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## Calculated milk production losses associated with elevated somatic cell counts in dairy cows: review and critical discussion

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**Abstract** – Relationships between somatic cell count (SCC) and variation in milk production at the cow level were reviewed to provide average reference values suitable for the assessment of economic losses due to subclinical mastitis. The literature analysis involved 19 papers, defining milk yield and/or its composition either at test-day level or at the whole lactation level as statistical unit. Within each type of approach, study populations and designs differed. Regression models implemented also showed large differences. At test-day level, the average trend was a loss of 0.4 kg of milk in primiparous cows and 0.6 kg in multiparous, by each 2-fold increase of SCC above 50 000 cells/mL. At the lactation level, the average trend was a loss of 80 kg of milk in primiparous and 120 kg in multiparous, by each 2-fold increase of the geometric mean of SCC above 50 000 cells/mL. Protein content of milk showed a small increase of 0.15 g/kg (at the test-day level) while fat content showed a small decrease of 0.20 g/kg (both at the test-day and at the lactation level), by each 2-fold increase of SCC. The value of further studies was underlined, especially to provide more accurate quantification of the composition changes associated with elevated SCC, and to improve the imperfect knowledge about the effects of parity and stage of lactation on the studied relationships. © Inra/Elsevier, Paris.

**dairy cow / milk yield / milk composition / somatic cell count**

**Résumé** – Pertes de production calculées associées aux teneurs élevées du lait en cellules somatiques chez la vache laitière : revue et discussion critique. La revue porte sur les variations de production laitière associées à l'élévation de la teneur du lait en cellules somatiques. Il s'agit de produire des informations de référence utilisables pour évaluer l'impact économique des mammites subcliniques. Dix-neuf études utilisant, comme unité statistique, la production par lactation ou la production au contrôle laitier mensuel et analysant les variations de production laitière, de matière grasse ou de matière protéique ont été retenues. Les populations d'étude, les variables d'étude et les modèles de régression utilisés différaient considérablement entre études. Au niveau du jour du contrôle, la perte moyenne estimée, associée à chaque doublement de la teneur en cellules somatiques (au-delà de 50 000 cel-

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lules/mL), était de 0,4 kg de lait chez les vaches primipares et de 0,6 kg chez les multipares. Au niveau de la lactation, la perte moyenne estimée était de 80 kg chez les primipares et de 120 kg chez les multipares, pour chaque doublement de la moyenne géométrique de la teneur en cellules somatiques (au-delà de 50 000 cellules/mL). Les effets moyens estimés sur le taux protéique et sur le taux butyreux, associés à un doublement de la teneur en cellules somatiques, étaient, respectivement, une augmentation de 0,15 g/kg (au niveau d'étude du jour de contrôle) et une diminution de 0,20 g/kg (aux deux niveaux d'étude). L'intérêt de nouveaux travaux pour préciser les modifications de composition associées aux teneurs élevées en cellules somatiques et pour mieux prendre en compte l'effet de la parité et du stade de lactation sur la relation étudiée, est souligné. © Inra/Elsevier, Paris.

## vache laitière / quantité de lait / composition du lait / teneur du lait en cellules somatiques

### 1. INTRODUCTION

Mastitis is considered the most frequent health disorder in dairy farms. The assessment of the economic value of a control plan for mastitis has to be supported by a reliable evaluation of the economic losses caused by the disease. Decrease in milk yield is one of the major origins of these economic losses, both for clinical and subclinical infections (e.g. [9, 12]). Critical analysis of the literature on economics of mastitis control shows that results differ widely between studies [33]. Discrepancies are due to variation in methods used to translate the basic data describing the production losses in economic terms, but also to large variation in these basic data used as input for the calculations.

New tighter limits for bulk-milk somatic cell count (BMSCC) have been recently set by regulations in many countries [35]. For example, the current limit-value prevailing in the E.U. countries for milk delivery to dairy plants is 400 000 cells/mL. However, a penalty or a bonus on the milk price is frequently implemented at lower thresholds (for example, a penalty is applied above 250 000 cells/mL in most of France). In this context, the value of methods allowing assessment of the economic value of plans implemented to lower the BMSCC level is very high. To that purpose, an accurate estimation of the loss in milk yield associated with an increase in BMSCC is needed. Related effects on milk composition have

also to be dealt with, especially in the European context, given the existence of a quota for annual milk delivery, and given the large weight of the composition parameters in the pricing system of milk.

The most relevant basic input to estimate production losses at the herd level are cow-level values for losses in yield and variations in composition associated with individual somatic cell count (SCC) variations. The aggregation of these individual effects can best provide an accurate estimate of the herd-level effect. Although in one article [6], results were compared to previous studies, no specific review on the relationship between SCC and milk production at the cow level has been recently published.

Therefore, the aim of this review paper was to draw basic reference values regarding changes in milk production associated with a variation in SCC at the cow level. Modifications of composition parameters which are used in standard milk pricing systems were also included in the analysis.

### 2. REVIEW MATERIALS

#### 2.1. Selection of papers

Literature on relationships between subclinical intramammary infections and milk production is quite abundant. However, these studies consisted in various approaches using different definitions in subclinical

mastitis, and different nature of study unit (quarter, cow or sometimes herd; test-day yield or lactational yield). Since the individual cow-level SCC values are routinely available to the dairy farmers from the Milk Recording Schemes, studies based on California Mastitis Test (CMT) were not included in the analysis. The cow level as study unit was also justified because non-infected quarters may partially compensate for production losses of infected quarters [40].

Milk yield of cows (considered at phenotypic and at genetic levels) and farming conditions (especially, housing, feeding, milking machine and milking techniques) have changed enormously over the last decades. Pathogens involved in intramammary infections have also changed [37]. Consequently, the most relevant information for use under the current farming conditions was to be provided by recent studies, if available.

Therefore, the following criteria were applied to select papers:

- 1) definition of the SCC as an independent variable and the yield or composition as dependent variables, at the cow level;
- 2) use of data collected after 1975 (to retain a sufficient number of papers).

## 2.2. Study populations and samples in selected papers

Nineteen papers were selected (*tables I and II*). Only very few of them considered changes in fat and protein yields together with changes in milk. All were published between 1981 and 1993. The breed under study was mostly Friesian/Holstein-Friesian. Most of the studies used North-American data. Usually, the dairy farms were randomly chosen from the Milk Recording Scheme and the basic data consisted of individual cow results at monthly test days within a lactation. One study used only one test-day result per cow. Five studies included

more than 300 herds. No information about the incidence of clinical mastitis was available, except in two papers [10, 26]. In six papers, no information was available about the mean SCC in the sample.

## 3. STUDY DESIGNS AND STATISTICAL METHODS OF SELECTED PAPERS

All the selected studies were supported by multivariate analyses, mostly generalised linear models (GLM). Modelling designs of papers that provided sufficient information are summarised in *tables III and IV*.

### 3.1. Dependent variable defined for milk yield

The effect of the SCC on milk yield was studied at two levels: the test-day yield (*table III*) or the cumulative lactational yield (*table IV*). Three papers dealt with both.

Twelve studies defined the milk yield per 24 h and per cow as dependent variable (one was not reported in *table III* because of the lack of detailed model description [7]). In addition to these 12, Miller et al. [26] used the a.m. milk yield as dependent variable.

Eight studies defined the lactational yield as dependent variable (standard lactation of 305 or 308 d.). In one of these eight studies, the dependent variable was defined as the difference between two consecutive lactations of a same cow [17]. One particular study considered 119 d. cumulative milk yield [10].

### 3.2. Dependent variables defined for milk composition

Of the selected papers (*table II*), only four papers dealt with fat yield (two at the test-day level and two at the lactation level) and one paper dealt with fat content of the milk [28]. Only two papers dealt with pro-

**Table I.** Summary of selected literature on milk yield loss and composition changes associated with elevated somatic cell counts: study populations and samples.

Reference	Country breed	Data collection period	No. of			Herd type <sup>b</sup>	Milk yield (kg/lact. or d.)
			Cows <sup>a</sup>	Test-days	herds		
Bartlett et al. (1990) [3]	U.S. Michigan NA <sup>c</sup>	1985–1986		397 172	504	C	24.3
Batra (1986) [4]	Canada Holstein and Ayrshire	1982–1983	665	2 181	1	I	5 727 (lact. 1) 6 124 (lact. > 1) 18.8 (lact. 1) 20.1 (lact. > 1)
Cameron and Anderson (1993) [6]	Australia NA	1990–1991	23 700	75 821	154	C	18.0
Clabaugh et al. (1981) [7]	U.S. Virginia NA	3 years <1981		43 677	28	C	24.0
Deluyker et al. (1993) [10]	U.S. California Holstein	about 3 months	112		1	C	10 900
Dentine and McDaniel (1983) [11]	U.S. Carolina Holstein	1980–1982	1 567		8	I	NA
Dohoo and Martin (1984) [14] <sup>d</sup>	Canada Holstein	1979–1981	2 008 (2 875)		32	C	23.5
Fabre et al. (1990) [16]	France Holstein	1987–1988	1 145	8 937	20	C	18.1 (lact. 1) 21.4 (lact. > 1)
Fetrow et al. (1991) [17]	U.S. Carolina Holstein	3 years <1990	10 705		770	C	≈ 8 000
Gill et al. (1990) [19]	U.S. Ontario Holstein and other	Nov. 1988	26 667		719	C	33.8 (lact. 1)
Jones et al. (1984) [22]	U.S. Virginia NA	1977–1980		67 707	34	C; I	22.1 (lact. 1) 26.2 (lact. > 1)
Miller et al. (1993) [26] <sup>e</sup>	U.S. Holstein	NA	24	264		C	24.4 (lact. 1)
Ng-Kwai-Hang et al. (1983) [28]	Canada Holstein	1979–1981		41 783	63	C	20.4
Quaassdorff et al. (1987) [29]	U.S. Wisconsin Holstein	14 months <1987			11	C	NA
Raubertas and Shook (1982) [30]	U.S. Wisconsin NA	1972–1977	6 671		548	C	5 802 (lact. 1) 6 867 (lact. > 1)
Salsberg et al. (1984) [31]	Canada Ontario Holstein	1981–1984	9 406	85 236	748	C	6 233 20.3
Serieys (1985) [36]	France Holstein	30 months <1985	62 (125)		1	I	6 841
Tyler et al. (1989) [38]	U.S. California Holstein	Nov. 1985	8 352		10	C	24.2 (lact. 1) 28.8 (lact.>1)
Youl and Nicholls (1988) [41]	Australia NA	1979–1981		11 033	≈ 300	C	NA

<sup>a</sup> In parenthesis, number of lactations; <sup>b</sup> C, commercial; I, institutional; <sup>c</sup> NA: not available; <sup>d</sup> data described in Dohoo et al., 1983 [15]; <sup>e</sup> data described in Miller et al., 1991 [25].

tein production at the test-day level, one with protein yield [19] and one with protein content [28].

### 3.3. Independent variables defined for SCC

Distribution of individual SCC values is right skewed [5, 8]. According to Ali and Shook [1],  $\text{SCC} \times 10^{-3}$  values (at test-day or

as lactational geometric mean) were therefore generally handled as a continuous variable after transformation into its logarithm ( $\log_e$  or  $\log_2$ ), to better fulfil the assumptions underlying the use of GLM models. Bartlett et al. [3] used a derived transformation: the transformed term was corrected by subtracting its average value [ $\log_e(\text{SCC} \times 10^{-5} + 1) - 1.5$ ]. Quadratic and cubic terms of transformed SCC were tested in several studies. Five of the described models han-

**Table II.** Summary of selected literature on milk yield loss and composition changes associated with elevated somatic cell counts: study designs and SCC levels in samples.

Reference and study level	Production variables <sup>a</sup>	Frequency of SCC measurement	Mean SCC <sup>b</sup> ( $\times 1\,000$ cells/mL)	Calculated SCC central 95 % range <sup>c</sup> or SD ( $\times 1\,000$ cells/mL)
<i>Test-day</i>				
Bartlett et al. (1990) [3]	M	monthly	427 (A <sup>d</sup> )	13–401
Batra (1986) [4]	M	2 months	305 (A, lact. 1); 522 (A, lact. > 1)	NA <sup>e</sup>
Cameron and Anderson (1993) [6]	M	monthly	272 (A)	13–1 224
Clabaugh et al. (1981) [7]	M	monthly	NA	NA
Dohoo and Martin (1984) [14]	M	monthly or 3 months	NA	NA
Fabre et al. (1990) [16]	M	monthly	219 (A, lact. 1); 485 (A, lact. > 1)	SD = 537 (lact. 1); 859 (lact. > 1)
Gill et al. (1990) [19]	M, F, P	monthly	NA	NA
Jones et al. (1984) [22]	M, F	monthly	231 (A, lact. 1); 409 (A, lact. > 1)	SD = 617 (lact. 1); 953 (lact. > 1)
Miller et al. (1993) [26]	M	weekly	163 (G <sup>f</sup> , lact. 1)	74–312 (lact. 1)
Ng-Kwai-Hang et al. (1983) [28]	M, F, P	monthly	314	SD = 662
Quaassdorff et al. (1987) [29]	M	monthly	NA	NA
Salsberg et al. (1984) [31]	M	monthly	178 (A)	SD = 252
Tyler et al. (1989) [38]	M	one test per cow	137 (lact. 1); 243 (lact. > 1)	16–450 (lact. 1); 13–973 (lact. > 1)
<i>Lactation</i>				
Batra (1986) [4]	M	2 months	305 (A, lact. 1); 522 (A, lact. > 1)	NA
Dentine and McDaniel (1983) [11]	M, F	NA	NA	NA
Dohoo and Martin (1984) [14]	M	monthly or 3 months	NA	NA
Fetrow et al. (1991) [17]	M	monthly	NA	NA
Raubertas and Shook (1982) [30]	M	monthly or bimonthly	128 (A, lact. 1); $\approx 200$ (A, lact. > 1)	NA
Salsberg et al. (1984) [31]	M	monthly	178 (A)	SD = 252
Serieys (1985) [36]	M	monthly	116 (A)	14–965
Youl and Nicholls (1988) [41]	M, F	monthly	(<250 in 70 % cows)	NA
<i>Partial 110 d. lactation</i>				
Deluyker et al. (1993) [10]	M	daily <sup>g</sup>	<300 (bulk milk SCC)	NA

<sup>a</sup> M: milk yield; F: fat yield; P protein yield; <sup>b</sup> SCC at test-day or at the lactation level; <sup>c</sup> 95 % central range calculated from mean and SD of logarithmic values of SCC when available; <sup>d</sup> arithmetic mean of SCC; <sup>e</sup> NA: not available; <sup>f</sup> geometric mean of SCC; <sup>g</sup> SCC data corresponding to clinical mastitis episodes were excluded.

**Table III.** Regression models in analyses at the test-day level.

Variables	References <sup>a</sup>																
	1	2	3	3	3	4	5	5	6	7	8	8	9	9	10	11	12
<i>Dependent variables</i>																	
24 h test-day yield	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
a.m. yield																	x
<i>SCC independent variables</i>																	
<i>– Continuous variables</i>																	
SCC × 10 <sup>-3</sup>	x				x												
[SCC × 10 <sup>-3</sup> ] <sup>2</sup>					x												
[SCC × 10 <sup>-3</sup> ] <sup>3</sup>					x												
Log <sub>e</sub> (SCC × 10 <sup>-3</sup> )		x	x			x	x				x <sup>b</sup>	x <sup>b</sup>	x			x	x
[log <sub>e</sub> (SCC × 10 <sup>-3</sup> )] <sup>2</sup>					x						x <sup>b</sup>	x <sup>b</sup>					x
[log <sub>e</sub> (SCC × 10 <sup>-3</sup> )] <sup>3</sup>					x						x <sup>b</sup>	x <sup>b</sup>					x
Log <sub>2</sub> (SCC × 10 <sup>-3</sup> )																	x
[log <sub>2</sub> (SCC × 10 <sup>-3</sup> )] <sup>2</sup>																	x
<i>– Categorized SCC classes</i>																	
SCC × 10 <sup>-3</sup>						x		x	x								x
Log <sub>e</sub> (SCC × 10 <sup>-3</sup> )										x							
<i>Other independent variables</i>																	
Cow				x	x	x				NA	x	x <sup>c</sup>					x <sup>c</sup> x
Parity				x	x	x		x	x		x	x	x	x	x		
Age at calving		x					x										
[Age at calving] <sup>2</sup>							x										
Age of cow	x											x					
Stage of lactation	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x
[Stage of lactation] <sup>2</sup>		x					x										
Stage of lactation, classes												x					
Genetic group or BCA <sup>d</sup>							x	x									x
Previous lactation milk yield		x															
Previous day milk yield									x								
Season or month of calving				x	x	x		x	x		x	x	x	x			
Herd	x	x	x	x	x				x	x	x	x <sup>c</sup>	x	x	x <sup>c</sup>	x <sup>c</sup>	
Year-season	x												x	x			
Other	x	x							x							x	x
<i>Interaction terms</i>																	
SCC variable × parity												x					
R <sup>2</sup>		.84	.78			.55				.40	.78	.78	.63	.63	.38	.83	
<i>Separate models by parity</i>																	
			x	x	x		x										

<sup>a</sup> (1) Ng-Kwai-Hang et al., 1983 [28]; (2) Dohoo and Martin, 1984 [14]; (3) Jones et al., 1984 [22]; (4) Salsberg et al., 1984 [31]; (5) Batra, 1986 [4]; (6) Quaassdorff et al., 1987 [29]; (7) Tyler et al., 1989 [38]; (8) Bartlett et al., 1990 [3]; (9) Fabre et al., 1990 [16]; (10) Gill et al., 1990 [19]; (11) Cameron and Anderson, 1993 [6]; (12) Miller et al., 1993 [26].

<sup>b</sup> Variables were defined as: [log<sub>e</sub>(SCC × 10<sup>-5</sup> + 1)] – 1.5.

NA: Not applicable (only one test-day per cow).

<sup>c</sup> Herd and cow variables were absorbed during the analysis according to the SAS GLM procedure definition.

<sup>d</sup> Breed and breed class average for milk.

<sup>e</sup> Number of cows in the herd.

**Table IV.** Regression models in analyses at the lactation level.

Variables	References <sup>a</sup>												
	1	1	2	3	4	5	6	7	8	8	9	9	
<i>Dependent variable</i>													
305 d or 308 d yield	x	x	x	x	x	x	x	x					
305 d deviation from previous lactation									x	x			
119 d yield											x	x	
<i>SCC independent variables</i>													
<i>– Continuous variables</i>													
Log <sub>e</sub> (geometric mean SCC × 10 <sup>-3</sup> )	x	x	x	x	x	x	x	x	x				
Log <sub>e</sub> (SCC) score <sup>b</sup>											x		
Variability of SCC term	x	x											
Log <sub>e</sub> (geometric mean SCC × 10 <sup>-3</sup> ) in previous lactation	x								x				
Variability of SCC term in previous lactation	x												
Log <sub>e</sub> (SCC) score <sup>b</sup> in previous lactation											x		
<i>– categorised SCC classes</i>													
Three levels for log <sub>e</sub> (geometric mean SCC × 10 <sup>-3</sup> )												x	x
<i>Other independent variables</i>													
Cow									x				
Breed				x				x					
Parity			x				x				x	x	
Age at calving	x	x	x	x	x			x					
Age at previous calving	x												
[Age at calving] <sup>2</sup>					x			x					
[Age at calving] <sup>3</sup>								x					
Genetic group or sire genetic level							x				x	x	
Season or month of calving	x	x	x	x	x			x			x	x	
Length of lactation	x	x			x		x						
Length of previous lactation	x												
Udder pathogen						x							
Clinical mastitis												x	
Other clinical diseases				x								x	x
Days to conception				x									
Herd	x	x	x		x	NA	NA		x <sup>c</sup>	x <sup>c</sup>	NA	NA	
Year								x					
R <sup>2</sup>					.32	.28					.56	.54	
<i>Separate models by parity</i>	x	x							x	x			

<sup>a</sup> (1) Raubertas and Shook, 1982 [30]; (2) Dentine and McDaniel, 1983 [11]; (3) Dohoo and Martin, 1984 [14]; (4) Salsberg et al., 1984 [31]; (5) Serieys, 1985 [36]; (6) Batra, 1986 [4]; (7) Youl and Nicholls, 1988 [41]; (8) Fetrow et al., 1991 [17]; (9) Deluyker et al., 1993 [10].

<sup>b</sup> The score represented the proportion of high tests for [ $\log_e(\text{SCC} \times 10^{-3}) \geq 4.5$ ] that the cow had during the lactation. NA: Not applicable (only one herd was included).

<sup>c</sup> The dependent variable was adjusted based on herd average milk production in alternative models.

dled SCC as a categorised variable (*table III*). The possible carry-over effect of SCC in the previous lactation was studied in two papers by including SCC terms regarding the two lactations in the same model [17, 30].

### 3.4. Other independent variables

When studies included data of several parities, the parity or the age of the cow (at calving or at test day) were accounted for, except in four studies ([4] in one model only, [6, 36, 38]). The stage of lactation was systematically included in all test-day models, except by Miller et al. [26]. Variables describing calving season were also mainly included.

A herd effect and a cow effect were included, simultaneously or not, in most of the tested models in which it could be relevant. However, the cow effect and the herd effect have in fact a hierarchical structure [20]. It is not feasible to deal with this when common statistical packages and usual computing facilities are used. For this reason, many authors included only a herd effect or only a cow effect. The GLM procedure under SAS (Statistical Analysis System, SAS Institute Inc., Cary, NC) gives an alternative with the 'absorb' option, to limit the power requirement of the computer. Nevertheless, the solutions provided by the regression analysis are limited when this option is set [3, 6].

Some other variables were included by only very few authors (e.g. genetic merit, breed class average, previous lactation milk yield, ketone test score, management practices of the farmer, etc.).

### 3.5. Yield loss calculation in original papers

Loss in milk yield was expressed differently among studies: 1) as a deviation from

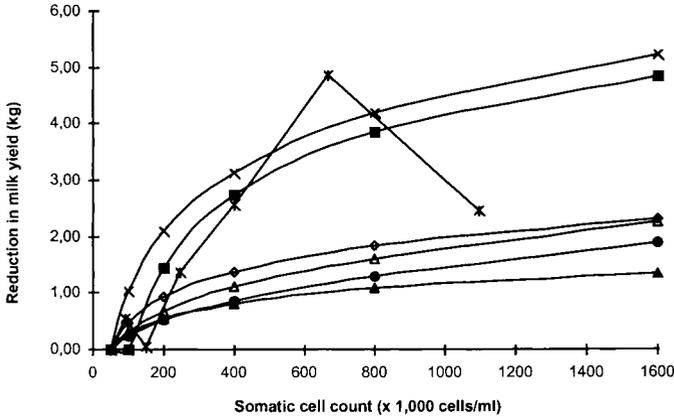
the milk yield of cows with a reference SCC (the reference varied from < 20 000 to < 100 000 cells/mL); 2) as a decrease in milk yield per unit of the independent variable (corresponding to the effect, divided by 0.6931, of a 2-fold increase of the SCC value, when a single linear logarithmic effect was assessed or in equivalent terms when non-linear effects were modelled); 3) as solutions for yield at the several levels of categorised SCC variables; or 4) by graphical display. Deviation in yield was directly chosen as dependent variable by Fetrow et al. [17].

## 4. SECONDARY YIELD LOSS ASSESSMENT MADE BY REVIEW AUTHORS

A common reference class of SCC assumed to correspond to healthy cows was set at  $\leq 50\,000$  cells/mL. This value was based on values of SCC reported in bacteriologically negative test-day cultures and within-lactation sequences of such negative cultures [23, 34].

This reference value was used to implement additional calculations from the original data to compare more efficiently the estimates given by the selected papers. These calculations were made for standardised values of SCC up to 1 600 000 cells/mL. Comparison of higher levels was not relevant because of their low frequency (*table II*), except in the study of Jones et al. [22], which included 10 % of records above 800 000 cells/mL.

Central tendency values for milk yield loss and related composition changes associated with elevated SCC, were finally assessed from values provided by the previous calculations and expressed for a 2-fold increase step of SCC (SCC at test-day or geometric mean of SCC at the lactation level).



**Figure 1.** Loss in milk yield at test day for primiparous cows expressed in deviation from yield of cows with SCC lower than 50 000 cells/mL. ● : Jones et al. (1984) [22]; ◇ : Batra (1986) [4]; \* : Tyler et al. (1989) [38]; Δ : Bartlett et al. (1990) [3]; ▲ : Fabre et al. (1990) [16]; ■ : Gill et al. (1990) [19]; × : Miller et al. (1993) [26]; the a.m. losses were extended by a factor 2.

## 5. ESTIMATES OF MILK YIELD LOSS AND COMPOSITION CHANGES

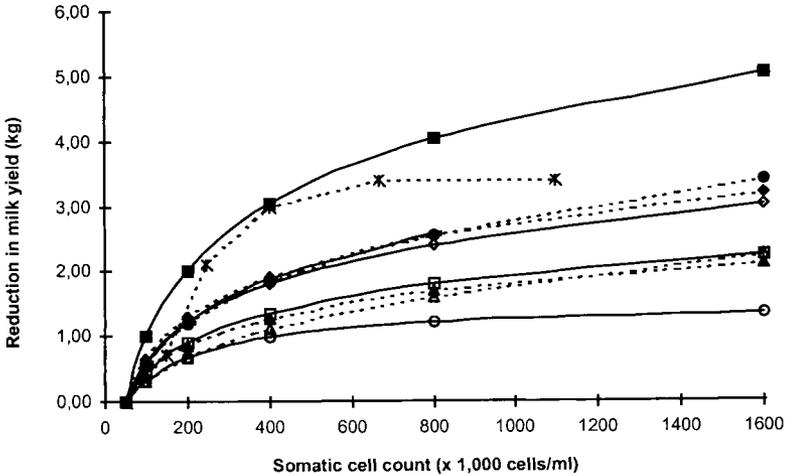
### 5.1. Milk yield loss

All the reported models resulted in statistically significant ( $P \leq 0.001$ ) negative effects of elevated SCC on milk yield, whatever the study level (test day or lactation). For both study levels, the central tendency showed a less than proportional increase in the loss in milk yield for increasing non-transformed SCC values. The R-square values of the models fluctuated from 0.28 to 0.84, and were generally lower for the lactational study level (tables III and IV). When a relationship was fitted by a loglinear model, the reduction in yield is structurally constant for all 2-fold increase steps of SCC. Graphic representations of the reported (or secondarily derived) relationships are displayed in figures 1–3.

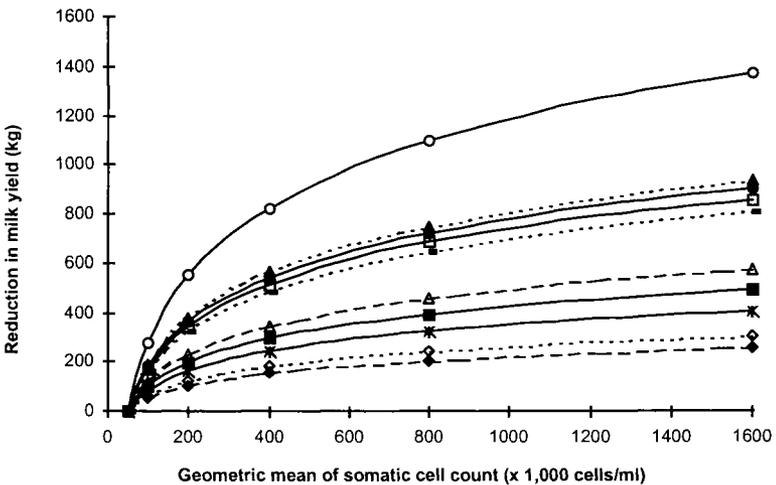
Figure 1 displays the reduction in test-day milk yield associated with the SCC level in primiparous cows. At 400 000 and at

800 000 cells/mL, the estimated daily loss varied from 0.8 to 3.1 kg milk and from 1.1 to 4.2 kg of milk, respectively. The central trend was difficult to assess owing to large discrepancies between displayed results. However, a mean loss of about 0.4 kg in milk yield per 2-fold increase of SCC could be stated, except for three studies [19, 26, 38], which resulted in higher losses. For the study of Miller et al. [26], the explanation could be related to the fact that they calculated only the loss in a.m. yield (which was here extrapolated and thereby possibly overestimated), and also to the fact that they did not include any term to account for stage of lactation. In Tyler et al. [38], the SCC variable was categorised and the results did not show a continuous trend. However, no reason for higher losses could be found in Gill et al. [19].

Estimated reductions in daily yield of all-parity cows and in multiparous cows are displayed in figure 2. At 400 000 and at 800 000 cells/mL, this estimated loss varied from 1.0 to 3.0 kg milk and from 1.2 to 4.0 kg of milk, respectively. A daily loss of about 0.6 kg in milk yield per 2-fold increase



**Figure 2.** Loss in milk yield at test day for multiparous cows (and all-parities cows) expressed in deviation from yield of cows with SCC lower than 50 000 cells/mL. .... multiparous cows; — multiparous and primiparous cows; - : Clabaugh et al. (1981) [7]; ■ : Dohoo and Martin (1984) [14]; ● : Jones et al. (1984) [22]; □ : Salsberg et al. (1984) [31]; ◆ : Batra (1986) [4]; ◇ : Quaassdorf et al. (1987) [29]; \* : Tyler et al. (1989) [38]; Δ : Bartlett et al. (1990) [3]; ▲ : Fabre et al. (1990) [16]; ○ : Cameron and Anderson (1993) [6].



**Figure 3.** Loss in milk yield at the lactation level expressed in deviation from yield of cows with a geometric mean of SCC lower than 50 000 cells/mL. .... multiparous cows; - - - primiparous cows; — multiparous and primiparous cows; ▲ : Raubertas and Shook (1982) [30]; Δ : Raubertas and Shook (1982) [30]; ● : Dentine and McDaniel (1983) [11]; ■ : Dohoo and Martin (1984) [14]; □ : Salsberg et al. (1984) [31]; ○ : Serieys (1985) [36]; ◇ : Batra (1986) [4]; ◆ : Batra (1986) [4]; \* : Youl and Nicholls (1988) [41]; - : Fetrow et al. (1991) [17].

of SCC was the central trend in multiparous cows.

At the lactation level, losses were found to be larger in multiparous cows than in primiparous, except in Gill et al. [19], who did not find any significant difference. Losses of 153 and 343 kg milk at 400 000, and 204 and 457 kg milk at 800 000 cells/mL, respectively, were reported by two studies in primiparous cows (*figure 3*) [4, 30]. Loss estimates at the lactation level were provided for multiparous cows (or all-parity cows) by a larger number of studies and are displayed in *figure 3*. Variation between studies was large. At geometric means of 400 000 and 800 000 cells/mL, the estimated loss varied from 166 to 823 kg milk and from 222 to 1 098 kg of milk, respectively. The central tendency was a loss of about 120 kg (i.e. about 1.7 %) in milk yield per 2-fold increase of geometric mean of SCC in multiparous cows and about 80 kg (i.e. about 1.3 %) in milk yield in primiparous cows.

Intra-study variability of estimates of losses was reported to differ widely in magnitude. Standard deviation varied from about 10 to 100 kg per lactation and from < 0.01 to 0.3 kg at the test-day level per 2-fold increase of SCC term. The variation coefficient was high (> 25 %) in three studies (two of them at the lactation level [4, 30] and the last one at a.m. level [26]) and small (< 6 %) in four studies [3, 17, 19, 41] (two at the test-day level and two at the lactation level).

## 5.2. Changes in milk composition

Two studies provided results, only at the test-day level, for total protein content. In the first one, for a variation of  $\log_2(\text{SCC} \times 10^{-3})$  from 0 to 4, the total protein yield decreased from 1.121 to 0.995 kg/d while the total protein content increased from 33.2 to 34.0 g/kg of milk [19]. In the second one, the total protein content was found to be increased only for high SCC levels (>1 000 000 cells/mL) [28]. The derived

mean was an increase of about 0.15 g/kg per 2-fold increase of SCC.

Only three studies provided estimates of fat yield change at the test-day level [19, 22, 28]. Changes varied from -12 to 0 % for SCC variations between 50 000 and 1 600 000 cells/mL. Corresponding variations in fat content were negative or positive and averaged a decrease of 0.25 g/kg per 2-fold increase of SCC. At the lactation level, losses of 4–9 kg fat per 2-fold increase of the geometric mean of SCC were reported in two studies [11, 41]. The central trend of decrease in fat yield resulted in a decrease in fat content of 0.2 g/kg per 2-fold increase of the geometric mean of SCC.

Udder infection is associated with a higher susceptibility to lipolysis, especially after storage of the milk [18, 27]. However, no study available to us provided quantified results for lipolysis associated with variations of SCC at the cow level.

## 6. DISCUSSION

The main objective of the present review was to establish a reference for the average relationship between SCC and milk yield of a cow. Elevated SCC levels in individual milk were found significantly associated with a loss in milk yield. This loss increased when the SCC level increased, both at the test-day level and at the lactation level. This increase was loglinear, i.e. less than proportional to the increase in non-log-transformed SCC. The average magnitude of loss in milk yield with increasing SCC was lower in primiparous than in multiparous cows.

The second objective of our study was to provide a central trend for changes in milk composition related to the loss in milk quantity. Regarding fat content, the reported changes could be summarised by a small decrease, both at the test-day level and at the lactational level. Regarding protein content, reported changes consisted of a very

small increase at the test-day level and no study provided any information at the lactation level. Nevertheless, it has to be underlined that only very few results regarding composition parameters were available. Some previously published studies (using CMT) could not be used to confirm or infirm these results, as they did not specify the reduction in milk yield associated with changes in milk composition.

However, the possible increase in total protein content has to be examined critically, despite its favourable effect under the European milk-pricing systems. Simultaneously, intramammary infections generate a significant reduction in casein synthesis. In fact, the increase of blood elements (serum albumin, immunoglobulins and polymorphonuclear neutrophils) due to the udder inflammatory reaction more than compensates for the effects of the reduction of casein secretion [12, 21]. The casein content of the milk will probably be taken into account, as a criterion for milk pricing in the future, because the manufacturers of dairy products report problems in processing milk with poor casein content [2].

The validity of the loglinear model for yield loss is first questionable. Several authors [4, 16, 22] fitted two models: one with SCC after log-transformation and one with a categorised SCC variable. These comparisons confirmed the global relevance of the loglinear transformation. However, they observed a trend of obtaining underestimated losses for SCC below 600 000 cells/mL with the loglinear transformation, specifically in primiparous cows. On the contrary, the log-transformation tends to over-estimate the loss in milk yield for very high SCC levels. Models testing quadratic or cubic terms for log-transformed SCC found a significant effect, except in [11]. These modelling approaches resulted in slightly higher estimates of loss in milk yield than the other studies, especially when high values of SCC were included in the sample. However, the distribution of the residues was generally not studied, except by

Dentine and McDaniel [11] who reported a non-independence of the residues.

The overall goodness-of-fit and the field covered by the adjustment variables included in the models also have to be considered. Samples from cows with clinical mastitis or other health disorders were generally not excluded from the analysis, nor adjustment terms for health disorders included (except in four studies [10, 17, 36, 41]). However, most of the cows experiencing a clinical mastitis or another disorder at test day are not sampled. The main physiological factors of variation of milk yield were taken into account in nearly all the studies: parity and stage of lactation (in test-day models). Conversely, feeding, housing and milking techniques were mostly not taken into account. Herd and/or cow effects as modelled in the studies could only partially offset this drawback [6].

The between-study variability originated not only from differences in modelling approaches. The characteristics of populations studied (breed, yield, demographic and managerial factors) also had a probable effect. More concerning is the difference in range of SCC between samples and the dependence of regression estimates on this range. Therefore, we considered data up to 1 600 000 cells/mL.

The accuracy of the SCC measurement by the usual Fossomatic or Coulter techniques [24] was probably not equal between studies. However, this difference seems to be very small for the most frequent values of SCC. More fundamentally, the within-cow repeatability of a SCC measurement as a concentration measure can be assumed to be low because many factors can influence them. The intensity and the magnitude of an intramammary infection and the related influx of polymorphonuclear neutrophils to the infected quarter can vary very quickly (hours or days) [32]. The concentration can also be influenced by short-term (days or week) variations in milk yield due to other health disorders, stress or reduced feed

intake [8]. However, in the available models, these factors could not be corrected for.

Further research has to focus on sources of some lack of consistency between the test-day loss and lactation loss estimates [4]. More generally, interaction terms must probably be tested. First candidates for these interaction tests would be terms between SCC and parity [3] and between SCC and stage of lactation, because of an existing relationship [39]. It would also be relevant to explore the possible role of the main confounder in the studied relationship: the pathogen responsible for the intramammary infection. Additionally, the use of statistical packages designed to model hierarchical data can be advised to better deal with the hierarchical structure of the data for cow and herd.

## 7. CONCLUSION

The aim of the study can be answered only with reservations, as regards the small number of elementary results for some aspects and the previous elements of discussion. Assuming that no significant modification occurs up to 50 000 cells/mL, the average magnitude of loss in daily milk yield is about 0.6 kg per 2-fold increase of non-transformed SCC in multiparous, and about 0.4 kg in primiparous cows. The average lactational loss is about 120 kg (or about 1.7 %) in multiparous cows and about 80 kg (or about 1.3 %) in primiparous cows. The impact of elevated SCC on the milk composition parameters currently used as pricing parameters is quite small. It can be either neglected or possibly accounted for by a very small increase in protein content (at the test-day level, and by extension, at the lactation level) and a very small decrease in fat content (both at test-day and at the lactation levels).

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