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Somatic Cell Score as Predictor of Daily Milk Yield in Holsteins

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معدلات الخلايا الجسدية كعامل تنبؤ لمعدل إنتاج الحليب اليومي في أبقار الهولستين

الملخص : تهدف هذه الدراسة إلى تفسير التباين أثناء إنتاجية الحليب في المراحل الأخيرة لدورة الحلب بناء على معدلات الخلايا الجسدية في المراحل الأولي ، وكذلك إمكانية تحسين درجة التنبؤ بالإنتاج المستقبلي خلال دورة الحلب بتضمين معدل الخلايا الجسدية مع معدلات التنبؤ الأخرى . لقد استخدمت ثلاث مجموعات من البيانات (أكثر من ستمائة ألف لكل مجموعة) هي : إنتاج الحليب خلال فترات ٢٠ و ٢٥ و ١٤٠ يوما . ثم استخدمت ثلاث مجموعات في نظام التحليل الأحصائي المسمي بالانحدار ذي الخطوات ، بدرجة أهمية تعادل أقل من ٠,٠١ لأي معدل خلايا جسدية تبقى في النموذج . تم أجراء تحاليل منفصلة لعدد اثنتي عشرة مجموعة خلال أربعة مواسم ، وأول ثلاث فترات متكافئة لكل مجموعة من البيانات . وقد وجد أن انتخاب معدلات الخلايا الجسدية لم يكن منتظما خلال المواسم أو الفترات المتكافئة حيث تراوحت معامل الارتباط (R^2) بين ٥٤ و ٧٤% مع تسجيل التقييم الأعلى للأيام ذات الإدرار الأعلى وفترات الحلب المبكرة . وقد أدى إدخال معدلات الخلايا الجسدية ضمن معاملات التنبؤ إلى تحسين معامل الارتباط (R^2) بأقل من ١% . وكان معدل الخلايا الجسدية مرتبطا بإنتاج الحليب ليوم أخذ العينات لكن ليس بدرجة قوية تكفي للتنبؤ بالإنتاج المستقبلي إذا أخذت عوامل إنتاج الحليب الأخرى في الاعتبار .

ABSTRACT : The purpose of our study was to determine if variation in milk yield at later stages of lactation can be explained by expressions of early lactation somatic cell score (SCS) and if the prediction of future yield within lactation can be improved by including SCS among the predictors. Three data sets (n >600,000 each) were: milk yield with sample days near 20, 50 and 140. Stepwise regression was used requiring F statistic ($P < .01$) for any SCS variable to stay in the model. Separate analyses were run for 12 combinations of four seasons and first three parities for each data set. Selection of SCS variables was not consistent across seasons or parities. Coefficients of determination (R^2) ranged from 54 to 74% with higher values for higher days in milk (DIM) and earlier lactations. The inclusion of SCS expressions in the prediction equations improved R^2 by <1%. SCS was associated with milk yield on sample day, but the association was not strong enough to improve the prediction of future yield when other expressions of milk yield were taken into account.

Relationship between somatic cell count (SCC) and milk production has been well documented (Kennedy *et al.*, 1982; Raubertas and Shook, 1982; Miller *et al.*, 1983; Jones *et al.*, 1984; Emanuelson and Funke, 1991; Sender *et al.*, 1992; Miller *et al.*, 1993; Nielsen *et al.*, 1993). The observed negative relationship between milk yield and SCC reflects both the true biological effects of udder inflammation and a dilution effect (Honkanen-Buzalski *et al.*, 1981; Emanuelson and Persson, 1984; Wiggans and Shook, 1987; Emanuelson and Funke, 1991; Miller *et al.*, 1993). According to Emanuelson and Funke (1991), about half of the decrease in average bulk milk SCC over the years could be attributed to the increase in yield milk. Miller *et al.* (1993) reported that regressions of milk yield on various functions of SCC decreased by about one-half, but remained significant, when adjustment was made for the next day's milk yield.

Association between SCC and test-day milk yield has been reported to exist (Eberhart *et al.*, 1982; Jones *et al.*, 1984; Batra, 1986; Bartlett *et al.*, 1990; Sender *et al.*, 1992; Miller *et al.*, 1993; Nielen *et al.*, 1993; Miller *et al.*, 1996). Eberhart *et al.* (1982) reported that bulk tank SCC accounted for 26% of the variation in average daily milk yield of the cows. Jones *et al.* (1984) used different models to predict daily milk yield from test day SCC. Predicted milk yield decreased at a decreasing rate as SCC increased. For each doubling of SCS, milk production was reported to be reduced by 0.36 and 0.72 kg per day in first lactation and older cows. SCC was an important source of variation in test day milk yield in the study of Batra (1986). Average daily milk yield loss was 0.5 kg and 0.7 kg for the first

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and later-lactation cows, when SCC increased from 200 to 400 cells per microliter. Bartlett *et al.* (1990), using Michigan DHIA data from 504 Holstein herds, analyzed the test day milk production. The statistical model used to predict milk production included the effect of herd, cows within herd, stage of lactation, month of calving, lactation, and SCC. The final model predicted that the average herd lost a mean of 1.17 kg of milk per cow per day associated with SCC. Cell counts were negatively correlated with milk yield and accounted for 17% and 23% of the variation in milk yield in the studies of Nielen *et al.* (1993) and Sender *et al.* (1992). Although, most of these studies explain the relationship of somatic cells with milk yield, potential usefulness of SCC for improving accuracy of yield projections has not been explored.

Incomplete lactation records are normally extended to a 305-day basis for herd management as well as genetic evaluations of cows and bulls. Yields are usually recorded monthly and 305-day lactation yield is calculated by linear interpolation between monthly weights. Various methods of extending partial records have been used in the past. Miller *et al.* (1972) compared four such methods i.e. ratio factors, multiple regression, modified regression, and regression of yield in the remainder of the lactation on last test yield. They concluded that records could be more accurately extended if the production on the last sample day rather than the cumulative yield was used to predict the unknown remaining yield. Wiggans and Van Vleck (1979), and Wiggans (1980) confirmed that the yield on the last test day is the best single predictor of the remaining yield. Herd average milk yield was reported to improve prediction of future yield during early stages of lactation in both studies.

The current method used by the United States Department of Agriculture (USDA) for projecting 305-day milk yield from partial performance involved regressing average daily yield in the later stages of lactation on measures of yield in early lactation (Wiggans and Dickinson, 1985). Predictors included days in milk (DIM) for the partial record, herd average milk yield (mature equivalent), and last test yield (BASE variables). The purpose of this study was to examine whether variation in yield at later stages can be explained by early lactation SCS and if prediction of future yield within parity can be improved by including SCS variables among predictors.

Materials and Methods

Lactation records, including test-day records of milk yield and somatic cell count (SCC) of Holstein cows calving between 1988 and 1992 were used. Data were from herds that participated in the Wisconsin Dairy Herd Improvement (DHI) program. Lactations were required to be at least 275 days in length and have at least nine sample days, of which at least one was after 250 days in milk (DIM). Cows were required to be on an official test plan and have sire identification. Only records from first, second and third parities were kept. Age of calving within lactation was limited to 18 to 36, 30 to 54 and 42 to 72 months for the three parities.

TABLE 1

Description and limits of milk yield (kg) variables

Variable	Limits	Description
M305	2270-15000	305 day milk yield
M20	7-68	Milk yield of sample near day 20
M50	9-68	Milk yield of sample near day 50
M140	9-68	Milk yield of sample near day 140

Three data sets with samples near days 20,50 and 140 (DM20, DM50 and DM140) were created. Sample DIM were restricted between 7 to 35, 36 to 65 and 126 to 155 to cover days 20, 50 and 140. Lactations with less than 305 days in length but more than 275 days were extended to 305 days both for milk and protein yields (Wiggans, 1985). Yields for partial records were obtained from test interval yields as described by Wiggans (1985). Description of production variables and limitations imposed on them are on Table 1. Somatic cell scores (SCS) were obtained by transforming test-day somatic cell counts to the $\log_2$ scale (Ali and Shook, 1980). Herd average 305-day ME milk yields, and herd average SCS were calculated within years. Four seasons were defined as winter (December-February), spring (March-May), summer (June-August) and fall (September-November).

The model used by USDA for projecting milk yield records of less than 305 days to 305 days was employed. The procedure is based on the number of days the cow actually milked, plus an estimate for the remainder of the 305-day lactation computed from the last available sample-day yield (Wiggans and Dickinson, 1985). It can be represented as :

$$\hat{Y}_{305} = Y_{DIM} + (\hat{Y}_D)(305 - DIM)$$

where $\hat{Y}_{305}$ is the projected 305-day yield, Y_{DIM} is the observed yield for the partial record, $\hat{Y}_D$ is the estimated daily yield for the remainder of the lactation, and DIM is days in milk for the partial record. Estimated average daily yield for lactations with less than 155 days in length is then calculated :

TABLE 2

Somatic cell score (SCS) variables included as predictors of future average daily yield

Variable	Description
S20	SCS of sample near day 20
SA20	Herd average SCS of sample near day 20
S50	SCS of sample near day 50
SB50	SCS on sample day previous to sample near day 50
SU50	Average SCS of samples up to (including) sample near day 50
SA50	Herd average SCS of sample near day 50
S140	SCS sample near day 140
S1B140	SCS of sample one previous to sample near day 140
S2B140	SCS of sample 2nd previous to sample near day 140
S3B140	SCS of sample 3rd previous to sample near day 140
S4B140	SCS of sample 4th previous to sample near day 140
S5B140	SCS of sample 5th previous to sample near day 140
SA140	Herd average SCS of sample near day 140
SX140	Maximum SCS of sample on or before sample near day 140

$$\hat{Y}_D=[\hat{\alpha}_s+\hat{\beta}_s(\mathrm{DIM})]+[\hat{\alpha}_h+\hat{\beta}_h(\mathrm{DIM})](\mathrm{HA})$$

where $\hat{\alpha}_s$ and $\hat{\beta}_s$ are the intercept and slope constants for the sample day yield (Y_s) and $\hat{\alpha}_h$ and $\hat{\beta}_h$ are the intercept and slope constants for the herd average milk yield (HA) divided by 1000. The estimated average daily yield can be computed as :

$$(\hat{Y}_{305}-Y_{\mathrm{DIM}})/(305-\mathrm{DIN})=[\hat{\alpha}_s+\hat{\beta}_s(\mathrm{DIM})](Y_s)$$
$$+[\hat{\alpha}_h+\hat{\beta}_h(\mathrm{DIM})](\mathrm{HA})$$

Predictors of daily milk yield are sample day yield with an adjustment for DIM, and herd average milk yield with an adjustment for DIM (BASE variables). For DIM >155, HA is replaced by the constant, 1, in estimating average daily milk yield.

The SCS variables considered as additional predictors are on Table 2. Products for these variables with DIM and HA were also included. For example, to estimate the future average daily milk yield, samples near day 20, S20 and SA20 and their products with HA and DIM were included with the BASE variables. The regression equation thus was :

TABLE 3

Number of observations used in the analyses for milk yield with sample days near 20, 50 and 140 (DM20, DM50, DM140) by parity and calving season

Parity	Season	DM20	DM50	DM140
1	Winter	58,909	55,601	58,545
	Spring	69,721	70,382	67,278
	Summer	70,797	69,784	68,774
	Fall	93,696	86,379	90,661
2	Winter	48,135	45,594	48,216
	Spring	52,055	52,771	50,660
	Summer	55,626	55,307	54,519
	Fall	65,745	61,197	64,235
3	Winter	33,292	31,541	33,319
	Spring	33,812	34,224	32,762
	Summer	40,530	40,249	39,671
	Fall	47,600	43,979	46,412
Total		669,918	647,008	655,052

$$\hat{Y}_D=\hat{\alpha}+[\hat{\beta}_1+\hat{\beta}_2(\mathrm{DIM})](\mathrm{M20})+$$
$$[\hat{\beta}_3+\hat{\beta}_4(\mathrm{DIM})](\mathrm{HA})+$$
$$[\hat{\beta}_5+\hat{\beta}_6(\mathrm{DIM})+\hat{\beta}_7(\mathrm{HA})](\mathrm{S20})+$$
$$[\hat{\beta}_8+\hat{\beta}_9(\mathrm{DIM})+\hat{\beta}_{10}(\mathrm{HA})](\mathrm{SA20})$$

where $\hat{\alpha}$ is the intercept and $\hat{\beta}_1$ to $\hat{\beta}_{10}$ are the regression coefficients.

Stepwise regression (SAS®, 1990) was used requiring F statistic ($P<.01$) for SCS variables to stay in the model. Separate analyses were run for four seasons and three parities of all three data sets, a total of 36 models. Number of observations used in these models are on Table 3. Fine models were run having BASE variables and selected SCS variables. In these models, if the product of any SCS variable with HA or DIM was selected initially, the corresponding SCS variable was also included.

Results and Discussion

Means and standard deviations (SD) of sample day milk yields and corresponding SCS by parity are on Table 4. Average SCS for any sample day increased with parity. Averages were lower for samples near day 50 as compared to samples near day 20 or 140. For the first parity, the highest mean was for samples near day 20 in contrast to 2nd and 3rd parities, where the highest value is for samples near day 140. The increase of

TABLE 4

Means ± standard deviations* of sample day milk yield (kg) and SCS for samples near days 20, 50 and 140 (DM20, DM50, DM140) by parity.

Parity	Trait	DM 20	DM 50	DM 140
1	Milk Yield	25.9 ± 5.2	28.2 ± 5.2	25.3 ± 5.2
	SCS	2.78 ± 1.71	2.24 ± 1.63	2.42 ± 1.64
2	Milk Yield	34.6 ± 6.9	35.9 ± 6.9	29.2 ± 6.2
	SCS	2.45 ± 1.83	2.14 ± 1.86	2.69 ± 1.79
3	Milk Yield	36.4 ± 7.2	38.3 ± 7.2	30.9 ± 6.5
	SCS	2.77 ± 1.96	2.45 ± 1.99	3.01 ± 1.87

* Averaged over seasons

somatic cells with parity conforms with many studies (Kennedy *et al.*, 1982; Miller *et al.*,1983; Emanuelson and Persson, 1984; Wiggans and Shook, 1987; Schutz *et al.*, 1990). Coffey (1984) argued that infection rate increases with age and that there was only a slight corresponding increase in cell count with parity.

The decline of SCS in the initial part of lactation (lowest values for samples near day 50 as compared with day 20) was followed by an upward trend for the rest of the lactation (highest values for samples near day 140). This is in agreement with other studies (Honkanen-Buzalski *et al.*, 1981; Emanuelson and Persson, 1984; Ng-Kwai-Hang *et al.*,1984; Wiggans and Shook, 1987), thus indicating that SCC was high shortly after parturition, being at its lowest in the 2nd and 3rd months of lactation, and then increased slowly towards the end of lactation. Ng-Kwai-Hang *et al.* (1984) also reported that somatic cells were high during the early stages of lactation, reached a minimum within 2 months of lactation, and rose gradually throughout the rest of the lactation. Curves for lactations with low average SCS have been reported to differ from high SCS lactations (Wiggans and Shook, 1987). Lactations with SCS averaging above 4.5 displayed an increase from the beginning of the lactation instead of an early minimum followed by a gradual increase.

Sample day milk yield declined as the SCS increased. The rate of decline in sample day milk yield for samples with increased SCS was higher at the start of the lactation (near day 20) as compared to the middle (near day 140). The decline was also higher for later parities as compared with the first parity. For example, for first parity cows and samples near day 20, test day milk yield declined from 27.6 kg as compared to 20.8 kg for SCS of 0 and 9, respectively. For the 3rd parity, these values were 39.1 and 28.4 kg for the lowest and highest values of SCS, respectively. However, the second and third parities were in agreement with these trends in contrast to the first parity. Similar observations have been made by many researchers (Kennedy *et al.*, 1982; Raubertas and Shook, 1982; Emanuelson and Persson, 1984; Jones *et al.*, 1984; Batra, 1986; Wiggans and Shook, 1987; Bartlett *et al.*, 1990). Jones *et al.* (1984) studied the relationship between dairy milk yield and somatic cell counts for all lactations and reported that the linear, quadratic, and cubic effects were highly significant. Test day milk yield decreased with increasing somatic cell count and this decrease was greater for the second and later lactations than the first lactation.

Estimates of predictors of average future daily milk yield from samples near day 20 are on Table 5 (results for samples near day 50 and 140 are not presented). The estimates are from models without SCS variables (BASE variables only) and models with BASE and SCS variables selected in the stepwise regression process. Only results from the Fall season are presented; similar general conclusions can be drawn for other seasons of calving. Selection of SCS variables to predict average daily yield was not consistent across parities and seasons. For the first parity, the interaction of SCS, taken on sample day, with the herd average milk yield was always chosen at DM20. For DM50 and DM140 on the other hand, the interaction of SCS with the herd average yield was always taken previously to the sample day. For second and third parities, herd average SCS generally stayed in the model. SCS is expected to behave differently in different parities but the choice of different SCS variables at different stages of lactation is perhaps due to the influence of many other factors affecting SCS. Lucy and Rowlands (1984) and Lucy *et al.* (1986) concluded that the occurrence of mastitis both before and within 10 weeks following the peak yield results in a depressed milk yield for the remainder of the lactation. The size of the short-term fluctuation associated with clinical cases of mastitis depended on the stage of lactation at which the disease occurred. Significant short-term reduction was seen when the disease occurred the week following the peak yield. Cows gave more milk one week before and after the diagnosis. Deluyker *et al.* (1991) found that the average daily milk yield at the onset of lactation (1 to 5 DIM), cumulative yield to 21 DIM, and cumulative yield from 22 to 49 DIM were decreased significantly with mastitis in 1 to 21 DIM. No indication of production decreases were found to occur outside the period in which clinical mastitis was diagnosed.

Coefficients of determination (R^2) ranged from 51 to 74% for different models. Differences in R^2 between the first and third parity was about 5% and 15% for predicting daily milk yield from samples near day 140,

TABLE 5

Estimates of predictors of average daily milk yield (kg) in the Fall season of calving for samples near day 20 by parity.

		Without SCS variable		With SCS variable	
Parity	Variable	Estimate	SE	Estimate	SE
1	Intercept	-2.4879	0.0779	-2.2629	0.1446
	M20	0.3552	0.0051	0.3599	0.0052
	M20 x DIM	0.0032	0.0002	0.0031	0.0002
	HA	1.9883	0.0155	1.9317	0.0208
	HA x DIM	-0.0128	0.0006	-0.0122	0.0006
	S20			-0.1091	0.0460
	S20 x HA			0.0176	0.0050
		R^2 = 59.6		R^2 = 59.7	
2	Intercept	-2.4686	0.1129	-4.1212	0.5071
	M20	0.3067	0.0061	0.3067	0.0061
	M20 x DIM	0.0028	0.0003	0.0028	0.0003
	HA	2.1753	0.0242	2.4003	0.0596
	HA x DIM	-0.0128	0.0010	0.0136	0.0011
	S20			-0.0253	0.0204
	S20 x DIM			0.0024	0.0009
	SA20			0.5736	0.1628
	SA20 x HA			-0.0761	0.0181
		R^2 = 56.7		R^2= 56.7	
3	Intercept	-2.3217	0.1415	-2.7458	0.6104
	M20	0.2804	0.0071	0.2787	0.0071
	M20 x DIM	0.0019	0.0003	0.0020	0.0003
	HA	2.3769	0.0297	2.4875	0.0725
	HA x DIM	-0.0102	0.0013	-0.0113	0.0013
	S20			-0.0475	0.0236
	S20 x DIM			0.0026	0.0010
	SA20			0.2020	0.1922
	SA20 x HA			-0.0367	0.0217
		R^2= 54.0		R^2= 54.1	

as compared with samples near day 20. As expected, prediction was better for earlier lactations and from samples with higher DIM. Inclusion of SCS in the prediction equations improved R^2 by less than 1%.

Regression of average daily future milk yield on test-day milk yield, herd average milk yield and their interactions with DIM were not different with or without SCS variables in the model. Regression of future daily milk yield on test-day milk yield was higher when predictions were made from samples near day 140, as compared to samples from the earliest part of the lactation. This trend was, however, reversed in the regression of daily future milk yield on herd average with values being lower for samples near day 140. These trends were consistent with the findings of Wiggans and Van Vleck (1979). Standardized regression estimates showed that predictors of future milk yield were similarly important. For DM20, the herd average daily future yield had the highest correlation (0.49) with the average daily future yield. However, sample day milk yield became more important to predict future milk yield as DIM increased. Thus correlations were 0.49 and 0.69 for DM50 and DM140 for the first parity, as compared with 0.42 for DM20. A similar trend occurred in the second and third parities. Regression coefficients for the product of herd average milk yield and DIM were always negative and generally decreased as DIM increased. This indicated that herd average became less important as the lactation length increased.

Regressions obtained from this study were somewhat different from the factors currently used (Wiggans and Dickinson, 1985) by USDA for the lactation length adjustment of cows in Wisconsin. Samples near day 20 and 50 fell in the first category of days in milk currently being used, i.e. 7-55 days while samples near day 140 fell in the range of 106-155 days. The USDA procedure also combined the second and later lactations for the adjustment of lactation length. The regressions of this study estimated the daily future milk yield from any sample day and were different for the second and third parities. Values of regression coefficients for future daily milk yield on test day milk yield were lower than the USDA regressions. The future daily milk yield estimates from sample day milk yield (near day 50) for cows calving in Fall was 0.494 kg for the first parity and 0.416 kg for the second and later parities. Comparable values to these regressions from our study were 0.419±0.012, 0.323±0.014, 282±0.016 kg for the first, second and third parities. Regression of future daily milk yield on ME herd averages were, on the other hand, higher in the present study than the USDA values. For samples near day 140 for example, USDA values for the Fall season and 106 to 155 DIM were 0.619 and 0.957 kg for first and later parities. By comparison, the first, second and third parities in the present study gave: 1.696±0.036, 1.910±0.055, and 2.201±0.067 kg. The regressions for the product of sample day milk yield and herd average milk yield with DIM were also higher than the USDA values.

Apparently the variance-covariance structure between herd average milk yield and test day milk yield has changed since the projection factors were developed. Currently, future yield is more closely associated with herd performance than cow performance, which may be partly due to a more uniform treatment of cows at the herd level.

Conclusions

Somatic cell score was associated with sample day milk yield. A decrease in test day milk yield with increased SCS was observed for all seasons and parities. However, the association was not strong enough to improve the production of future yield when other expressions of milk yield were in the model. Selection of SCS variables as predictors of future daily milk yield was not consistent across seasons or parities. Improvement of R^2 was nominal when expressions of SCS were added to the usual prediction equations. Regressions of future daily milk yield on herd average milk yield were higher and on test-day milk yield, lower when compared with those of USDA. Perhaps, more consistent management at the herd level has resulted in higher values of regression of future daily milk yield on herd average milk yield and lower regression on test day yield as compared to the USDA values.

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