzling, because the presence of low concentrations of leukocytes, predominately macrophages, in milk from uninfected cows has been considered to be "normal". Dentine et al. (5) reported that milk yield declined for SCC (geometric mean) exceeding 43,000 cells/ml.

Other authors (6, 7, 9, 17) have attributed this relationship, or a portion of it, to a "dilution effect". According to this hypothesis, the total number of somatic cells secreted into the milk is normally rather stable in the absence of udder infection. Honkanen-Buzalski et al. (9) indicated that the total daily output of somatic cells into milk reaches a plateau after about 1 mo of lactation. Consequently, the increase in SCC in later stages of lactation is hypothesized to be partially due to the naturally occurring decline in milk yield. Raubertas and Shook (17) reasoned that a dilution effect would cause the regression of milk yield on SCC to overestimate milk loss. They examined this

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effect by including a regression of current lactation milk yield on the cow's previous lactation milk yield in addition to regression of current milk yield on SCC. They reported that adjustment for yield in a previous lactation had little effect on the regression of current milk yield on SCC, suggesting that dilution effect was not large.

Emanuelson and Funke (6) studied relationships among herd averages of bulk milk SCC, milk yield, and prevalence of clinical mastitis (as predicted by individual cow SCC). They concluded that about one-half of the decreases observed in national herd average SCC were an artifact of increased milk yield and that the other half were due to reduction in frequency of mastitis.

Giesecke (8) stated that the action of mechanical milking itself causes low levels of cell migration from blood into the alveolar spaces and that this process damages alveolar cells. This hypothesis was supported by Paape et al. (15), who reported that concentrations of leukocytes in lymph in the mammary lymphatic duct increased at 5 min after milking compared with those at premilking. Also, Paape and Guidry (14) found that blood leukocyte counts in the subcutaneous abdominal vein decreased significantly after milking. Results of Capuco et al. (3) supported the hypothesis that milking negatively affects the mammary tissue; when neutrophils were added to mammary tissue in vitro, morphological damage to the tissue was detected. Additionally, Giesecke (8) suggested that neutrophils phagocytize opsonized milk fat globules in the alveolar ducts and subsequently release inflammatory agents from lysosomes, which damage mammary tissues.

Our primary purpose was to determine whether the dilution effect is responsible for part of the relationship between milk yield and SCC. We hypothesized that the dilution effect would cause the regression of milk yield on SCC to decrease significantly if an adjustment were made for the cow's general milk yield.

A secondary objective was to determine whether milk yield was related to the SCC obtained 1 wk previously, that is, whether a carry-over effect existed.

## MATERIALS AND METHODS

Twenty-four Holstein heifers were sampled 1 d postcalving and weekly for first 75 d of lactation. The design of this study was described previously (12).

### Samples for Total Milk SCC

Foremilk (200 ml) samples were drawn weekly, beginning at d 7, from each quarter after milk letdown (all samples were taken at the a.m. milking). A composite sample was taken from the weigh jar at the end of milking and after agitation ("bucket milk"), and milk yield was recorded. For each sample date, the following day's a.m. milk weight was also recorded.

All samples were analyzed for SCC within 24 h; samples were refrigerated overnight, and no preservatives were added. For the first 16 cows, SCC were performed by a Coulter electronic cell counter (Coulter Electronics, Inc., Hialeah, FL). However, in the third trial, SCC were determined exclusively by a Fossomatic cell counter (model 215; A/S N. Foss Electric, Hillerød, Denmark). The Coulter and Fossomatic cell counters were checked at the beginning of the study and biweekly using reference milk samples of Heald (C. W. Heald, 1985, somatic cell count samples, Department of Animal Science, The Pennsylvania State University). Milk samples were split into two aliquots, and each was counted.

### Statistical Analysis

The SCC were converted to natural logarithms. Regression equations were calculated 1) to relate bucket milk weights to SCC from the same day's a.m. milking, adjusted for general level of milk yield (as reflected by partial regression on the following day's a.m. milk yield), and 2) to relate SCC measured at 1 wk to milk yield recorded at the a.m. milking 1 wk later to estimate the carry-over effect. The following regression equations were fitted using the general linear models procedure of SAS [(19); SAS PROC GLM].

$$Y_{ij} = \mu + c_i + (b_1X_{1ij}) + b_2X_{2ij} + e_{ij}$$

where

$Y_{ij}$ = a.m. milk yield for cow i on the day j,

$\mu$ = overall mean,

$c_i$ = effect of cow i,
$X_{1ij}$ = SCC from milk of cow i on sample day j,
$b_1$ = regression of milk yield on sample day j on an SCC obtained from milk on the same sample day,
$X_{2ij}$ = a.m. milk yield for cow i on the day following sample day j,
$b_2$ = regression of a.m. milk yield at sample day j on a.m. milk yield on the day following sample day j, and
$e_{ij}$ = random residual.

(Note: the term $b_1X_{1ij}$ represents a series of alternatives, from single SCC to as many as four SCC in different analyses.)
For regressions on SCC, seven alternatives were included: 1) bucket milk SCC, 2) quarter average milk SCC, 3) bucket milk SCC and quarter average milk SCC, 4) bucket milk SCC and each of four quarter milk SCC, 5) all four quarter milk SCC, 6) bucket milk SCC and quarter milk SCC with highest correlation with milk yield, and 7) single quarter milk SCC with highest correlation with milk yield.

## RESULTS AND DISCUSSION

Table 1 contains number of samples and means for milk yields and the various milk SCC (natural log scale). Mean log SCC were very low (11.79 to 12.03), as expected for heifers in early first lactation. As reported previously (12), frequency of coagulase-negative staphylococci was high at calving, but only 2 cows had clinical mastitis during the study.

TABLE 1. Means for milk yields and natural log of milk SCC from 233 samples.

| SCC or Measure[1] | $\overline{X}$[2] | SD[3] |
|---|---|---|
| SCC | | |
| Bucket | 12.03 | .39 |
| Quarter avg | 11.93 | .36 |
| LF | 11.83 | .39 |
| LR | 12.00 | .45 |
| RF | 11.79 | .48 |
| RR | 11.88 | .35 |
| Milk 1, kg | 11.2 | 1.25 |
| Milk 2, kg | 12.2 | 1.56 |

[1]avg = Average; quarters: LF = left front, LR = left rear, RF = right front, and RR = right rear. Milk 1 is a.m. milk yield concurrent with SCC, and milk 2 is a.m. milk yield on day following SCC.

[2]Mean SCC are in natural log units.

[3]Square root of variance within-cow.

### Regressions of Milk Yield on SCC on Same Test Day

Table 2 contains results for the first analysis, which included an effect for cow, regression of bucket milk yield on one or more functions of SCC obtained at the same milking, plus a regression on the cow's a.m. bucket milk weight from the following day. Also given in the right side of Table 2 are regression coefficients obtained for the same model but excluding the regression on the following day's milk yield.

Regression coefficients for SCC in Table 2 were derived from seven different analyses. Three analyses contained only a single SCC regression coefficient in addition to the cow

TABLE 2. Within-cow regressions of milk yield on functions of SCC, adjusted and unadjusted for following day's milk yield.[1,2]

| SCC | Adjusted | | Unadjusted | |
|---|---|---|---|---|
| Measure | Regression | SE | Regression | SE |
| Bucket milk | –1.51** | .55 | –3.17** | .61 |
| Quarter avg | –1.85** | .58 | –3.52** | .64 |
| Bucket milk | –.38 | .88 | –1.45 | 1.03 |
| Quarter avg | –1.53 | .95 | –2.26* | 1.10 |
| Bucket milk | .02 | .67 | –.86 | .93 |
| LF | .76 | .76 | .08 | .89 |
| LR | –1.22 | .65 | –.82 | .75 |
| RF | –.04 | .50 | .33 | .54 |
| RR | –1.90* | .83 | –3.26** | .93 |
| LF | .76 | .76 | .01 | 1.00 |
| LR | –1.21* | .57 | –1.16 | .66 |
| RF | –.03 | .43 | .24 | .53 |
| RR | –1.89* | .77 | –3.60** | .85 |
| Bucket milk | –.70 | .67 | –1.37 | .76 |
| RR | –1.59* | .76 | –3.13** | .84 |
| RR | –2.05* | .89 | –4.09** | .65 |

[1]avg = Average; quarters: LF = left front, LR = left rear, RF = right front, and RR = right rear.

[2]Units of measure of regression coefficients and standard errors: kilograms of milk/natural log of SCC.

*$P < .05$.

**$P < .01$.

effect (alternatively, bucket milk SCC, quarter milk average SCC, and SCC for right rear quarter).

Of the 16 regression coefficients in each section of Table 2, 7 were significant ($P < .05$) for those coefficients both without or with adjustment for milk yield. However, the regression coefficients and $t$ values were generally smaller for the equations in which adjustment was made for the next day's milk yield.

For those equations in which more than one regression on SCC was included, the two corresponding partial coefficients (one adjusted for milk yield and one not) are difficult to compare. Comparisons are more direct for the three equations containing only one regression on SCC (bucket milk, quarter average, or right rear quarter). Adjustment for the next day's yield reduced these regressions to 48, 53, and 50%, respectively, of the corresponding value without adjustment for the next day's yield. For the three equations including regression on right rear quarter SCC in addition to one or more other regressions, the coefficient for the right rear quarter was reduced 58, 53, and 51% compared with the corresponding coefficients for which no adjustment for the next day's yield was made.

The right rear quarter SCC had the largest effect on milk yield, as indicated by the regression on milk yield. For this reason, right rear quarter SCC were included in two additional models compared with other quarters (right rear quarter alone and right rear quarter plus bucket milk SCC). Rear quarters contribute more than front quarters to total milk yield. Additionally, in this herd, rear quarters were infected more frequently than front quarters (12). (In one of the models listed in Table 2, the partial regression of milk on quarter foremilk SCC of left rear was significant.)

Results in Table 2 indicate that quarter foremilk SCC were slightly more useful in prediction of milk yield than were the bucket SCC. The SCC of foremilk were slightly lower than the bucket milk SCC (Table 1). Others (13, 16) have reported that, during milking, SCC declines from foremilk to main milk, but SCC rises in milk collected near completion of milking. Information on SCC from each of the four quarters would likely be somewhat more informative than that on SCC from a sample of pooled milk.

The three regression coefficients from models with only one regression term in the unadjusted column of Table 2 ranged from $-5.23$ to $-6.27$ kg/$\log_e$ SCC. Our milk yield measure was milk weight from a single a.m. milking in the first 75 d. Results of other studies employed varying milk yield measures and varying SCC functions; thus, comparisons are difficult. Jones et al. (10) reported regressions ranging from $-.39$ to $-.52$ in first lactation, but SCC was in $\log_2$ units, and milk yield was test day for all stages of lactation. Emanuelson and Persson (7) found a quadratic regression relationship, and, thus, their linear coefficients are not comparable. Raubertas and Shook (17) reported a regression of $-135$ kg/$\log_e$, but yield was for an entire lactation.

The results in Table 2 suggest that, although a dilution effect may exist, a significant, reproducible, and rather consistent relationship also occurs between milk yield and SCC observed at a single milking. Taken alone, the results suggest that perhaps one-half of the milk and SCC relationship is due to general level of milk yield (and therefore possibly due to a dilution effect). This relationship may be an overestimate if adjustment for the next day's milk yield removed too much variation, which is likely because of the autocorrelation between SCC and subsequent a.m. milk weight. However, the results indicate that at least one-half of the observed relationship is due to genuine dynamics of somatic cell infiltration into the alveolar spaces and therefore into the milk. The magnitude of dilution effect in our results is greater than that reported by Raubertas and Shook (17).

#### Carry-Over Effect of SCC on Milk Yield

Bartlett et al. (2) reported that the impact of clinical mastitis infections on milk yield could be detected up to 60 d after onset of infection. In Table 3 are results of the second analysis, in which SCC was used in equations to predict milk yield at the corresponding a.m. milking 1 wk after SCC were obtained. Six different models, varying in the SCC terms included, were fitted, both with and without adjustment for general milk yield of the cow.

When adjustment for milk yield was included, only one regression of milk yield on

TABLE 3. Carry-over effects determined by within-cow regression of milk yield SCC measured 1 wk earlier, both adjusted and unadjusted for concurrent milk yield.[1,2]

| SCC Measure | Adjusted | | Unadjusted | |
|---|---|---|---|---|
| | Regression | SE | Regression | SE |
| Bucket milk | –.38 | .23 | –.66* | .26 |
| Quarter avg | –.22 | .25 | –.42 | .28 |
| Bucket milk | –.60 | .38 | –.98* | .44 |
| Quarter avg | .30 | .41 | .93 | 1.01 |
| LF | .29 | .33 | .12 | .38 |
| LR | –.10 | .26 | .01 | .33 |
| RF | .16 | .20 | .20 | .23 |
| RR | –.71* | .33 | –.93* | .38 |
| Bucket milk | –.18 | .29 | –.41 | .34 |
| RR | –.34 | .33 | –.43 | .38 |
| RR | –.47 | .25 | –.72* | .29 |

[1]avg = Average; quarters: LF = left front, LR = left rear, RF = right front, and RR = right rear.

[2]Units of measure of regression coefficients and standard errors: kilograms of milk/natural log of SCC.

*$P < .05$.

**$P < .01$.

SCC was significant: the partial regression on right rear quarter foremilk SCC in the model that contained foremilk SCC of each of the four quarters ($P < .05$). In addition, three other regression coefficients approached significance. When adjustment for milk yield was omitted, four partial regressions were significant ($P < .05$), each in a different one of the six models.

Table 3 does not provide much evidence for a carry-over effect of SCC on milk yield from a given week to the next. However, only 24 cows provided data. If the carry-over effect is comparatively small, much larger numbers of cows may be required to detect it. The DHI monthly data for milk and SCC should be used to study this question, even though a carry-over effect between test days will be even smaller than between weeks. With large numbers, detection of a small residual effect on milk yield may be possible.

## CONCLUSIONS

The contribution of a dilution effect to the negative relationship of SCC and milk yield was investigated. We hypothesized that a dilution effect would cause the regression of milk yield on SCC to diminish if adjustment was made for the cow's general milk yield (represented by milk yield on the following day). Regressions of milk yield on various functions of SCC decreased by about one-half when adjustment was made for the next day's milk yield but remained significant, suggesting that the observed negative relationship between milk yield and SCC reflects both true biological effects and artificial aspects that were merely due to changes in milk yield alone rather than to changes in leukocyte infiltration into the mammary gland. Carry-over effect of SCC on a cow's milk yield 1 wk later was investigated. Carry-over effects appeared to be present, but data were too few to be conclusive.

## REFERENCES

1 Ali, A.K.A., and G. E. Shook. 1980. An optimum transformation for somatic cell concentration in milk. J. Dairy Sci. 63:487.

2 Bartlett, P. C., J. Van Wijk, D. J. Wilson, C. D. Green, G. Y. Miller, G. A. Majewski, and L. E. Heider. 1991. Temporal patterns of lost milk production following clinical mastitis in a large Michigan Holstein herd. J. Dairy Sci. 74:1561.

3 Capuco, A. V., M. J. Paape, and S. C. Nickerson. 1986. In vitro study of polymorphonuclear leukocyte damage to mammary tissues of lactating cows. Am. J. Vet. Res. 47:663.

4 Coffey, E. M., W. E. Vinson, and R. E. Pearson. 1986.

Somatic cell counts and infection rates for cows of varying somatic cell count in initial test of first lactation. J. Dairy Sci. 69:552.

5 Dentine, M. and B. T. McDaniel. 1983. Evidence for nonlinearity in the relationship between milk and fat yields and the logarithm of the geometric mean of somatic cell counts. J. Dairy Sci. 66(Suppl. 1): 112.(Abstr.)

6 Emanuelson, U., and H. Funke. 1991. Effect of milk yield on relationship between bulk milk somatic cell count and prevalence of mastitis. J. Dairy Sci. 74: 2479.

7 Emanuelson, U., and E. Persson. 1984. Studies on somatic cell counts in milk from Swedish dairy cows. I. Non-genetic causes of variation in monthly test-day results. Acta Agric. Scand. 34:33.

8 Giesecke, W. H. 1979. Somatic cells in milk and mastitis in cows. S. Afr. J. Sci. 75:158.

9 Honkanen-Buzalski, T., R. Kangasniemi, F. Atroshi, and M. Sandholm. 1981. Effect of lactation stage and number on milk albumin (BSA) and somatic cell count. Zentralbl. Veterinaermed. Reihe A 28:760.

10 Jones, G. M., R. E. Pearson, G. A. Clabaugh, and C. W. Heald. 1984. Relationships between somatic cell counts and milk production. J. Dairy Sci. 67:1823.

11 Miller, R. H., U. Emanuelson, E. Persson, L. Brolund, J. Philipsson, and H. Funke. 1983. Relationships of milk somatic cell counts to daily milk yield and composition. Acta Agric. Scand. 33:209.

12 Miller, R. H., M. J. Paape, and L. A. Fulton. 1991. Variation in milk somatic cells of heifers at first calving. J. Dairy Sci. 74:3782.

13 Ostensson, K., M. Hageltorn, and G. Astrom. 1988. Differential cell counting in fraction-collected milk from dairy cows. Acta Vet. Scand. 29:493.

14 Paape, M. J., and A. J. Guidry. 1968. Effect of milking on leukocytes in the subcutaneous abdominal vein of the cow. J. Dairy Sci. 52:998.

15 Paape, M. J., W. D. Schultze, and G. Astrom. 1985. Trafficking of leukocytes in the lactating bovine mammary gland. Page 622 *in* Proc. Ind. Dairy Fed. Semin. Progress in the Control of Bovine Mastitis, May 21–24, 1985. Int. Dairy Fed., Brussels, Belgium.

16 Paape, M. J., and H. A. Tucker. 1966. Somatic cell content variation in fraction-collected milk. J. Dairy Sci. 49:265.

17 Raubertas, R. F., and G. E. Shook. 1982. Relationship between lactation measures of somatic cell concentration and milk yield. J. Dairy Sci. 65:419.

18 Salsberg, E., A. H. Meek, and S. W. Martin. 1984. Somatic cell counts: associated factors and relationship to production. Can. J. Comp. Med. 48:251.

19 SAS Institute, Inc. 1987. Page 549 *in* SAS/STAT™ Guide for Personal Computers. SAS Inst., Cary, NC.

20 Ward, G. E., and L. H. Schultz. 1972. Relationship of cells in quarter milk to type of bacteria and production. J. Dairy Sci. 55:1428.