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Association of season and herd size with somatic cell count for cows in Irish, English, and Welsh dairy herds

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ABSTRACT

The aims of this study were to describe associations of time of year, and herd size with cow somatic cell count (SCC) for Irish, English, and Welsh dairy herds. Random samples of 497 and 493 Irish herds, and two samples of 200 English and Welsh (UK) herds were selected. Random effects models for the natural logarithm of individual cow test day SCC were developed using data from herds in one sub-dataset from each country. Data from the second sub-datasets were used for cross validation.

Baseline model results showed that geometric mean cow SCC (GSCC) in Irish herds was highest from February to August, and ranged from 111,000 cells/mL in May to 61,000 cells/mL in October. For cows in UK herds, GSCC ranged from 84,000 cells/mL in February and June, to 66,000 cells/mL in October. The results highlight the importance of monitoring cow SCC during spring and summer despite low bulk milk SCC at this time for Irish herds. GSCC was lowest in Irish herds of up to 130 cows (63,000 cells/mL), and increased for larger herds, reaching 68,000 cells/mL in herds of up to 300 cows. GSCC in UK herds was lowest for herds of 130–180 cows (60,000 cells/mL) and increased to 63,000 cells/mL in herds of 30 cows, and 68,000 cells/mL in herds of 300 cows. Importantly, these results suggest expansion may be associated with increased cow SCC, highlighting the importance of appropriate management, to benefit from potential economies of scale, in terms of udder health.

Introduction

For individual dairy producers, treatment costs, production losses, and reduced sale value of high somatic cell count (SCC) milk are well known consequences of mastitis (Halasa et al., 2007). In the dairy processing industry, increased SCC is associated with both shortened shelf life of pasteurised milk (Santos et al., 2003), and reduced cheese yields (Barbano et al., 1991). Seasonal increase in bulk milk SCC (BMSCC) supplied to dairies has been reported from Ireland (Berry et al., 2006) and from England and Wales (Green et al., 2006b), reducing the ability of these countries to meet demand for high quality milk products.

In general BMSCC is highest in spring and summer in those countries where calving patterns are non-seasonal, such as England and Wales (Green et al., 2006b), Canada (Sargeant et al., 1998; Olde Riekerink et al., 2007) and Holland (Barkema et al., 1998; Lievaart et al., 2007), and is possibly related to the influence of higher temperature and humidity on intramammary infection (IMI) risk (Morse et al., 1988). In Ireland, however, BMSCC is generally lowest during April, and highest in November (Berry et al., 2006), because spring-calving predominates in this country. BMSCC in Ireland is therefore lowest when most milk is produced, but this may not reflect udder health, because cow level SCC dynamics associated with IMI may be masked by dilution (Green et al., 2006a). A key time for the occurrence of new infections in Irish dairy herds may therefore be overlooked if monitoring strategies use only BMSCC.

Increasing herd size is common throughout the developed dairy industry worldwide; producers hope to benefit from economies of scale accrued from lower investments per cow, lower variable costs per unit of production, and increased labour efficiency (Bailey et al., 1997). Larger herds in the US have been reported to have lower cow level average SCC compared to smaller herds (Oleggini et al., 2001), however, large Dutch herds have been reported to have higher BMSCC (Barkema et al., 1998). In general, Irish, English, and Welsh dairy herds are increasing in size (DairyCo, 2010; ICBF, 2010), and it is important for these industries to evaluate the effect on SCC.

The aims of this research were twofold. Firstly, we wished to investigate the association between time of year and cow SCC, particularly in Irish dairy herds after accounting for stage of lactation. Secondly, we evaluated the association between herd size and cow SCC in Irish, English, and Welsh dairy herds in order to assess the impact of herd expansion on SCC.

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Table 1
Selection criteria for the Irish, and English and Welsh datasets.

Variable	Range before selection	Range after selection	Recordings removed (%)
Irish dataset			
Days in milk	−503 to 3548	5–304	10
Parity	1–87	<15	0.2
Test day milk yield (kg)	0.2–92.6	>1 and <71	0.003
Calving interval[a] (days)	−1046 to 2265	⩾300	0.4
English and Welsh dataset			
Days in milk	1–1794	5–304	17
Parity	1–19	<15	0.001
Test day milk yield (kg)	0.2–99.8	>1 and <71	0.003
Calving interval (days)	36–1647	⩾300	0.3

[a] For cows with more than 1 recorded calving date from subsequent parities.

Table 2
Descriptive results for the selected Irish dataset (Ire_dat), and the selected English and Welsh dataset (UK_dat).

Variable	Lower quartile	Median	Upper quartile
Irish dataset			
Test day milk yield (kg)	17	22	28
Test day fat proportion	0.034	0.038	0.043
Test day protein proportion	0.032	0.034	0.036
Test day somatic cell count (cells/mL)	55,000	110,000	243,000
Mean herd size (cows)	46	71	81
English and Welsh dataset			
Test day milk yield (kg)	21	27	33
Test day fat proportion	0.034	0.039	0.043
Test day protein proportion	0.030	0.032	0.034
Test day somatic cell count (cells/mL)	37,000	74,000	173,000
Mean herd size (cows)	101	139	189

Materials and methods

Data

Data from 2005 to 2009, comprising 11,619,287 records from 964,612 cows in 8095 Irish herds, were provided by Irish Cattle Breeders Federation, and restricted to remove impossible values (Table 1). For each herd year, the mean number of cows present per test day was determined (herd size); herds with a mean of ⩽10 cows were excluded. The minimum proportion of cows present per test day in each herd year had a distribution with distinct modes at 0.05 and 0.65. It was deemed that there were differences between recordings with a low minimum proportion of the herd present at a test date, compared to the majority (possibly associated with purchased cows), and 0.7% of recordings were excluded in which <10% of the mean annual number of cows were present. For inclusion, ⩾4 herd test day recordings per year were required; 5% of herd years not meeting this criterion were excluded. The cleaned dataset (Ire_dat) contained 10,181,545 recordings from 1,938,359 lactations in 860,563 cows, in 7551 herds.

A second dataset was available for English and Welsh (UK) herds from 2004 to 2006, provided by National Milk Records. Selection criteria for this dataset have been described in detail (Madouasse, 2009). Briefly, herd years with at least 10 test dates based on ⩾20 cows were included, and those with factored data were removed. At least 80% of cows were Holstein or Friesian breeds. The data were limited (Table 1) and the final dataset (UK_dat) contained 6,772,182 records from 953,242 lactations in 474,669 cows in 2128 herds.

Descriptive statistics

Since not all variables were normally distributed, median and interquartile ranges (IQRs) were evaluated for each variable. The numbers of cows (parity 1 and >1) calving in each calendar month were determined. Herd level geometric means of test day SCC were calculated for cows by lactation month (1–10), and parity (1 and >1), because lactation curve shape differed mostly between these groups.

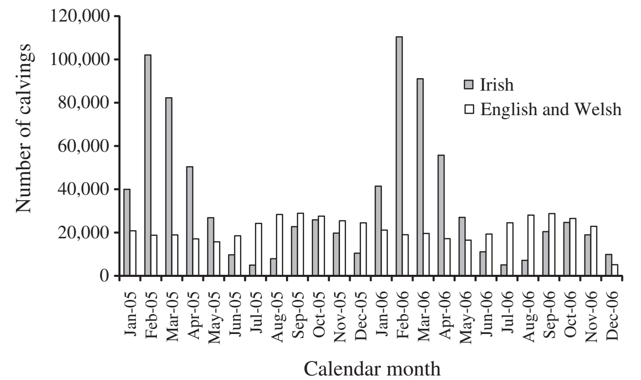

Fig. 1. Number of cows calving per month during 2005 and 2006 for 7551 Irish (Ire_dat) and 2128 English and Welsh dairy herds (UK_dat).

Table 3
Geometric mean cow level somatic cell count (cells/mL) for the median herd by month of lactation in the selected Irish (Ire_dat) and English and Welsh (UK_dat) datasets.

Month of lactation	Irish dataset		English and Welsh dataset	
	Parity 1	Parity > 1	Parity 1	Parity > 1
1	104,000	101,000	75,000	75,000
2	75,000	93,000	50,000	60,000
3	77,000	106,000	50,000	67,000
4	83,000	121,000	54,000	76,000
5	89,000	137,000	57,000	86,000
6	96,000	154,000	59,000	96,000
7	102,000	173,000	61,000	107,000
8	112,000	196,000	65,000	121,000
9	122,000	224,000	69,000	137,000
10	127,000	245,000	74,000	158,000

Random samples of 497 Irish, and 200 UK herds were selected from Ire_dat, and UK_dat respectively, and the corresponding records extracted. Sample sizes were selected to give the largest sub-datasets of Irish ($\text{Ire\_dat}^{\text{SUB1}}$), and UK ($\text{UK\_dat}^{\text{SUB1}}$) herds, with similar numbers of lines in each, that could be handled with the available computing power. $\text{Ire\_dat}^{\text{SUB1}}$ contained 633,751 records from 122,707 lactations in 56,899 cows, and $\text{UK\_dat}^{\text{SUB1}}$ contained 635,346 records from 88,798 lactations in 43,943 cows. Actual BMSCC was not available for the herds of interest; therefore BMSCC over the study period was estimated from individual cow records using $\text{Ire\_dat}^{\text{SUB1}}$ and $\text{UK\_dat}^{\text{SUB1}}$.

For each calendar month j, in each herd k, BMSCC was approximated by the arithmetic mean of the yield corrected SCC from test day records i as:

$$\text{BMSCC}_{jk} \approx \sum(\text{SCC}_{ijk}\ (\text{cells/mL}) \times \text{TDY}_{ijk}\ (\text{mL}))/\sum \text{TDY}_{ijk}\ (\text{mL}),$$

where $\sum$ = sum of, and TDY = test day milk yield.

Estimated BMSCC was compared with the cow level data, both before and after adjustment for the confounding influence of stage of lactation, and milk yield in the following models.

Model development

Random effects models that include random effects in addition to fixed effects were used to account for a lack of independence due to clustering in the data. Models were constructed using $\text{Ire\_dat}^{\text{SUB1}}$ and $\text{UK\_dat}^{\text{SUB1}}$; natural logarithm (ln) SCC at the test day level for individual cows was the outcome variable used to ensure normality of residuals. The models took the form;

$$Y_{ijkl} = \alpha + X_{ijkl}\beta_1 + X_{jkl}\beta_2 + X_{kl}\beta_3 + X_l\beta_4 + f_l + v_{kl} + u_{jkl} + e_{ijkl}$$

$$f_l \sim \text{MVN}\left(0, \sum_f\right)$$

$$v_{kl} \sim N(0, \sigma_v^2)$$

$$u_{jkl} \sim N(0, \sigma_u^2)$$

$$e_{ijkl} \sim N(0, \sigma_e^2)$$

where $y_{ijkl} = \ln\text{SCC}$ at test day i, in parity j, for cow k, in herd l, α = intercept value, X_{ijkl} = matrix of test day variables, β_1 = vector of coefficients for X_{ijkl}, X_{jkl} = matrix of parity variables, β_2 = vector of coefficients for X_{jkl}, X_{kl} = matrix of cow variables, β_3

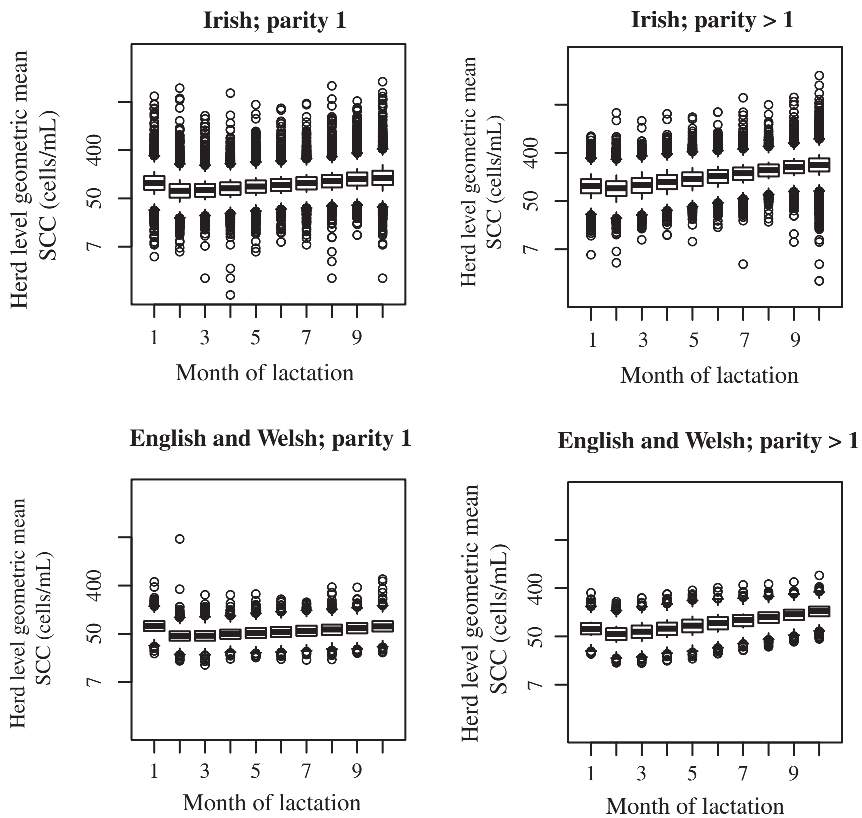

Fig. 2. Distributions (For each calendar month; the median herd is the horizontal black line, the surrounding boxes contain data for 50% of herds, the attached whiskers extend to 1.5 times the interquartile range (95% of the data), and outliers are marked by circles.) of herd level geometric mean test day somatic cell count, for primiparous and multiparous cows, by month of lactation for 7551 Irish (Ire_dat) and 2128 English and Welsh dairy herds (UK_dat).

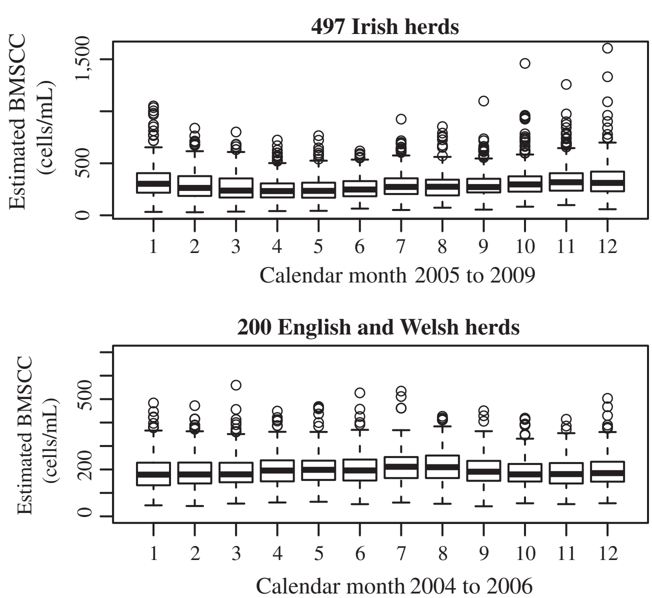

Fig. 3. Herd level distributions of bulk milk somatic (BMSCC) (Estimated from test day milk yield and somatic cell count data.) by calendar month for 497 Irish (Ire_dat^{SUB1}) and 200 English and Welsh dairy herds (UK_dat^{SUB1}).

= vector of coefficients for X_{kl}, X_l = matrix of herd variables (including polynomials of herd size), β_4 = vector of coefficients for X_l, f_l = matrix of random effects to account for herd level variation in α, and fixed effect coefficients for calendar month (multivariate normal distribution with mean = 0 and covariance matrix $\sum_f$), v_{kl} = random effect to account for variation between cows (normal distribution with mean 0 and variance σ_v^2), u_{jkl} = random effect to account for variation between parities (normal distribution with mean 0 and variance σ_u^2), and e_{ijkl} = residual level 1 error (normal distribution with mean 0 and variance σ_e^2). Model parameters were estimated by the iterative generalised least squares procedure (Goldstein, 2003), using MLwiN 2.22 (Rasbash et al., 2009).

Categorical variables were constructed for year, calendar month, and parity (1 to 5+). To account for dilution of SCC with increased TDY on a linear scale, and reduced TDY with increased SCC due to IMI on an exponential scale (Green et al., 2006a), ln TDY and ln ln TDY were included as the outcome of the models was ln SCC. Stage of lactation was included as days in milk (DIM) + $e^{-0.065 \times \text{DIM}}$ (Silvestre et al., 2006). Biologically plausible interactions, and herd level variation in fixed effects were assessed. Variables remained in the model if the mean value of coefficients was more than twice the standard error ($P \leqslant 0.05$), and their inclusion resulted in a decrease in the deviance. Intra-class correlation coefficients (ICCs) for the unexplained variance at each level of the model were calculated (Dohoo et al., 2009).

Assessment of model fit

To assess model fit, distributions of standardised residuals at the herd, cow, parity, and recording level were examined for normality. Further checking used within model predictions; fixed effects were applied to each line of Ire_dat^{SUB1} and UK_dat^{SUB1} to predict ln SCC. Predictions were compared graphically to observed data, and residuals checked for normality, and correlation (r^2; Petrie and Watson, 2004). Equations for regression lines between observed and predicted values were estimated.

To further assess model fit and usefulness, cross validation was carried out in two further random samples of 493 different Irish, and 200 different UK herds taken from Ire_dat and UK_dat respectively. The second Irish sub-dataset (Ire_dat^{SUB2}) contained 678,950 records from 125,493 lactations in 56,902 cows, and the second UK sub-dataset (UK_dat^{SUB2}) contained 613,072 records from 86,036 lactations in 42,539 cows. Fixed effects from the respective model were used to predict ln SCC for every line of Ire_dat^{SUB2}, and UK_dat^{SUB2} using Microsoft Excel (2007). Comparisons with the observed data were repeated. Shrinkage of r^2 on cross validation (Dohoo et al., 2009) was assessed to determine if the models could be generalised to other herds, not involved in parameter estimation.

Table 4
Final models of repeated ln[a] SCC ('000 cells/mL) within cow parity, from 497 and 200 randomly selected herds from Ireland and England and Wales respectively; fixed effects.

Fixed effects (baseline)	Irish model		English and Welsh model	
	Mean	Standard error[b]	Mean	Standard error
Intercept	4.146	0.040	4.119	0.036
Year (2005)				
2004	NA[c]	NA	−0.055	0.004
2006	0.004	0.006	0.027	0.004
2007	−0.038	0.006	NA	NA
2008	−0.105	0.007	NA	NA
2009	−0.020	0.007	NA	NA
ln TDY[d] (mean)[e]	−0.965	0.026	−1.396	0.034
ln ln TDY (mean)	0.762	0.068	1.650	0.096
ln TDF[f] (mean)	0.444	0.008	0.351	0.008
ln TDP[g] (mean)	1.124	0.017	1.477	0.019
DIM[h] (5)	−0.0004	0.00001	0.0007	0.0001
$e^{(-0.065 \times \mathrm{DIM})}$ (5 DIM)	0.055	0.060	0.188	0.041
Month of recording (October)				
January	0.308	0.047	0.282	0.032
February	0.481	0.042	0.312	0.034
March	0.483	0.040	0.237	0.034
April	0.495	0.041	0.242	0.036
May	0.524	0.043	0.149	0.037
June	0.549	0.049	0.235	0.036
July	0.494	0.059	0.168	0.033
August	0.463	0.068	0.125	0.031
September	0.122	0.056	0.058	0.029
November	0.126	0.049	0.173	0.030
December	0.422	0.054	0.200	0.032
Parity (2)				
1	0.320	0.020	0.220	0.021
3	0.082	0.022	0.150	0.022
4	0.266	0.024	0.307	0.024
5+	0.514	0.020	0.533	0.021
Size (mean)				
$(\mathrm{Size})^1$	0.00007	0.0001	0.0005	0.0002
$(\mathrm{Size})^2$	0.000003	0.000001	0.000004	0.000001
$(\mathrm{Size})^3$	−0.000000007	0.000000004	NA	NA
Month of recording and DIM (October, 5 DIM)				
January	−0.0002	0.0001	−0.0007	0.00008
February	0.0002	0.0001	−0.0007	0.00008
March	0.0008	0.0001	−0.0005	0.00008
April	0.0011	0.0001	−0.0003	0.00008
May	0.0008	0.0001	−0.000004	0.00008
June	0.0004	0.0001	0.00003	0.00008
July	0.00002	0.0001	−0.0001	0.00008
August	−0.0003	0.0001	−0.00005	0.00007
September	−0.0001	0.0001	0.0001	0.00007
November	0.0002	0.0001	−0.0003	0.00007
December	−0.00002	0.0001	−0.0006	0.00007
Month of recording and $e^{\mathrm{DIM} \times -0.065}$ (October, 5 DIM)				
January	0.290	0.079	0.226	0.053
February	0.574	0.070	0.219	0.054
March	0.709	0.065	0.129	0.054
April	0.760	0.064	0.087	0.056
May	0.756	0.068	−0.051	0.058
June	0.671	0.076	0.081	0.057
July	0.514	0.090	−0.062	0.054
August	0.485	0.102	−0.071	0.052
September	0.076	0.089	0.007	0.049
November	0.229	0.081	0.219	0.049
December	0.507	0.090	0.149	0.053
Parity and DIM (parity 2, 5 DIM)				
1	−0.0011	0.00004	−0.0011	0.00004
3	0.0003	0.00005	0.0004	0.00005
4	0.0002	0.00005	0.0003	0.00005
5+	−0.0002	0.00004	0.0002	0.00004
Parity and $e^{\mathrm{DIM} \times -0.065}$ (parity 2, 5 DIM)				
1	0.525	0.031	0.400	0.032
3	−0.147	0.034	−0.079	0.034
4	−0.198	0.037	−0.185	0.037
5+	−0.355	0.031	−0.201	0.031
Deviance	1,646,471		1,647,317	

[a] Natural logarithm.
[b] Coefficients are significant at the 5% level if the mean effect > twice the standard error.
[c] Not applicable.
[d] Test day milk yield (kg).
[e] Baseline = mean value in respective dataset.
[f] Test day fat proportion.
[g] Test day protein proportion.
[h] Days in milk.

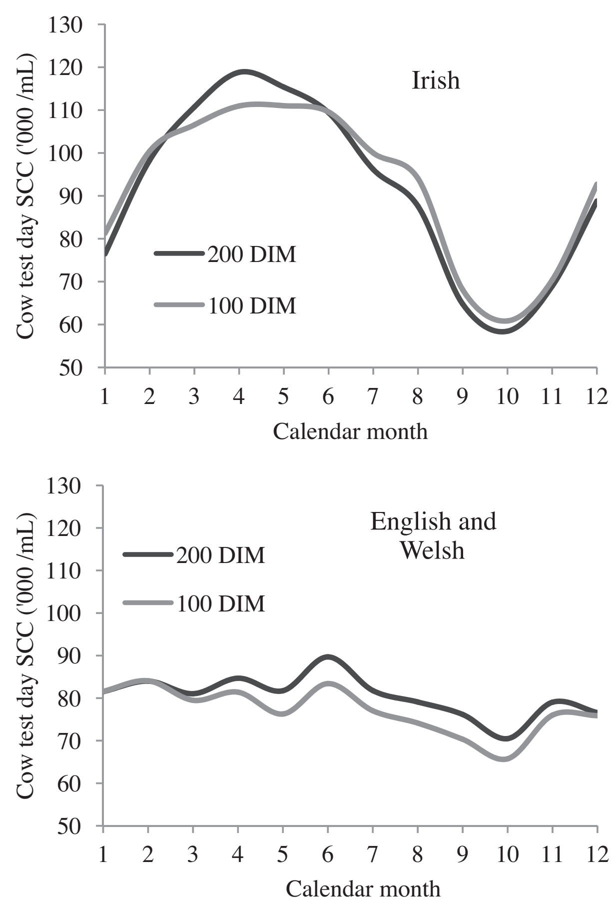

Fig. 4. Model predictions for the impact of calendar month on cow level geometric mean test day SCC (Refers to parity 2 cows in 2005 with mean test day milk yield (Irish herds; 21 kg, English and Welsh herds; 27 kg), and fat (3.8%) and protein proportions (Irish herds; 3.4%, English and Welsh herds; 3.2%), in herds of mean size for Ireland (96 cows), and England and Wales (196 cows).) (000 cells /mL) for cows at 100 and 200 days in milk (DIM) in Irish, English, and Welsh dairy herds.

Results

Descriptive statistics

Summaries of TDY, test day fat proportion (TDF), test day protein proportion (TDP), SCC, and herd size are presented in Table 2. In Ire_dat, 25%, 50% and 25% of recordings were from cows in parities 1, 2–4, and ⩾5 respectively. In UK_dat, 22%, 53%, and 25% of recordings were from cows in parities 1, 2–4, and ⩾5 respectively. Calving patterns also differed (Fig. 1); 59% and 56% of parity 1 and parity 2+ cows' calving dates were from January to March in Ire_dat. In UK_dat, 64% and 58% of parity 1 and parity 2+ cows' calving dates were from July to December.

The median herds' geometric means of cow SCC for primiparous, and multiparous cows by month of lactation, and the full distributions are shown in Table 3 and Fig. 2 respectively. Distributions of approximate herd level BMSCC by calendar month, based on sub-datasets; Ire_dat^{SUB1} and UK_dat^{SUB1} are shown in Fig. 3. For the Irish herds, geometric mean BMSCC was lowest in April (223,000 cells/mL), and highest in November and December (314,000 cells/mL). For the UK herds, geometric mean BMSCC was lowest in January (176,000 cells/mL) and highest in August (205,000 cells/mL).

Model results

Table 4 shows the fixed effect coefficients in the final models for ln SCC, developed from Ire_dat^{SUB1} and UK_dat^{SUB1}. Having accounted for stage of lactation and TDY, October was associated with lowest ln SCC in both models, and was set as the reference. Calendar month interacted with stage of lactation, and parity. For baseline cows (parity 2, mean TDY, TDF, and TDP, and in herds of mean size) in Irish herds (Fig. 4), geometric mean SCC was highest from February to August, independent of stage of lactation; for cows that were 100 DIM, geometric mean SCC peaked at 111,000 (95% confidence interval [CI]; 92,000–133,000) cells/mL during May, and was 61,000 (95% CI; 56,000–66,000) cells/mL in October. For baseline cows in UK herds (Fig. 4), geometric mean SCC was highest from January to June; for cows that were 100 DIM, geometric mean SCC was highest during February and June, at 84,000 (95% CI; 71,000–100,000) cells/mL, and was 66,000 (95% CI; 60,000–72,000) cells/mL in October. Random effects and ICC from the models (Table 5) show additional herd level variance in ln SCC from February to August; this was larger for the Irish than the UK herds. As a result, less total variance in ln SCC in the null model (Table 6) was explained by the fixed effects in the Irish model from February to August (11–13%), compared to September to January (16%). For the UK model, 11–13% of the total variance in ln SCC in the null model was explained by the fixed effects all year round.

Following adjustment for confounding influences, there was a non-linear relationship between herd size and test day SCC, included in the final Irish and UK models as 3rd and 2nd degree polynomials respectively (Fig. 5). For herd sizes of up to 130 cows, test day SCC for baseline cows (parity 2, 5 DIM, recorded in October with mean TDY, TDF, and TDP) in Irish herds remained at 63,000 (95% CI; 59,000–68,000) cells/mL. Further increase in herd size was associated with non-linear increase in test day SCC; reaching 68,000 (95% CI; 59,000–89,000) cells/mL with a herd size of 300 cows. In UK herds, test day SCC decreased for baseline cows in herds of up to 130 cows; reaching 60,000 (95% CI; 57,000–65,000) cells/mL, and this was maintained in herd sizes up to 180 cows. For larger herds, test day SCC increased with increasing size at a higher rate than for the Irish herds; also reaching 68,000 (95% CI; 59,000–77,000) cells/mL with a herd size of 300 cows. For the Irish herds, there was more uncertainty in these estimates that increased with increasing herd size from 130 cows, due to relatively few larger herds compared to the UK dataset. For the UK herds, uncertainty in the estimates, increased with increasing herd size, particularly for >230 cows.

Model fit

For Ire_dat^{SUB1} and UK_dat^{SUB1}, standardised residuals were distributed approximately normally at all levels, suggesting good model fit. For the Irish and UK within model predictions, lines of best fit between predicted and observed ln SCC had intercepts of

Table 5
Final models of repeated ln[a] SCC (000 cells/mL) within cow parity, from 497 and 200 randomly selected herds from Ireland and England and Wales respectively; random effects.

Random effects	Irish model			English and Welsh model		
Level	Variance	Standard error	ICC[b]	Variance	Standard error	ICC
Herd	$\sum_{f1}$	$\sum_{f1}$	0.08	$\sum_{f2}$	$\sum_{f2}$	0.08
Cow	0.256	0.003	0.21	0.289	0.004	0.22
Parity	0.296	0.002	0.24	0.351	0.003	0.26
Recording	0.570	0.001	0.47	0.592	0.001	0.44

$\sum_{f1}$ = Herd level (co)variance matrix for the Irish model (standard error)

Intercept	0.095 (0.0066)							
February	−0.020 (0.0056)	0.082 (0.0080)						
March	−0.015 (0.0046)	0.046 (0.0056)	0.072 (0.0060)					
April	−0.014 (0.0041)	0.050 (0.0061)	0.054 (0.0054)	0.096 (0.0071)				
May	−0.015 (0.0041)	0.038 (0.0050)	0.041 (0.0044)	0.054 (0.0050)	0.066 (0.0050)			
June	−0.0004 (0.0037)	0.028 (0.0045)	0.037 (0.0040)	0.049 (0.0045)	0.040 (0.0038)	0.054 (0.0041)		
July	0.0031 (0.0034)	0.017 (0.0041)	0.024 (0.0035)	0.033 (0.0039)	0.031 (0.0034)	0.030 (0.0031)	0.044 (0.0035)	
August	0.0027 (0.0034)	0.017 (0.0040)	0.018 (0.0033)	0.032 (0.0038)	0.029 (0.0032)	0.029 (0.0030)	0.022 (0.0027)	0.042 (0.0034)

$\sum_{f2}$ = Herd level (co)variance matrix for the English and Welsh model (standard error)

Intercept	0.11 (0.011)							
February	0.00039 (0.0030)	0.013 (0.0016)						
March	−0.0015 (0.0031)	0.0073 (0.0013)	0.013 (0.0016)					
April	−0.0084 (0.0038)	0.0048 (0.0014)	0.0083 (0.0016)	0.021 (0.0025)				
May	−0.0094 (0.0035)	0.0018 (0.0013)	0.0048 (0.0014)	0.0077 (0.0017)	0.017 (0.0021)			
June	−0.0089 (0.0037)	0.00069 (0.0014)	0.0061 (0.0014)	0.0092 (0.0018)	0.013 (0.0018)	0.02 (0.0024)		
July	−0.012 (0.0039)	0.00011 (0.0014)	0.0038 (0.0015)	0.0064 (0.0018)	0.0092 (0.0018)	0.014 (0.0020)	0.022 (0.0025)	
August	−0.0067 (0.0036)	−0.0032 (0.0014)	0.00085 (0.0014)	0.0052 (0.0017)	0.0068 (0.0016)	0.012 (0.0019)	0.012 (0.0019)	0.019 (0.0022)

[a] Natural logarithm.
[b] Intra-class correlation coefficient = proportion of unexplained variance at each level from September to January.

Table 6
Random effects from the null models of repeated ln[a] SCC (000 cells/mL) within cow parity, from 497 and 200 randomly selected herds from Ireland and England and Wales respectively.

Random effects	Irish null model			English and Welsh null model		
Level	Variance	Standard error	ICC[b]	Variance	Standard error	ICC
Herd	0.107	0.007	0.074	0.108	0.011	0.070
Cow	0.295	0.003	0.204	0.321	0.004	0.208
Parity	0.313	0.002	0.217	0.384	0.003	0.248
Recording	0.730	0.001	0.505	0.732	0.001	0.474
Totals	1.445		1.000	1.545		1.000
Deviance	1,813,845			1,771,367		

[a] Natural logarithm.
[b] Intra-class correlation coefficient is the proportion of unexplained variance at each level.

0.6 and 0.9 respectively, both with slopes of 0.8 (r^2 = 0.14 Irish, and 0.12 UK). For Ire_dat^{SUB2} and UK_dat^{SUB2}, lines of best fit between predicted and observed ln SCC had intercepts of 0.6 and 1.2, and slopes of 0.9 and 0.7 (r^2 = 0.14 Irish and 0.12 UK), indicating zero shrinkage on cross validation, suggesting that the model results can be generalised to herds not involved in parameter estimation (Dohoo et al., 2009). However, the models were not good at predicting extremes of SCC in either sample datasets, resulting in low r^2 values.

Discussion

Association between season and SCC

The association between calendar month and cow SCC was of particular interest in the Irish dataset. When confounding by stage of lactation and TDY were removed, the underlying values of cow SCC were highest, and most variable from February to August, despite BMSCC being at its lowest at this time in Irish herds. Despite the limited number of years studied, seasonal patterns in SCC dynamics for both datasets were therefore consistent with previous observations (Green et al., 2006b; Lievaart et al., 2007; Olde Riekerink et al., 2007), with underlying cow SCC being increased and more variable during spring and summer. In addition to an association with high SCC, infection status is reported to be the most important factor influencing SCC variance (Schepers et al., 1997). Having adjusted for other confounding factors, unexplained variation in SCC is therefore most likely to be attributable to increased new IMI rate (resulting in low r^2 values). Inclusion of herd level random coefficients between February and August demonstrated additional unexplained variation in cow SCC that was herd specific suggesting that there is important between herd variation in the rates of new IMI and cures during these months. Monitoring new IMI rate using SCC thresholds is recommended (Bradley and Green, 2005) so that control measures can be applied and adapted as necessary. It thus appears important to characterise differences in rates of new IMI between Irish herds so achievable targets, based on individual cow SCC can be used to improve udder health management.

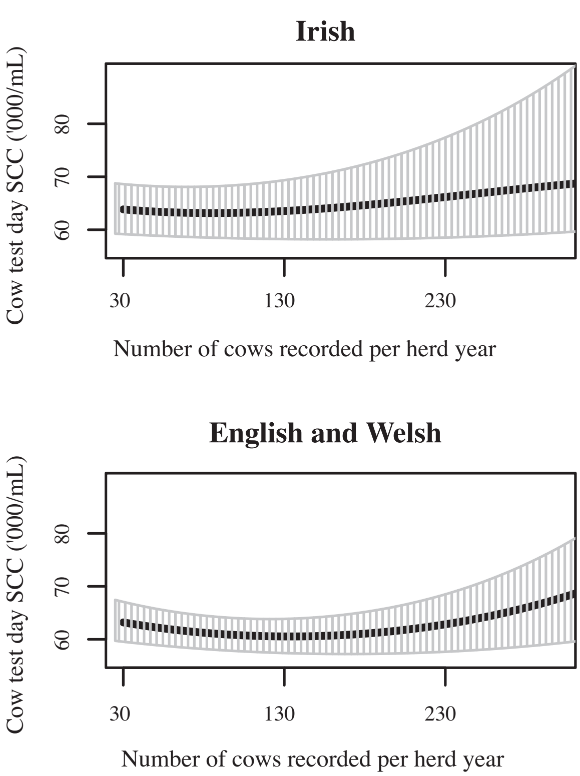

Fig. 5. Model predictions for the impact of herd size on cow level geometric mean test day SCC (Refers to parity 2 cows in October 2005 that are 5 days in milk, and have mean test day milk yield (Irish herds; 21 kg, English and Welsh herds; 27 kg), and fat (3.8%) and protein proportions (Irish herds; 3.4%, English and Welsh herds; 3.2%), truncated at 300 cows per herd.) ('000 cells/mL) with 95% CI for Irish, English and Welsh dairy herds.

Association between herd size and SCC

In general, increase in herd size was associated with increased cow SCC, although thresholds for the increase differed between the countries. This suggests more attention is required to optimise udder health management as herds increase cow numbers. These findings contrast with the previously observed lower average SCC with increasing herd size in a dataset with a higher frequency of larger herds (Oleggini et al., 2001), but are consistent with Dutch experience (Barkema et al., 1998).

For typical ranges of Irish, English, and Welsh herd sizes, the results suggest that expansion may be associated more with penalties, and loss of efficiency, than economic advantage in terms of SCC. The size of this effect on geometric mean cow SCC was small, and uncertainty increased with herd size, however the 95% CI indicate that for Irish herds, increased herd size was more likely associated with higher, than lower cow SCC (Fig. 5).

Risk of transmission of udder pathogens during milking may increase with herd size, as more susceptible quarters could be exposed. Poor management of higher pasture stocking rates in larger herds could contribute to increased risk of *Streptococcus uberis* IMI (Lopez-Benavides et al., 2009). Capital investments in improved facilities requires a critical herd size such that the fixed cost per cow is acceptable, and many Irish, English, and Welsh herds may not have reached this point. More labour units are required by larger herds, although the number of labour units per cow is less, emphasising the importance of farm staff developing expertise in cow management.

Conclusions

After correcting for stage of lactation and TDY, SCC for cows in Irish, English and Welsh dairy herds was higher and more variable in spring and summer, than autumn and winter. For Irish dairy herds, monitoring individual cows is particularly important in spring and summer, despite low BMSCC, and farmers should not be complacent about udder health at this time. Increasing herd size was associated with a non-linear increase in cow SCC in these countries, highlighting an important area that may influence cost effective dairy herd expansion.

Conflict of interest statement

None of the authors has any financial or personal relationships that could inappropriately influence or bias the content of the paper.

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