Investigating a dilution effect between somatic cell count and milk yield and estimating milk production losses in Irish dairy cattle

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ABSTRACT

Increased somatic cell counts (SCC) are associated with reduced milk yield. Additionally, it has been hypothesized that as milk yield increases, SCC is diluted in cattle without an intramammary infection (IMI). If the hypothesis is correct, estimates of SCC from high-yielding cattle without an IMI are likely to be lower than those from low-yielding cattle without an IMI. The objectives of this paper were to investigate the presence of a potential dilution effect between SCC and milk yield, overall and by parity, and to estimate lactation milk production losses with increasing SCC in Irish dairy cattle. The data consisted of 100 randomly selected herds from all milk recording herds between 2008 and 2010. The data set comprised 8,229 cows, of which approximately 90% were Holstein or Holstein crossbred animals. Various adjustments were used to investigate the presence of a potential dilution effect between SCC and milk yield; additionally, lactation milk production losses with increasing SCC and parity were estimated. The data had an inherent hierarchical structure, with lactations nested within cows and cows within herds; thus, a linear mixed model with 2 random effects was used. We found no evidence of a dilution effect of SCC with increasing milk yield in Irish dairy cattle. Average milk production losses were estimated, and they increased with increasing SCC compared with the referent of $\leq 50,000$ cells/mL. Additionally, for all SCC values for parities 1 to 3, this production loss increased significantly with increasing parity. Estimated milk losses for parities 4 and 5 did not differ, and differences between parities 3 and 4 were significant only for SCC values $< 300,000$ cells/mL. The estimated milk loss with increasing SCC varies greatly across studies, with the results from the current study exceeding most previously published results (except for results from the UK). Several factors could explain these differences,

including geographic factors such as milk yield and predominant mastitis pathogens. The dilution effect warrants further work, as does the effect of prior duration of increased SCC on milk yield and the potential for compensation of milk yield losses over a lactation.

Key words: somatic cell count, dilution, parity, milk yield

INTRODUCTION

Increased SCC is associated with reduced milk yield (most recently demonstrated by Hand et al., 2012), and several studies have estimated the effect of subclinical mastitis on estimated milk production and on-farm economic loss (Seegers et al., 2003; Halasa et al., 2007). Estimates of milk yield loss with increased SCC have varied across studies, most likely because of differences in methodology (modeling approaches) and the animals under investigation (genotype and phenotype of the Holstein breed; Hand et al., 2012). Several factors are known to impact how increased SCC affects decreased milk yield, including mastitis incidence, pathogen involved, and management (Halasa et al., 2007). Further, higher producing cows exhibit greater milk loss with increased SCC than do lower producing cows (Hand et al., 2012).

One further consideration relates to the potential effect of dilution. Green et al. (2006) hypothesize that as milk yield increases, SCC is diluted in cattle without an IMI; the authors suggested, therefore, that estimates of SCC from high-yielding cattle without an IMI are likely to be lower than estimates of SCC from low-yielding cattle without an IMI. An inverse relationship between SCC and milk yield in quarters without infection has been noted in some studies (Emanuelson and Funke, 1991; Schepers et al., 1997), but not all (Laevens et al., 1997). Emanuelson and Funke (1991) and Schepers et al. (1997) attribute this to a possible dilution effect, although Schepers et al. (1997) does indicate that this effect could also be caused by false positives or by undetected clinical mastitis. A dilution effect was subsequently demonstrated in a single study (Green et al., 2006), using 2-level hierarchical models, based on data

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from approximately 850 Friesian/Holstein dairy cows on 5 farms in Gloucestershire, United Kingdom. The results suggested a decreased concentration of somatic cells with higher yields, particularly in low SCC categories, which led the authors to conclude that failing to account for a dilution in SCC with increasing yield would lead to an error in estimates of the effect of high SCC on milk yield, generally leading to an overestimate of the milk yield loss attributable to increased SCC. Given the small sample size, the authors recommended that “further work ... be done to refine approaches to the estimation of SCC dilution,” including “analysis of quarter milk yields on a large number of cattle and farms ... to further investigate this phenomenon.” No work on this dilution effect has subsequently been published to confirm the results of Green et al. (2006). Although the effect of dilution has been raised in subsequent publications, researchers have either not considered it further (Hand et al., 2012), suggesting that “to date, the dilution effect has not been quantified,” or used the Green et al. (2006) estimates in their calculations (Halasa et al., 2009). Further, no work has yet reported any effect of parity on the dilution effect.

There are no published data on milk yield losses with increasing SCC in an Irish context; such data are required to estimate the on-farm costs of clinical and subclinical mastitis in the national herd. These estimates may differ from those published elsewhere, because Irish dairy farming is primarily spring-calving and pasture-based, with average milk production of approximately 4,700 kg per lactation (production of cow milk/number of dairy cows; International Dairy Federation, 2009). These yields are higher than those reported from New Zealand, but lower than in either the United States or the Netherlands (International Dairy Federation, 2009).

The objectives of this research were 2-fold: (1) to investigate the presence of a potential dilution effect between SCC and milk yield, overall and by parity, and (2) to estimate lactation milk production losses with increasing SCC in Irish dairy cattle, after taking into account a dilution effect, if present.

MATERIALS AND METHODS

The Data

Initially, all test-day records for 2008 to 2010 inclusive were extracted from the Irish Cattle Breeding Federation (ICBF, Bandon, Co. Cork, Ireland) database. Herds with fewer than 10 cows milk recorded in a year, cows that calved twice within 300 d, lactations >5, and test-days after 320 DIM were removed from the data set. A random sample of 100 herds was selected to

reduce the size of the data set for modeling purposes. Simple random sampling was used to randomly select the herds, and all animals in the selected herds were included in the study.

Summary Statistics and Dilution Estimates

First, test-day SCC was divided into 7 categories (<51, 51 to <101, 101 to <201, 201 to <301, 301 to <401, 401 to <1,001, and $\geq 1,001$; $\times 10^3$ cells/mL) and test-day milk yield into 4 categories (10 to <21, 21 to <31, 31 to <41, and ≥ 41 kg). For all parities, mean SCC for each milk yield category and mean milk yield for each SCC category were calculated and plotted.

Second, mean SCC values within parity for each milk yield and SCC category were calculated and used to calculate dilution estimates. As computed in Green et al. (2006), dilution estimates for each SCC category for all parities were calculated by dividing the mean SCC for each milk yield category by the mean SCC for the lowest milk yield category (i.e., 10 to <21 kg).

Statistical Modeling

First, the relationship between SCC (with no adjustment for dilution) and milk yield was investigated. Linear mixed models were used to analyze the data and to take into account the correlations between parities on the same cow and possible correlation between cows in the same herd. Two random effects were included in the model, herd (h) and cow within herd (a), to model these correlations. The random effects were assumed to have normal distributions with means 0 and variances σ_h^2 and σ_a^2 , respectively. Together with the random effects, DIM, and exponential ($\text{DIM}^{-0.05}$) (Wilmink, 1987; Green et al., 2006), breed, parity, SCC category, and SCC category $\times$ parity were included in the model as fixed effects. The response was test-day milk yield.

Then, SCC test-day values were adjusted for dilution in 4 ways and the relationship between the adjusted SCC values and milk yield investigated. Adjustments 3 and 4 were investigated as a result of initial findings in this study (see Results section). The adjustments were as follows.

Adjustment 1. The dilution estimates calculated (described above) were used to adjust test-day SCC as follows: Adjusted SCC = SCC/corresponding SCC dilution estimate.

Adjustment 2. Only test-days with SCC <50,000 cells/mL (these animals were presumed uninfected) were modeled. Somatic cell count was set as the dependent variable, with herd and cow within herd as the random effects. Milk yield, parity, and milk yield $\times$ parity were included as fixed effects. The regression

Table 1. Number of test-day records, number of cows, and mean and standard deviation of milk yield by parity

Parity	Test-day records (no.)	Cows (no.)	Milk yield (kg)	
			Mean	SD
1	19,551	4,250	19.69	5.69
2	16,719	3,428	22.49	6.80
3	13,841	2,836	23.95	7.31
4	10,253	2,152	24.45	7.62
5	7,179	1,540	24.55	7.56

coefficient for milk yield (β) was estimated for each parity, multiplied by -1 , multiplied by milk yield, and added to the SCC: Adjusted SCC = SCC + $(-\beta)(\text{milk yield})$. This adjustment assumed a linear dilution with increasing yield.

Adjustment 3. Dilution estimates were calculated using only 2 SCC categories, $\leq 200,000$ and $> 200,000$ cells/mL and used to adjust SCC test-day values as in adjustment 1.

Adjustment 4. Dilution estimates were calculated using 4 SCC categories $< 51,000$, $51,000$ to $< 101,000$, $101,000$ to $< 201,000$, and $\geq 201,000$ cells/mL and used to adjust SCC test-day values as in adjustment 1.

The data were analyzed using the MIXED procedure (SAS Institute, 1999) for linear mixed models. The residuals from the models were assessed for normality using normal probability plots. The residuals were also plotted against the fitted values and tested for outliers with the significance level adjusted using the Bonferroni method. The approaches above to adjust milk loss for dilution were compared with the unadjusted model.

RESULTS

The Data

The data set contained 2,387,111 records from 6,199 herds containing 491,631 cows. Herds with fewer than 10 cows milk recorded in a year, cows that calved twice within 300 d, lactations > 5 , and test-days after 320 DIM were removed from the data set, leaving 1,470,635 records. After randomly selecting 100 herds and including all animals in these herds, the final data set consisted of 67,543 test-day records collected from 8,229 cows.

Summary Statistics and Dilution Estimates

Descriptive statistics were examined and the number of cows, number of test-day records, and mean and standard deviation of milk yield are given in Table 1.

Mean SCC for all milk yield categories for all parities were calculated and the results were plotted (Figure 1). For parities 2 and 4, mean test-day SCC decreased with

increasing milk yield to 31 to 41 kg and then increased. For parity 5, mean test-day SCC steadily decreased as milk yield increased and for parity 3 SCC decreased when milk yield increased to 21–31 kg before increasing. This indicates that SCC is not constant and, for parity 5 only, decreased as milk yield increased.

Mean SCC for all milk yield and SCC categories for all parities were calculated. Then, dilution estimates (Table 2) for each SCC category for all parities were calculated by dividing the mean SCC for each milk yield category by the mean SCC for the lowest milk yield category (i.e., 10 to < 21 kg). Table 2 also shows the mean SCC for the lowest milk yield category. For the first 3 SCC categories ($< 51,000$, $51,000$ to $< 101,000$, and $101,000$ to $< 201,000$ cells/mL), the majority of the estimates were < 1 , with the exception of parity 1 in the $< 51,000$ cells/mL category, indicating that SCC was lower in this category compared with the baseline of $< 51,000$ cells/mL. On the other hand, for SCC categories $201,000$ to $< 301,000$, $301,000$ to $< 401,000$, and $401,000$ to $< 1,001,000$ cells/mL, the majority of the estimates, with some exceptions, were close to or greater than 1. This suggests a possible dilution effect with increasing milk yield up to SCC values of 200,000 cells/mL. For SCC $> 200,000$ cells/mL, we found no evidence of a dilution effect. This led to adjustments 3 and 4 (see Materials and Methods section).

Statistical Modeling

When SCC was adjusted for dilution using the methods described above, the adjusted SCC values for adjustment 1 were, on average, slightly higher than the unadjusted values. Hence, for this adjustment, fewer observations were within the lowest SCC class in the adjusted data set compared with the unadjusted data set.

For adjustment 2, SCC was adjusted for a decrease in higher yield due to dilution. The regression parameters for yield (-0.2302 , -0.2724 , -0.2595 , -0.2857 , and -0.3499 for parities 1 to 5, respectively) were used to estimate dilution for all observations in the data set, regardless of SCC value.

Figure 1. Mean test-day SCC ($\times 1,000$ cells/mL) by milk yield category and parity.

Both random effects (herd and cow within herd) and all the fixed effects were significant in all models ($P < 0.05$). The variance components and -2 log-likelihood values were similar for all models (Table 3), but the unadjusted model showed the best fit to the data. The estimated change in milk yield with increasing SCC for all parities for the unadjusted model is given in Table 4. For all parities, a significant reduction in test-day milk yield, compared with that at a baseline of $<51,000$ cells/mL, was observed with an increase in SCC category, with one exception: no significant difference was observed in the estimated milk yield loss between SCC values $<51,000$ cells/mL and 51,000 to 101,000 cells/mL for parity 1. Additionally, this reduction in test-day milk yield increased with increasing parity, for all SCC values in parities 1 to 3 (results not shown). Estimated milk losses did not differ for parities 4 and 5, and differences between parities 3 and 4 were significant only for SCC values $<300,000$ cells/mL. The estimated change in milk yield with increasing SCC varied from approximately -0.13 to -1.52 kg and from -1.39 to -4.18 kg, with the unadjusted model, for parities 1 and 5, respectively.

Detailed information on the unadjusted association between milk loss and SCC for animals of different milk quartiles is also presented in Table 4. When milk yield was divided into quartiles, very few significant differences were found in the estimated milk losses with an

increase in SCC category for quartiles 2 and 3. Significant differences were seen for quartile 1 in parities 1, 2, and 3, and some differences were seen for quartile 4 in parities 4 and 5.

DISCUSSION

In contrast to earlier work (Green et al., 2006), we found no evidence in this study of a dilution effect (a decrease in SCC with increasing milk yield) in Irish dairy cattle. Various adjustments in SCC were used to test different patterns of dilution, and linear mixed models, adjusted for herd effects and cow effects by including 2 random effects, were used to model the data. Similar results were obtained, regardless of the assumptions made for each model, using adjustment approaches previously used by Green et al. (2006) to investigate different patterns of dilution (Table 3). Descriptive statistics (Figure 1) and dilution estimates (Table 2) indicated evidence of dilution in low SCC categories ($<200,000$ cells/mL) but using adjustments yielded similar results to the unadjusted model. Although the potential for a dilution effect has been considered for some time, it has only been demonstrated once, in a single study by Green et al. (2006). Our findings suggest that the production of SCC varies with milk volume, in agreement with earlier results from Emanuelson and Funke (1991). In keeping with a recommendation from those

Table 2. Estimated dilution by milk yield and SCC category for all parities (calculated by dividing the mean SCC for each milk yield category by the mean SCC for the 10 to <21 kg milk yield category)¹

Item	SCC category ($\times 10^3$ cells/mL)						
	<51	51 to <101	101 to <201	201 to <301	301 to <401	401 to <1,001	$\geq 1,001$
Parity 1							
Mean SCC							
10 to <21 kg	34	73	141	243	344	608	2,659
Dilution estimate							
21 to <31 kg	0.99	0.98	0.99	1.00	1.01	0.99	0.86
31 to <41 kg	1.00	0.97	1.00	1.01	0.99	0.97	1.40
≥ 41 kg	1.02	0.98	0.95	1.22	1.13	0.78	0.73
Parity 2							
Mean SCC							
10 to <21 kg	34	73	142	243	342	598	2,645
Dilution estimate							
21 to <31 kg	0.93	0.97	0.99	0.99	1.00	1.00	0.89
31 to <41 kg	0.95	0.96	1.00	0.96	0.99	1.00	0.89
≥ 41 kg	0.98	0.96	0.93	1.05	1.05	0.94	0.98
Parity 3							
Mean SCC							
10 to <21 kg	34	75	144	245	342	608	2,369
Dilution estimate							
21 to <31 kg	0.92	0.96	0.97	0.99	1.01	1.00	1.09
31 to <41 kg	0.94	0.94	0.96	0.99	1.01	1.01	1.21
≥ 41 kg	0.91	0.93	1.02	1.00	1.01	0.89	1.27
Parity 4							
Mean SCC							
10 to <21 kg	35	76	146	245	346	600	2,675
Dilution estimate							
21 to <31 kg	0.91	0.96	0.97	0.98	1.00	1.04	0.87
31 to <41 kg	0.91	0.95	0.97	0.98	1.00	1.08	0.80
≥ 41 kg	0.94	0.90	0.96	1.01	0.96	1.01	1.33
Parity 5							
Mean SCC							
10 to <21 kg	36	75	147	243	350	600	2,551
Dilution estimate							
21 to <31 kg	0.89	0.98	0.98	1.02	0.99	1.04	0.95
31 to <41 kg	0.83	0.96	0.95	1.00	1.00	1.04	0.99
≥ 41 kg	0.97	0.98	0.94	1.02	0.97	1.27	0.72

¹For the lowest milk yield category (10 to <21 kg), the mean SCC (10^3 cells/mL) is shown.

authors, the current study represents a 10-fold increase in animal numbers (8,229 cows from 100 randomly selected herds compared with the earlier ~850 cows from 5 farms).

In common with other studies, we observed an increase in estimated milk loss with increasing SCC and some parities (Table 4). We found a significant effect of parity for SCC values <300,000 cells/mL in parities 1 to 4, with the average estimated milk loss varying from 0.33 kg (0.09–0.58) for parity 1 to 2.76 kg (2.37–3.15) for parity 5 for an SCC value of 150,000 to 200,000

cells/mL compared with 50,000 cells/mL (Tables 4 and 5). Additionally, the estimated milk loss for all SCC categories and all parities was significantly different (compared with the referent of $\leq 50,000$ cells/mL; $P < 0.05$). The only exception was in parity 1 for 51,000 to <101,000 cells/mL. Estimated test-day milk losses with increasing SCC by parity were compared with results of other studies (Hortet et al., 1999; Green et al., 2006; Durr et al., 2008; Halasa et al., 2009; Hand et al., 2012), and the results are presented in Table 5. For comparison of estimated test-day milk loss, the

Table 3. Variance components (SE) and -2 log-likelihood estimates for the unadjusted model and those with adjustments

Item	No adjustment	Adjustment 1	Adjustment 2	Adjustment 3	Adjustment 4
Herd	9.32 (1.35)	9.37 (1.36)	9.39 (1.36)	9.38 (1.36)	9.31 (1.35)
Animal within herd	6.76 (0.15)	6.77 (0.15)	6.77 (0.15)	6.70 (0.15)	6.76 (0.16)
Error	15.17 (0.09)	15.22 (0.09)	15.28 (0.09)	15.47 (0.09)	15.19 (0.09)
-2 log-likelihood	387,064	387,274	387,485	388,200	387,189

Table 4. Estimated, unadjusted change in test-day milk yield (kg) with increasing SCC (compared with the baseline of <51,000 cells/mL) for all parities and milk quartiles

SCC ($\times 10^3$ cells/mL)	Milk yield (no adjustment)		Milk quartile							
			1		2		3		4	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Parity 1										
<51										
51 to <101	-0.13	0.08	-0.18	0.08	-0.02	0.08	-0.15	0.09	0.11	0.13
101 to <201	-0.30 ^a	0.09	-0.21	0.09	-0.14	0.09	-0.32 ^a	0.11	0.20	0.16
201 to <301	-0.50 ^a	0.13	-0.31 ^a	0.11	-0.16	0.14	-0.10	0.17	-0.92 ^a	0.26
301 to <401	-0.80 ^a	0.19	-0.51 ^a	0.16	-0.31	0.20	-0.39	0.26	0.15	0.38
401 to <1000	-0.58 ^a	0.16	-0.44 ^a	0.15	-0.07	0.16	-0.16	0.20	0.27	0.29
$\geq 1,000$	-1.52 ^a	0.20	-0.80 ^a	0.19	-0.42	0.21	-0.54	0.23	0.12	0.33
Parity 2										
<51										
51 to <101	-0.60 ^a	0.08	-0.17	0.12	-0.10	0.10	-0.23	0.09	0.12	0.09
101 to <201	-1.42 ^a	0.09	-0.51 ^a	0.12	-0.33	0.11	-0.37 ^a	0.10	-0.29	0.11
201 to <301	-2.00 ^a	0.13	-0.66 ^a	0.15	-0.26	0.15	-0.76 ^a	0.16	0.04	0.19
301 to <401	-2.23 ^a	0.19	-0.87 ^a	0.19	-0.50	0.23	-0.41	0.25	-0.37	0.26
401 to <1000	-1.92 ^a	0.17	-1.20 ^a	0.19	-0.47	0.20	-0.46	0.20	0.30	0.23
$\geq 1,000$	-2.07 ^a	0.22	-0.91 ^a	0.25	-0.57	0.26	-0.57	0.24	0.36	0.28
Parity 3										
<51										
51 to <101	-1.09 ^a	0.10	-0.16	0.18	-0.03	0.13	-0.28	0.11	0.12	0.09
101 to <201	-2.02 ^a	0.10	-0.27	0.17	-0.14	0.13	-0.49 ^a	0.11	-0.43 ^a	0.11
201 to <301	-2.81 ^a	0.14	-0.47 ^a	0.19	-0.39	0.17	-0.42	0.16	-0.24	0.17
301 to <401	-3.17 ^a	0.19	-0.80 ^a	0.23	-0.23	0.22	-0.68	0.24	-0.45	0.25
401 to <1000	-3.15 ^a	0.16	-0.85 ^a	0.21	-0.50	0.19	-0.69 ^a	0.19	-0.34	0.17
$\geq 1,000$	-2.96 ^a	0.21	-0.97 ^a	0.30	-0.72	0.26	-0.59	0.22	0.31	0.21
Parity 4										
<51										
51 to <101	-1.45 ^a	0.12	0.09	0.26	0.08	0.18	-0.27	0.14	-0.23	0.11
101 to <201	-2.48 ^a	0.12	-0.07	0.25	-0.13	0.18	-0.50 ^a	0.14	-1.01 ^a	0.11
201 to <301	-3.10 ^a	0.16	-0.27	0.27	-0.19	0.21	-0.59	0.19	-0.86 ^a	0.17
301 to <401	-3.69 ^a	0.20	-0.53	0.29	-0.15	0.26	-0.41	0.26	-1.29 ^a	0.23
401 to <1000	-3.74 ^a	0.17	-0.50	0.27	-0.34	0.22	-0.47	0.20	-0.96 ^a	0.18
$\geq 1,000$	-3.54 ^a	0.21	-0.61	0.33	-0.49	0.27	-0.73	0.24	-0.86 ^a	0.20
Parity 5										
<51										
51 to <101	-1.39 ^a	0.16	-0.66	0.39	0.09	0.25	-0.17	0.17	-0.12	0.13
101 to <201	-2.59 ^a	0.16	-0.70	0.37	0.09	0.23	-0.48	0.18	-0.84 ^a	0.14
201 to <301	-3.28 ^a	0.19	-0.93	0.39	-0.14	0.26	-0.45	0.28	-0.44	0.20
301 to <401	-3.58 ^a	0.24	-1.06	0.42	-0.07	0.32	-0.53	0.27	-0.49 ^a	0.26
401 to <1000	-4.16 ^a	0.20	-1.33 ^a	0.38	-0.25	0.27	-0.37	0.22	-1.26 ^a	0.19
$\geq 1,000$	-4.18 ^a	0.22	-1.52 ^a	0.41	-0.33	0.29	-0.62	0.24	-1.34 ^a	0.21

^aEstimated change in milk yield was significantly different ($P < 0.05$) from baseline (<51,000 cells/mL).

referent SCC value was adjusted to 50,000 cells/mL, and milk loss was expressed as a percentage of the average milk yield for that parity, whenever possible. The estimated milk loss with increasing SCC varied greatly across studies (Table 5), with the results from the current study exceeding most previously published values, with the exception of those from the UK (Green et al., 2006). However, no average milk yields were given in Green et al. (2006) and hence the proportions cannot be compared. This issue has been considered previously, and several possible reasons for the differences have been suggested. Hand et al. (2012) attribute the observed variation to differing modeling approaches, whereas Halasa et al. (2007) suggest that differences

may be due to geographic area, which can be supported by differences in reported average milk yields. Studies in France (Hortet et al., 1999), Canada (Durr et al., 2008), and the Netherlands (Halasa et al., 2009) reported larger average milk yields compared with those in the current study. Hand et al. (2012) showed that higher yielding animals demonstrated greater milk loss than lower yielding animals. In this study, we investigated the effect of milk quartile and estimated milk losses for all parities and milk quartiles (compared with the referent of 50,000 cells/mL; Table 4). We found that most significant differences were for parities 1 to 3 for milk quartile 1 (the lower producing cows) only, with very few significant differences seen for milk quartiles

Table 5. Estimated test-day milk loss (kg; % of average milk yield for that parity given in parentheses) and 95% confidence intervals (in brackets, where available) with increasing SCC ($\times 10^3$ cells/mL; compared with the baseline of 50,000 cells/mL unless otherwise stated) for all parities compared with previously published papers

Parity	This study	Hortet et al. (1999) ¹	Durr et al. (2008) ¹	Halasa et al. (2009) ^{2,3}	Green et al. (2006) ^{3,4,5}	Hand et al. (2012) ^{5,6}
	SCC = 150–200	SCC = 200	SCC = 200	SCC = 200	SCC = 100–200	SCC = 200
All	1.51 (7.60%) [1.37 to 1.64]				3.09 [2.68 to 3.50]	
1	0.33 (1.68%) [0.09 to 0.58]	0.61 (2.71%)	0.46–0.72 (1.70–2.66%)	0.28 (1.21%) [0.20 to 0.35]		0.35–0.80
2	1.43 (6.37%) [1.18 to 1.68]	0.63–1.77 (2.35–6.60%)				0.61–1.07
≥ 2	1.89 (7.99%) [1.74 to 2.04]		1.05–2.50 (3.29–7.83%)	0.50 (2.60%) [0.44 to 0.56]		
3	2.25 (9.41%) [1.98 to 2.53]					
≥ 3	2.41 (9.92%) [2.22 to 2.59]	0.60–1.85 (2.14–6.61%)				0.63–1.09
4	2.63 (10.76%) [2.31 to 2.95]					
5	2.76 (11.25%) [2.37 to 3.15]					
	SCC = 350–400		SCC = 400	SCC = 400	SCC = 200–400	
All	2.28 (10.15%) [2.02 to 2.55]				4.63 [4.10 to 5.16]	
1	0.94 (4.78%) [0.40 to 1.48]		0.69–1.08 (3.07–4.80%)	0.42 (1.82%) [0.34 to 0.50]		
2	2.00 (8.87%) [1.42 to 2.57]					
≥ 2	2.62 (11.06%) [2.32 to 2.91]		1.58–3.74 (4.95–11.71%)	0.78 (4.05%) [0.72 to 0.83]		
3	2.95 (12.30%) [2.40 to 3.50]					
4	3.23 (13.31%) [2.89 to 3.56]					
5	3.66 (14.97%) [3.10 to 4.22]					
	SCC = 550–600	SCC = 600	SCC = 600	SCC = 600	SCC >400	SCC = 600
All	2.68 (11.92%) [2.28 to 3.08]				3.88 [3.33 to 4.43]	
1	0.74 (3.77%) [–0.14 to 1.63]	1.09 (4.84%)	0.82–1.29 (3.64–5.73%)	0.50 (2.16%) [0.42 to 0.58]		0.89–2.08
2	2.48 (11.02%) [1.45 to 3.51]	1.13 ⁷ (4.22%)				1.59–2.77
≥ 2	3.05 (12.91%) [2.61 to 3.50]		1.88–4.47 (5.89–14.00%)	0.94 (4.88%) [0.88 to 1.00]		
3	3.53 (14.75%) [2.72 to 4.35]					
≥ 3	3.65 (15.04%) [3.16 to 4.13]	1.07 ⁷ (3.82%)				1.63–2.81
4	3.83 (15.66%) [3.00 to 4.66]					
5	4.17 (17.00%) [3.30 to 5.04]					

¹Estimates vary depending on stage of lactation (i.e., DIM).

²Referent SCC of 31,000 cells/mL.

³Adjusted for dilution.

⁴Milk loss in liters.

⁵No average milk yields were given in Green et al. (2006) and Hand et al. (2012) to calculate the average milk loss as a percentage of the average milk yield.

⁶Referent SCC of 100,000 cells/mL and estimates vary depending on milk quartile.

⁷Calculated for 50 DIM.

2, 3, and 4. Geographical differences are also likely in the relative importance of different mastitis pathogens. In Ireland, where udder health is a concern on many dairy farms (More et al., 2012), *Staphylococcus aureus* is the predominant pathogen (AFBI/DAFF, 2010). In contrast, *Streptococcus uberis* and *Escherichia coli* were the most common isolates from clinical cases of mastitis (and *Strep. uberis* from subclinical cases), highlighting the importance of environmental pathogens in England and Wales (Bradley et al., 2007).

CONCLUSIONS

We found no evidence of a dilution effect in Irish dairy cattle. Milk loss increased in association with increases in certain parities and SCC among Irish cattle, in agreement with several other studies. However, the effect of SCC on milk yield was greater in Irish dairy cattle compared with most of the other populations under investigation, despite the lower milk yields. Further work on the dilution effect in other countries is warranted, given the different results obtained and the potential influence of geographic factors such as predominant mastitis pathogen. Additional research is needed to investigate the effect of prior duration of increased SCC (the length of time that an animal has an SCC >50,000 cells/mL) on milk yield and the potential for compensation of the milk yield losses due to elevated SCC over a lactation.

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