Seasonal trends in milk quality in Ireland between 2007 and 2011

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ABSTRACT

The objectives of this study were to evaluate annual and seasonal trends in bulk tank somatic cell count (SCC), total bacterial count (TBC), and laboratory pasteurization count (LPC) in Ireland between 2007 and 2011 (inclusive), and to compare trends based on herd type and herd size. The unadjusted median SCC and TBC of all records were 266,000 and 17,000 cfu/mL, respectively. Data were transformed to log values and analyzed using a mixed model. Fixed effects included milk processor, year, month, and total monthly milk volume; milk producer was fitted as a random variable. After analysis, means were back transformed for interpretation. Annual SCC increased slightly from 259,000 cells/mL in 2007 to a peak of 272,647 cells/mL in 2009 and then declined slightly thereafter. Although statistically significant changes in annual TBC are probably not biologically relevant, values ranged between 23,922 and 26,290 cfu/mL. Annual LPC peaked in 2008 (265 cfu/mL), declined in 2009, and increased thereafter. Monthly mean SCC of all records increased from April onward, with the greatest increases seen from October to December, when the majority of cows entered late lactation. Monthly mean TBC exhibited a seasonal trend, whereby TBC was greatest at the beginning and end of the year, coinciding with winter housing. Seasonal milk production herds (n = 8,002 herds) calve all cows in spring (February to April), whereas split-calving herds (n = 1,829 herds) calve cows in the spring and autumn. From February to September, monthly SCC was lower for seasonal herds than for split-calving herds, whereas SCC was lower for split-calving herds for the remaining months. During winter (October to March), split-calving herds had lower monthly TBC than seasonal herds, most likely because of stricter regulations imposed upon them. Herd size was approximated using total annual milk production figures. Across all months, larger herds had lower SCC and TBC compared with smaller herds. No obvious improvements in milk quality were seen between 2007 and 2011. Farmers have the opportunity to improve milk quality by reducing bulk tank SCC in late lactation and by imposing stricter hygiene practices at the beginning and end of the year to overcome the seasonal variation of bulk tank TBC.

Key words: milk quality, herd size, somatic cell count, trend, total bacteria count

INTRODUCTION

Due to increasing market demand, forthcoming Common Agricultural Policy reform, and abolition of the milk quota system, milk production in Ireland is expected to dramatically increase (DAFM, 2010a). Improvements in udder health and milk quality are needed to maximize the ability of Irish dairy products to compete in export markets (More, 2009). In Ireland, the quality of raw bulk milk is routinely measured using total bacteria count (**TBC**) and SCC. In addition, some processors routinely use laboratory pasteurization count (**LPC**) to measure the quantity of thermoduric bacteria.

Bulk tank milk SCC is a general indicator of the overall udder health status of a herd (van Schaik et al., 2002; Schukken et al., 2003). Somatic cells are part of the innate immune system of the cow and are almost always a reflection of the inflammatory response to an IMI (Schukken et al., 2003). Bulk tank milk from herds with increased SCC has an increased risk of containing antibiotic residues (Ruegg and Tabone, 2000) and is one indicator of animal welfare (van Schaik et al., 2002; Schukken et al., 2003; Bertocchi et al., 2012). Both flavor and shelf life of pasteurized dairy products are altered when high-SCC milk is used (Barbano et al., 2006), and cows with subclinical mastitis produce less milk (Halasa et al., 2009). For an average Irish dairy herd, annual net herd losses from subclinical mastitis are estimated to reach €19,504 as bulk tank SCC increases from <100,000 to >400,000 cells/mL (Geary et al., 2012).

The TBC of bulk tank milk is an estimate of the quantity of aerobic bacteria (Chambers, 2002). The TBC is commonly used for regulatory purposes and fre-

quently by milk processors to help determine the milk price received by producers (Hayes et al., 2001). Bulk tank TBC is a comprehensive reflection of the hygienic conditions of the herd and can be influenced by teat preparation, prevalence of IMI in the herd, sanitation of milking equipment, and milk storage temperature (Hayes et al., 2001; Chambers, 2002; Ruegg and Reinemann, 2002).

The LPC is used to quantify thermoduric bacteria in milk and is often used as an indicator of milking equipment sanitation. A high LPC can indicate chronic cleaning failure (Jayarao and Wolfgang, 2003; Pantoja et al., 2009). An LPC <200 cfu/mL is considered normal, whereas LPC <10 cfu/mL indicates excellent equipment hygiene (Ruegg and Reinemann, 2002).

The European Union (**EU**) imposes a regulatory limit on bulk tank milk of <400,000 SCC cells/mL (geometric average over a period of 3 mo, with at least 1 sample a month) and <100,000 TBC cfu/mL (geometric average over a period of 2 mo, with at least 2 samples a month; EEC, 1992, Council Directive 92/46/EEC). When regulatory standards for bacterial counts are met, pasteurization of raw milk is highly effective in destroying foodborne pathogens (Ruegg, 2003). Currently, the EU does not specify a regulatory threshold for LPC but some processors have adopted a penalty when values exceed 1,000 cfu/mL. Some Irish milk processors have financial incentives for farmers to produce milk with bulk tank SCC <200,000 cells/mL, TBC <30,000 cfu/mL, and LPC <500 cfu/mL. Previous analyses of bulk tank milk quality trends in Ireland (Berry et al., 2006) have shown that farmers are unable to maintain SCC of bulk milk <250,000 cells/mL, particularly toward the end of seasonal lactation periods (November to December).

Most Irish dairy herds rely on grass as the primary nutrient source for their cattle (Dillon et al., 1995). Milk production in Ireland is predominantly based on seasonal calving, whereby farmers calve all their cows in spring (February to April) to coordinate peak milk production with periods of peak grass growth. However, to maintain the fresh milk supply, a small proportion of cows are calved in the autumn. Herds that calve cows in both spring and autumn are referred to as split-calving herds. Differences in milk quality between seasonal and split-calving herds have not been previously described.

Average herd size in Ireland tripled between 1985 and 2010 (Dillon, 2011) and is expected to continue to increase. The average herd size in Ireland is 58 cows, and 11.25% of farmers have herds with more than 100 cows (Central Statistics Office; CSO, 2012). Facilities and management practices often differ based on herd size and have been associated with differences in bulk milk SCC. A Wisconsin study demonstrated that smaller dairy herds had significantly greater SCC and TBC compared with larger herds (Rodrigues et al., 2005). However, for Irish dairy herds, inconsistent associations of herd size with milk quality have been reported (Berry et al., 2006; Archer et al., 2013).

The objectives of this study were to assess trends in bulk tank SCC, TBC, and LPC in Irish dairy herds between 2007 and 2011 and to compare trends based on milk herd type and herd size.

MATERIALS AND METHODS

Data

The complete data set (combined data set) was supplied by 9 milk processors in Ireland and consisted of bulk tank SCC and TBC obtained from January 2007 through December 2011. Depending on processor, SCC was evaluated using Fossomatic (Foss Electric, Hillerød, Denmark) or Somacount (Bentley Instruments, Chaska, MN) instruments. Different procedures to measure TBC were used among processors and included the Thompson plate loop method (Thompson et al., 1960), Petrifoss SPC (Foss Electric), and the Bactoscan machine (Foss Electric). The Bactoscan IBC (individual bacteria count) values were converted to colony-forming unit values by the processors before supplying the data. The Department of Agriculture is responsible for ensuring that all conversions are the same across milk processors (DAFM, 2011). Frequency of SCC and TBC testing per month differed depending on processor and ranged between 4 and 10 times for SCC and between 2 and 4 times for TBC. Data for LPC were provided by one processor from 2007 to 2011 inclusive, and were evaluated using the Petrifoss SPC (Foss Electric) with a minimum detection limit of 10 cfu/mL.

Five milk processors provided monthly data for each of their herds that included total monthly milk volume and monthly mean values for SCC and TBC. The remaining 4 processors provided daily milk collection data for each herd that included the date of milk collection, milk volume, SCC, and TBC. For data obtained from these processors, daily milk volume was summed for each month, and monthly averages were calculated for TBC and SCC for each herd.

Values for SCC that were <20,000 cells/mL were removed. Any TBC values that were <1,500 cfu/mL or >10 million cfu/mL (values outside of the operating range of the Bactoscan) were also removed. Records with monthly milk volume <227.5 L (the minimum milk volume collected by milk processors in Ireland) were also removed. Herds that supplied milk for less

than 6 mo/yr or were not included in all years of the study were also excluded. The distributions of monthly arithmetic means for SCC, TBC, and LPC values were positively skewed and so, to improve the normality of the distributions, the monthly means were transformed to base 10 logs.

Comparison of Herd Types

To compare data between herd types, herds were categorized as seasonal or split calving based on their annual calving patterns. Seasonal herds calved all cows between February and April and were defined as herds in which peak milk production occurred in May or June and exceeded the herd's minimum monthly milk production in the herd-year by >700%. To achieve year-round fresh milk supply, split-calving herds milk 2 calving cohorts. The spring cohort is calved from February to April and the winter cohort is calved from August onward. Split-calving herds were defined as herds that supplied milk throughout December and January and had peak milk production that exceeded herd minimum milk production for any month by <300%. Herds could be identified as seasonal or split calving for one or more years. Herds that did not meet the criteria for either seasonal or split calving for any year and herds that met both seasonal and split-calving criteria across different years were excluded.

Herd Size

Cow numbers per herd were not available; therefore, herd-size quartiles were estimated based on total annual milk volume. Milk yield was assumed to be 4,562 kg/cow per year (ICAR, 2009). Threshold values used to categorize herds into size quartiles were <162,881 L/yr (herd size 1, <36 cows), 162,881 to 252,735 L/yr (herd size 2, 36–55 cows), 252,736 to 366,764 L/yr (herd size 3, 56–80 cows), and >366,764 L/yr (herd size 4, >80 cows).

Statistical Analysis

Monthly and annual least squares means for each response variable were calculated using the HPMIXED procedure in SAS 9.3 (SAS Institute, 2011). Response variables were Log_{10} SCC, Log_{10} TBC, and Log_{10} LPC. The fixed effects of processor (1 to 9), year (2007 to 2011), month (January to December) and monthly volume on monthly and annual mean SCC and TBC were assessed in 2 separate models using the combined data set. Fixed effects of year, month, and milk volume on annual and monthly LPC were analyzed using data

supplied by one processor. Milk producer was included as a random effect in all models.

The combined data set was also used to analyze the effect of herd size on monthly SCC and TBC. Fixed effects included in the models included processor, year and month and the interaction between herd size and month. Milk producer was included as a random effect.

The general mixed model used in all analyses was as follows (volume was not included when assessing the effect of herd size on monthly SCC and TBC):

$$Y = \mu + PR + YR + MO + VOL + Producer + e,$$

where y = Log_{10} SCC, Log_{10} TBC, or Log_{10} LPC; PR = fixed effect of each individual processor; YR = fixed effect of year; MO = fixed effect of month; VOL = fixed effect of the volume of milk supplied each month; Producer = random effect of milk producer; and e = residual component.

Herds identified as either seasonal or split calving from the combined data set were used to investigate the effect of herd type on monthly SCC and TBC. Fixed effects were processor, year, month, and milk volume; milk producer was included as a random effect; and the interaction between herd type and month was included in these models.

RESULTS

After editing, the combined data set included 589,207 Log_{10} SCC, 527,616 Log_{10} TBC, and 200,883 Log_{10} LPC across 54,095 herd-years, representing 10,819 herds. A total of 63,658, 58,222, and 13,235 records of Log_{10} SCC, Log_{10} TBC, and Log_{10} LPC, respectively, were excluded. Almost 10% of the original records were removed (Table 1). Deletions due to minimal milk volume and outliers were minimal (Table 1). Only 46 records had a monthly mean SCC <20,000 cells/mL, of which 30 records had an SCC value of 0 cells/mL and the remaining 16 values had a value between 9,000 and 19,000 cells/mL.

Most records were excluded because herds did not supply milk for at least 6 mo per year or the herd was not present in all years (Table 1). In total, 3,878 herds were removed from the data set, of which 3,114 herds were removed for inconsistent supply. The number of milk producers that did not supply milk for all years of the study was 1,409, whereas the number of milk producers that did not supply for at least 6 mo in each year was 1,705. Of those 1,705 milk producers, only 363 milk producers supplied milk for all 5 yr. Of those 3,114 milk producers that were removed for inconsistent supply, 1,767 milk producers that supplied milk in 2007 did

Table 1. Number of SCC and total bacterial count (TBC) records supplied, reasons for removal, and the final number of records from Irish dairy farms included in the analysis of milk quality indicators between 2007 and 2011

Processor	Initial no. of records		Removed for volume[1]		Removed as outliers			Removed due to inadequate years and months[2]		Total remaining records		Percent removed	
	SCC	TBC	SCC	TBC	SCC <20,000 cells/mL	TBC <1,500 cfu/mL	TBC >10 ×10^6 cfu/mL	SCC	TBC	SCC	TBC	SCC	TBC
A	13,272	13,240	21	19	1	0	0	878	850	12,372	12,371	6.8	6.6
B	12,781	12,748	11	6	2	0	0	849	844	11,919	11,898	6.7	6.7
C	146,149	144,270	0	0	26	293	0	21,613	21,299	124,510	122,678	14.8	15.0
D	237,768	172,970	600	237	6	7	28	15,181	10,223	221,981	162,475	6.6	6.1
E	69,755	69,755	303	303	0	0	0	9,390	9,390	60,062	60,062	13.9	13.9
F	98,453	98,453	205	205	0	7	0	10,337	10,337	87,911	87,904	10.7	10.7
G	17,570	17,511	36	16	7	0	5	954	952	16,573	16,538	5.7	5.6
H	22,235	22,235	107	107	0	0	0	1,447	1,447	20,681	20,681	7.0	7.0
I	34,882	34,656	64	50	4	1	0	1,616	1,596	33,198	33,009	4.8	4.7
Total	652,865	585,838	1,347	943	46	308	33	62,265	56,938	589,207	527,616	9.7	9.9

[1]Records with a milk volume <227.5 L; detection for outlier was 20,000 cells/mL.
[2]Records from milk producers that had fewer than 6 mo of records each year or that were not present for all years of the study.

not supply milk in 2011 and it is assumed that they left dairying. The remaining 1,347 either entered dairying or supplied milk inconsistently between 2007 and 2011. Trends for SCC and TBC for the removed herds were identical but annual and monthly means were between 50,000 and 100,000 cells/mL greater for SCC and between 2,500 and 7,000 cfu/mL greater for TBC than the herds included in this analysis (data not shown).

Of the remaining 10,819 herds, 8,002 and 1,829 were categorized as seasonal and split-calving herds, respectively. A total of 988 herds did not meet the criteria for seasonal or split for any year, whereas 895, 1,221, 1,710, 2,887, and 4,106 herds were categorized as seasonal or split for 1, 2, 3, 4, and all years, respectively.

Milk Supply

During the study, milk production in the combined data set declined from 3.02 billion liters in 2007 to 2.96 billion liters in 2009 and then increased to 3.32 billion liters in 2011 (data not shown). As defined, seasonal herds had a distinct peak of milk supply during the summer months (May, June, and July), whereas split-calving herds had a steadier supply of milk across the year and a less-pronounced peak during summer months.

SCC

For the combined data set, the overall unadjusted mean and median SCC were 298,415 and 266,000 cells/mL, respectively. Of all monthly average SCC in the combined data set, 25% were <192,000 cells/mL and 10% were >486,000 cells/mL (Table 2). Similar distributions of SCC for the seasonal and split-calving herds were observed. Although the split-calving data set had a slightly greater median SCC, the range between the minimum and 90th percentile (399,000 cells/mL) was less than that in the seasonal data set (463,000 cells/mL).

For the combined data set, small differences ($P <$ 0.01) in annual SCC were identified for all adjacent years. Annual mean SCC increased from 2007 (259,000 cells/mL), peaked in 2009 (272,647 cells/mL), and then declined to 244,399 cells/mL in 2011 ($P <$ 0.01; data not shown).

Except for the months of April and May and November and December, monthly mean SCC for adjacent months were different ($P <$ 0.01). Monthly SCC declined from January (273,779 cells/mL) until April (226,777 cells/mL) and then gradually increased for the remainder of the year (Figure 1). Peak SCC occurred in December (331,436 cells/mL). The greatest monthly

Table 2. Distribution of SCC, total bacteria count (TBC), and laboratory pasteurization count (LPC) of 10,819 Irish dairy farms from 2007 to 2011

Item	Data set[1]	No. of records	Mean	Geometric mean[2]	Maximum	Minimum	Percentile				
							10th	25th	50th	75th	90th
SCC (cells/mL)											
	Combined	589,207	298,415	262,197	9,252,300	20,000	139,000	192,000	266,000	363,998	486,004
	Seasonal	307,819	295,546	256,426	7,260,000	20,000	133,000	185,000	258,000	354,000	483,000
	Split-calving	77,948	286,607	264,936	2,355,000	21,000	157,250	207,000	273,000	347,000	420,000
TBC (cfu/mL)											
	Combined	527,616	30,343	17,680	9,839,000	1,500	6,000	10,000	17,000	30,000	50,000
	Seasonal	300,009	30,480	17,661	9,839,000	1,500	6,000	10,000	16,500	30,000	51,000
	Split-calving	42,316	24,336	15,535	9,139,000	1,500	6,000	9,000	15,000	25,000	41,500
LPC (cfu/mL)		200,883	678	227	58,740	10	60	110	170	390	1,360

[1]Combined data set represented 60% of the entire population of dairy herds (n = 10,819); seasonal data set represented seasonal milk producers (n = 8,002 herds); split-calving data set represented herds that milk year round (n = 1,829 herds); LPC data were supplied by one processor.

[2]Geometric means were back-transformed from Log_{10} values.

increase in SCC occurred between October (279,254 cells/mL) and November (330,522 cells/mL).

Comparison of SCC Between Herd Types

Except for January, monthly mean SCC were different ($P < 0.01$) between herds characterized as seasonal and split calving. From February until September, monthly SCC were greater for split-calving herds compared with seasonal herds. Monthly SCC were greater for seasonal herds for the remaining months (Figure 2A). Mean monthly SCC of seasonal herds peaked in December (402,346 cells/mL), whereas monthly SCC of split-calving herds peaked in August (307,893 cells/mL). The lowest monthly mean SCC was seen in April (219,533 cells/mL) for seasonal herds and in November (271,393 cells/mL) for split-calving herds.

TBC

The unadjusted mean and median TBC for the combined data set were 30,343 and 17,000 cfu/mL, respectively (Table 2). The 25th and 75th percentiles were 10,000 and 30,000 cfu/mL, respectively (Table 2). The distribution of TBC for the seasonal and split-calving herds was similar; however, the 90th percentile was almost 10,000 cfu/mL less for split-calving herds than for seasonal herds (Table 2).

For the combined data set, with the exception of 2008 and 2009, annual values for TBC were slightly different for all adjacent years ($P < 0.01$). Mean annual TBC were 24,837 and 25,817 cfu/mL for 2007 and 2011, respectively. Very small changes in TBC were observed across the study period (data not shown).

A seasonal trend was observed for monthly TBC. Except for the months of April and May and November and December, monthly TBC values for adjacent months were different ($P < 0.01$). Monthly means for the combined data set decreased from 36,325 cfu/mL (January) to 18,910 cfu/mL (May) and then increased to 35,686 cfu/mL in December (Figure 1).

Comparison of TBC Between Herd Types. Except in September, monthly mean TBC were different ($P < 0.05$) between herds characterized as seasonal or split calving. From January to March and from October to December, monthly TBC were greater for seasonal herds compared with split-calving herds. Monthly TBC were greater for split-calving herds for the remaining months (Figure 2B). Mean monthly TBC of seasonal herds peaked in January (35,156 cfu/mL), as did monthly TBC of split-calving herds (23,735 cfu/mL). The lowest monthly mean TBC was seen in May for seasonal herds (15,399 cfu/mL) and split-calving herds (16,099 cfu/mL).
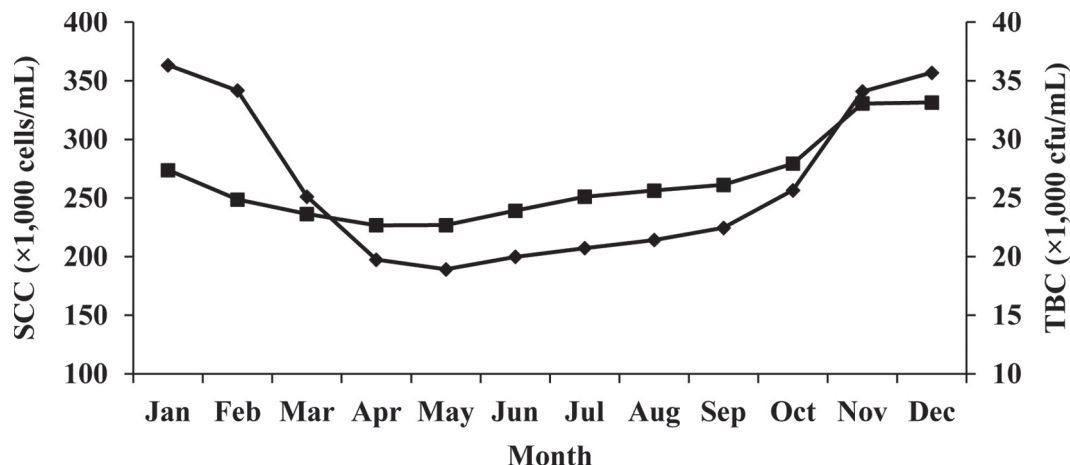
Figure 1. Monthly adjusted log$_{10}$ means (back-transformed from log$_{10}$ values after analysis) for SCC (■) and total bacteria count (TBC; ◆) for the combined data set (10,819 Irish dairy herds, 60% of the entire population of dairy herds in Ireland) from 2007 to 2011.

Comparison of Monthly TBC and SCC Among Herd Sizes. Across all months, herds that sold the least amount of milk (herd size 1) had the greatest TBC and SCC (data not shown). Across all months, differences in SCC were observed between herd sizes 1 (<36 cows) and 2 (36–56 cows), whereas differences in TBC were observed in all months except January and December. Differences in TBC between herd sizes 2 and 3 were observed across all months except January. Differences in TBC between herd sizes 3 and 4 were observed across all months except April to July and December. No significant differences in SCC were observed among herd sizes 2, 3, and 4 during February. Differences in SCC between herd sizes 3 and 4 were observed across all months except during the summer months of June, July, and August (Figure 3).

LPC

For LPC, all adjacent years were different ($P < 0.01$; data not shown): LPC increased from 194 cfu/mL in 2007 to 265 cfu/mL in 2008, declined to 216 cfu/mL in 2009, and then increased to 263 cfu/mL in 2011. Month by year interactions showed that LPC were greater between June and August 2008 compared with other years. The LPC for June, July, and August 2008 were 283, 348, and 374 cfu/mL, respectively. Meanwhile, LPC for these months in remaining years ranged between 145 and 282 cfu/mL.

Values for LPC demonstrated seasonal trends. The LPC was least in March and April, increased until September and October, and then declined (Figure 4). Differences in LPC were observed for the months of February and March, all months between May and August, and between October and November ($P < 0.01$).

DISCUSSION

The sustained delivery of high-quality dairy products depends on production of raw bulk milk with minimal bacterial contamination and SCC (Elmoslemany et al., 2010; Ruegg and Pantoja, 2013). Monitoring of trends in milk quality allows industry stakeholders to assess progress, evaluate the efficiency of control programs, and identify critical management issues. Knowledge of regional trends in milk quality can provide insight into how external factors (such as climate, milk pricing, and production systems) influence milk quality and increase understanding about differences in milk quality throughout the world.

The data included in this study were a convenience sample obtained from 9 processors. Herds were not randomly sampled and the results may not be representative of the entire Irish dairy industry. However, participating processors collected milk from 60% of all dairy herds in Ireland (IDF, 2012) and results can likely be extrapolated to most dairy herds in the regions where the processors operate. Additionally, the increase in milk yield of 9.44% seen in this study and the estimated herd size of 65 cows reflect national figures that indicate an increase in milk production of 10% and estimate current herd size to be 58 cows (CSO, 2012, 2014). It is also realistic to assume that the results may be applicable to dairy herds in other regions that have a similar climate and use similar production systems.

In the current study, annual bulk tank SCC reached a peak of 272,647 cells/mL in 2009 (an increase of almost 9,000 cells/mL from the previous year). Although statistically significant, this increase is probably not biologically relevant. During the same period, other EU countries (such as Spain and Belgium) reported similar
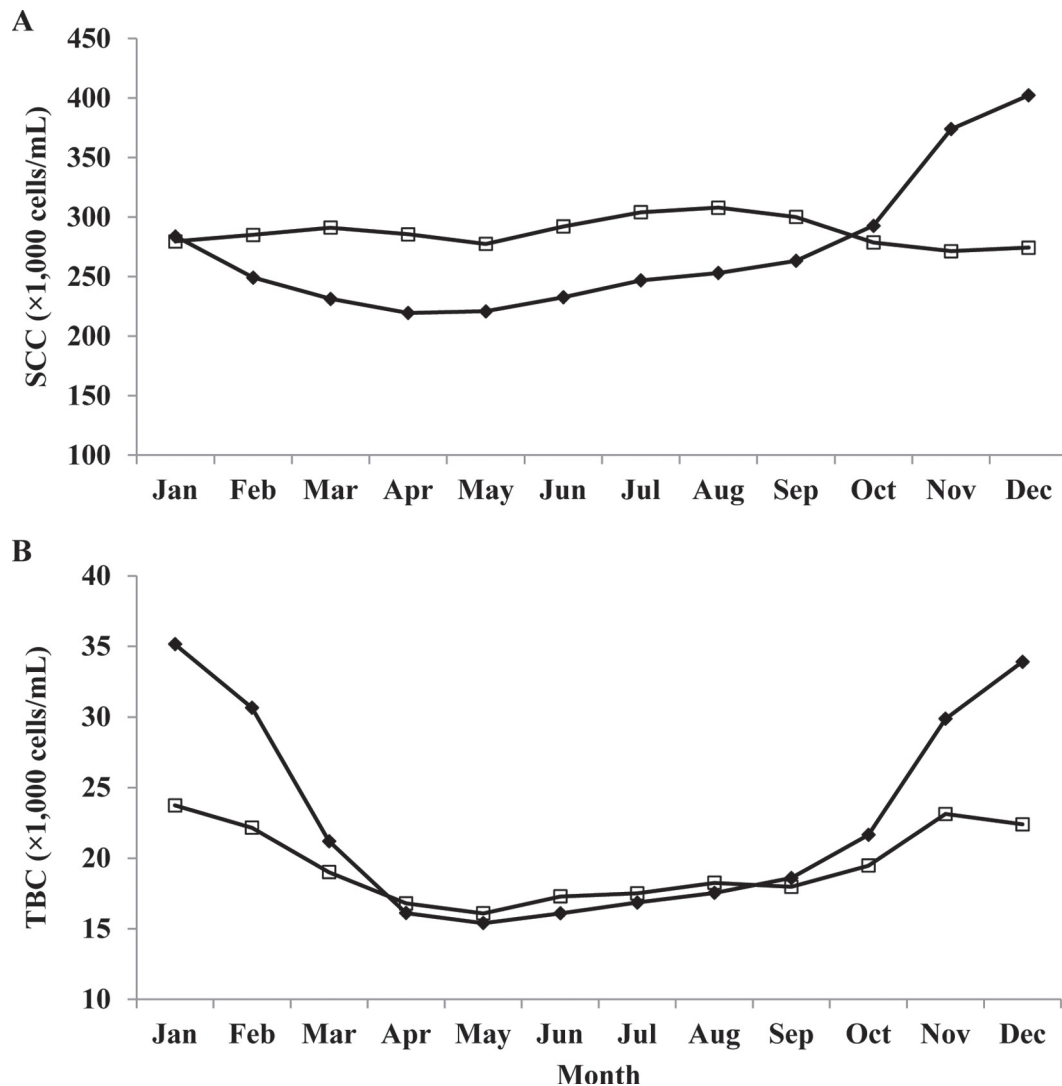
Figure 2. Comparison of monthly SCC (A) and total bacteria count (TBC; B) means (back-transformed from $\log_{10}$ values after analysis) for seasonal [◆; seasonal milk producers (n = 8,002 herds) in Ireland] and split-calving [□; producers that milk year round (n = 1,829 herds) in Ireland] data sets from 2007 to 2011.

minimal increases in SCC (De Vliegher; 2013; Jimenez, 2013). The worldwide decrease in milk prices in 2009 (IFCN, 2009) may have resulted in less investment in control practices and increased incidence of IMI.

To effectively manage bulk tank SCC, it is necessary to identify cows and quarters with high SCC. Participation in milk recording schemes has been associated with lower bulk tank SCC in Ireland (Kelly et al., 2009a). Although milk recording identifies problem cows, it is the subsequent actions of the farmer that have the ability to result in lower bulk SCC. Such actions include culture, segregation, treatment, or removal of infected cows from the herd (Cook et al., 2002; Rhoda and Pantoja 2012). The number of cows

enrolled in a milk-recording scheme in Ireland declined by 8% from 2008 to 2009, likely as a consequence of the severe financial pressure due to the decrease in milk price (ICBF, 2009). Subsequently, the number of cows enrolled increased by 10% from 2009 to 2011 (ICBF, 2011) while SCC declined by 28,248 cells/mL. Likewise, enrollment in milk-recording programs in the United States has been associated with reduced prevalence of subclinical mastitis (Wilson et al., 1997). United States dairy herds enrolled in monthly DHI testing of SCC have demonstrated continuous annual reductions in test-day SCC from 276,000 cells/mL (2007) to 217,000 cells/mL (2011; NMC, 2012). The substantial decrease in milk price experienced by farmers in 2009 in Ireland
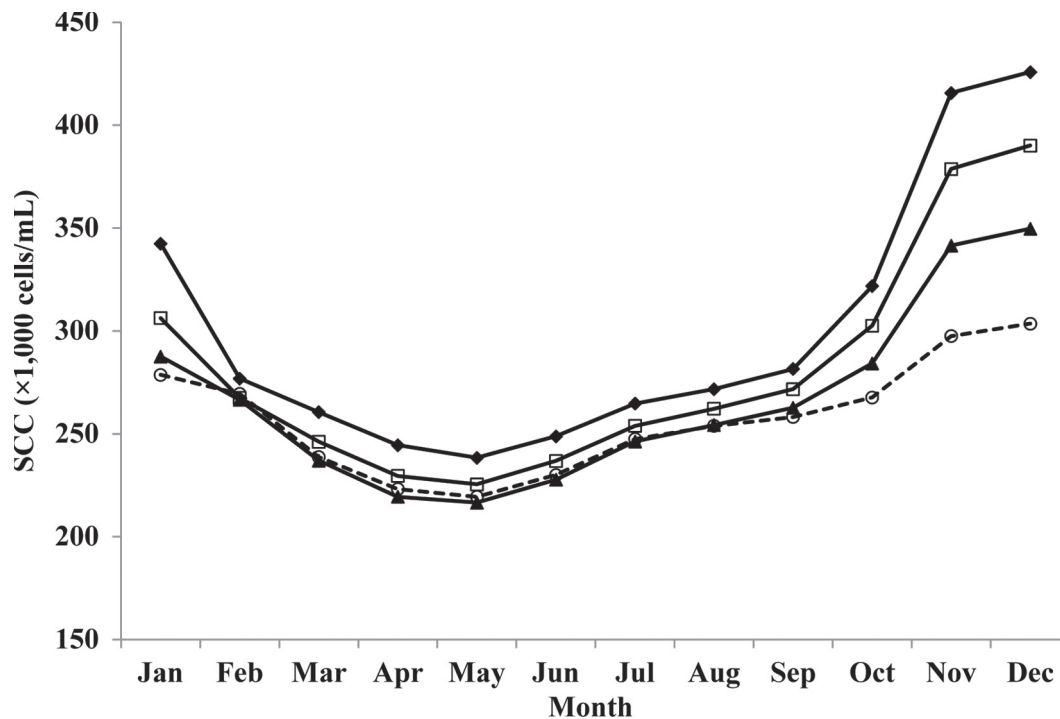
Figure 3. Association between herd size and SCC of Irish dairy herds. Herd size 1 (◆) = <162,881 L/yr, <36 cows; herd size 2 (□) = 162,881 to 252,735 L/yr, between 36 and 56 cows; herd size 3 (▲) = 252,736 to 366,764 L/yr, between 56 and 81 cows; herd size 4 (-○-, dashed line) = >366,764 L/yr, >81 cows. Monthly means were back-transformed from $\log_{10}$ values after analysis.

(DAFM, 2010b) may have resulted in less investment by farmers in mastitis control and milk recording for that year.

Cell Check is an Irish program that was established by Animal Health Ireland in 2009 with the objective of providing guidance and resources to help farmers produce higher quality milk (http://www.animalhealth ireland.ie). Bulk tank SCC values can respond rapidly to interventions (Rodrigues et al., 2005), and the launching of the Cell Check program may have influenced some dairy producers to work proactively to prevent mastitis. Additional factors that may have resulted
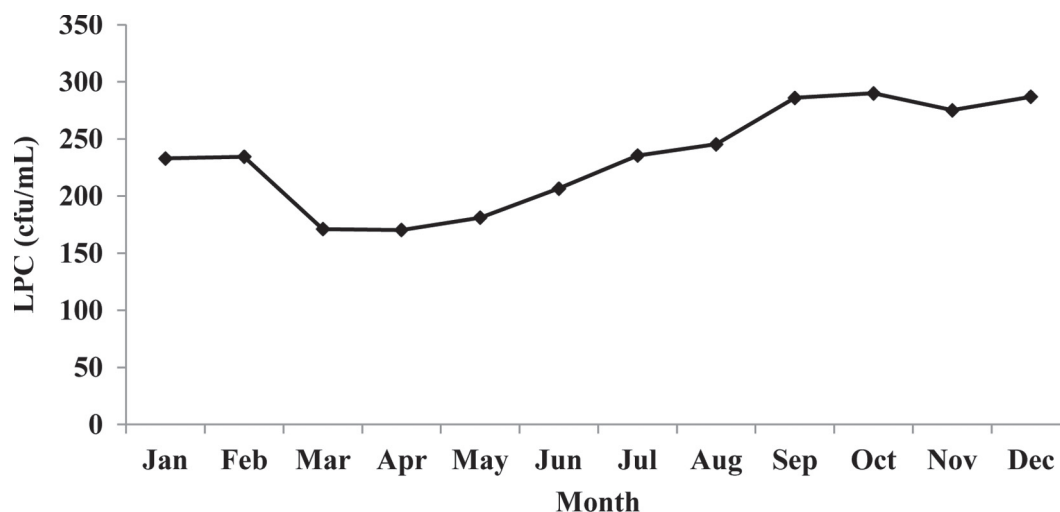

Figure 4. Monthly adjusted $\log_{10}$ means (back-transformed from $\log_{10}$ values after analysis) for laboratory pasteurization count (LPC; data are from one Irish processor only) from 2007 to 2011.

in lower BTSCC since 2009 include an increased milk price (National Milk Agency, 2010) and considerably less rainfall in 2010 (Met Éireann, 2010).

Due to the dominance of seasonal milk production in Ireland, any seasonal effects seen in monthly means for the combined data set are highly confounded with DIM. Therefore, it is difficult to establish seasonal trends independent of DIM. For herds included in the combined data set, monthly mean SCC was least during spring (February to April) and increased from May, with the greatest increase occurring between October and December. Similar but less-pronounced trends have been reported for dairy herds in New Zealand (DairyNZ, 2011). It is well documented that bulk milk SCC increases toward the end of lactation (Berry et al., 2006; Hagnestam-Nielsen et al., 2009; Kelly et al., 2009a) and is related to increased prevalence of cows with chronic subclinical mastitis. Herds with greater bulk tank SCC (>200,000 cells/mL) tend to have greater prevalence of IMI caused by contagious pathogens (Fenlon et al., 1995; Barkema et al., 1998; Rodrigues et al., 2005).

For the combined data set, peak milk production coincided with the lowest monthly mean bulk tank SCC. At the herd level, dilution due to increased milk production can contribute to a reduction in bulk tank SCC (Schepers et al., 1997). However infection at the cow level can still exist. When corrected for stage of lactation and test-day milk yield, individual cow SCC was greater and more variable in spring and summer compared with autumn and winter (Archer et al., 2013). This result highlights the importance of identifying and managing infected cows during spring and summer to prevent chronic infections from persisting into late lactation. The most prevalent mastitis pathogens among Irish herds are *Staphylococcus aureus* and *Streptococcus uberis* (Barrett et al., 2005; Keane et al., 2013). The prevalence of *Staph. aureus* mastitis in dairy herds is likely to increase with DIM due to increased exposure. Reducing bulk tank SCC in late lactation requires preventative action such as the implementation of the 5-point plan (Neave et al., 1969) and segregation of chronically infected cows earlier in lactation or premature dry-off of high-SCC cows.

Previous research conducted in the Netherlands has shown that farmers are more likely to respond to penalties (rather than bonuses) regarding the adoption of management measures aimed at improving udder health (Huijps et al., 2010). In Ireland, the SCC threshold for penalty was set at 400,000 cells/mL during 2007 and 2011. Monetary penalties applied to farmers by the processors are based on monthly arithmetic SCC means. In the current study, monthly mean SCC only approached threshold limits for penalty in November and December. For the majority of Irish produc-

ers (seasonal farmers), these months coincide with the end of lactation and drying off. As most farmers can maintain SCC below the penalty threshold for most of the lactation, there is little incentive for farmers to improve SCC in late lactation when minimal milk is produced. Additionally, although the EU limit for SCC is 400,000 cells/mL, this figure is based on a 3-mo rolling geometric mean. Thus, for seasonal herds, the dry months will compensate for the high SCC experienced at the end of lactation so it is very unlikely that milk collection will be refused despite considerably greater bulk tank SCC. Therefore, farmers can meet EU regulations without need for management changes that result in lower SCC.

To identify seasonal and split-calving herds from the national data set, we used the proportion of milk volume sold each month and the months in which milk was supplied. Peak milk production on seasonal herds typically occurs in May or June (90 d after calving). Thus, to be classified as a seasonal farm, peak milk production had to occur in May or June. Typically, seasonal farms will not milk during December and January (the dry period for spring-calving cows); therefore, to define split-calving herds, milk supply during these typical dry months was necessary. The national milk supply peak-to-trough ratio is 5.1:1 in Ireland (CSO, 2011), indicating the dominance of seasonal milk production in Ireland. Split-calving farms should have a lower ratio than this because they supply milk year round; thus, a benchmark of 3:1 was put in place to identify these herds. Alternatively, a ratio of 7:1 was put in place to identify seasonal herds.

Seasonal herds had lower monthly mean SCC from February to August and a greater SCC from October to January compared with split-calving herds. These trends correspond roughly to differences in stage of lactation resulting from differing calving periods. Between February and August, average DIM is greater for cows in split-calving herds because cows in the winter-calving cohort are in late lactation and all cows in seasonal herds are in early or mid lactation. In contrast, between October and January, average DIM for cows in seasonal herds is greater because all cows are in late lactation, whereas cows in the winter-calving cohort in split-calving herds are in early lactation. When contagious mastitis is present in a herd, the prevalence of cows with increased SCC usually increases with DIM as a result of persistent chronic IMI and increased risk of new IMI (Ruegg and Pantoja, 2013).

The pathogen profile of subclinical mastitis of 15 herds in Ireland indicated that *Strep. uberis* mastitis was more frequently isolated from high-SCC cows in split-calving herds than in seasonal herds, whereas *Staph. aureus* was more frequently isolated from high-

SCC cows in seasonal herds (Barrett et al., 2005). Both pathogens can behave in a contagious manner (Zadoks et al., 2003; Barkema et al., 2006) and spread from infected quarters to healthy quarters at milking time. Minimizing the spread of contagious pathogens must be a goal for both seasonal and split-calving herds.

Although statistically significant, changes in bulk tank TBC throughout the study were minimal and probably not biologically relevant. Monthly arithmetic means for TBC were received from the processors and log-transformed to improve the normality of the distribution. Though this transformation dramatically improved the distribution, the data were still slightly skewed, likely because monthly arithmetic means were used, which are greatly influenced by extreme values. Therefore, caution is warranted when comparing these values to those of other studies.

Annual means of TBC have remained unchanged in the United Kingdom for the same period (DairyCo, 2014). Berry et al. (2006) reported that bulk tank TBC of Irish dairy farms (n = 9,113) decreased from approximately 30,000 cfu/mL (1994) to 16,000 cfu/mL (2004). The 1992 imposition of EU policies for milking sanitation was considered to be the main cause of the reduction. Continued declines in TBC were not observed in the current study. Since 1992, no new policies for TBC have been implemented and so farmers may have become complacent about maintaining low TBC. As a result, bulk tank TBC of herds in the combined data set were considerably greater than that reported in 2004. Annual means of TBC easily meet EU thresholds and processors do not provide financial incentives that encourage further improvements in bulk tank TBC.

Most milk produced on Irish dairy herds is stored for a minimum of 48 h and may be stored for up to 4 d during the beginning and end of seasonal lactation periods, allowing considerable time for growth of bacteria (Champagne et al., 1994). The unadjusted mean TBC for 16 large Wisconsin herds was 12,545 cfu/mL (Pantoja et al., 2009), and the majority of the herds (average herd size of 924 cows) shipped milk directly to the plant at least once per day. Compared with Wisconsin herds, the longer storage of milk in farm bulk tanks may have allowed for incubation and resulted in greater TBC for the Irish farms participating in the current study. The effect of storage time on bacterial growth is very much dependent on the initial count at milk harvest. Although some processors provided data regarding pick-up frequency, examining the effect of pick-up frequency on TBC alone would neglect other factors such as hygiene and the initial quality of milk, which are likely to be more influential on the bacteria count. Risk factors for greater TBC on Irish herds include dirty housing conditions, absence of hot water

washing, and absence of teat preparation (Kelly et al., 2009b). Fewer than 10% of farmers (n = 400) reported that they washed and dried teats with a paper towel (Kelly et al., 2009b); therefore, increased emphasis on premilking teat preparation may be needed to further reduce TBC means.

Differences in monthly TBC between seasonal and split-calving herds were most apparent at the beginning and end of the year. Many split-calving herds have contracts to supply milk for the liquid milk market. Producers of liquid milk must meet stricter thresholds for TBC (<30,000 cells/mL) and this regulation may account for reduced TBC observed in bulk milk from split-calving herds at the beginning and end of the year. Additionally, the majority of split-calving herds were categorized as herd size 3 or 4 (data not shown) and larger herds had lower TBC, likely due to differences in facilities and management practices.

Annual means for LPC reported herein are greater than those reported elsewhere (Elmoslemany et al., 2009; Pantoja et al., 2009; Gillespie et al., 2012), suggesting that herds enrolled in this study were having difficulty maintaining low LPC counts. Four out of 5 annual mean LPC recorded were >200 cfu/mL, which is above the recommended threshold that requires action (Ruegg and Reinemann, 2002). Laboratory pasteurization count is usually associated with milking equipment hygiene and sanitation (Villar et al., 1996; Reinemann et al., 2003; Elmoslemany et al., 2009), and increased LPC often indicates a failure in the cleaning process. In dairy farms on Prince Edward Island (Elmoslemany et al., 2009), risk factors for increased LPC included low temperature of the cleaning solution, high water-hardness score, and high alkalinity of alkaline detergent wash. Regulations for equipment sanitation in the EU are brief (89/362/EEC) and only note that milking equipment must be cleaned, disinfected, and rinsed with potable water. There is no requirement for milking equipment to be washed with hot water. The absence of hot water in the parlor (Kelly et al., 2009b) and daily hot washes (O'Connell et al., 2013) could account for higher annual means than reported for countries where hot washes are a daily occurrence. Irish farmers should be encouraged to carry out daily hot washes with adequate detergent to overcome cleaning failures and ultimately lower LPC.

Annual LPC peaked in 2008, and greater monthly means were seen during the summer of 2008 compared with other years. Spore-forming thermoduric bacteria are ubiquitous in soil (Heyndrickx, 2011). As soil moisture increased and in the absence of teat preparation, Christiansson et al., (1999) found that the concentration of *Bacillus cereus* spores in bulk tank milk increased. The above-normal rainfall recorded during 2008 (Met

Éireann, 2008) could have caused greater contamination of teats with thermoduric bacteria, which then contaminated the bulk tank milk.

In the current study, herds were tested for LPC twice a month. The lack of frequent testing may make it difficult for farmers to identify risk factors that influence LPC. Similar to trends reported by Gillespie et al. (2012), LPC was greatest in autumn and least in spring and winter. Despite current recommendations to change liners twice a year or every 2,000 milkings (Teagasc, 2008), Kelly et al. (2009b) reported that 64% of 400 farmers surveyed changed their liners once a year or less and found that this was associated with higher TBC. Declining condition of rubber teat cups and the build-up of milk residues in the milk line following continuous inadequate washes could account for the increase in LPC as lactation progresses.

Because cow numbers were unavailable to determine herd size, annual milk volume divided by the overall average milk production of Irish cows was used to establish herd-size categories. Although this form of classification did not account for underperforming large herds or overperforming small herds, the estimate closely approximated Irish census data for herd size (CSO, 2012). The estimate used in the current study resulted in 50% of farms being categorized as having >55 cows compared with census results showing that 55.48% of all farms contained >50 cows (CSO, 2012). Likewise, in the current study, the 25th percentile was similar to census data, whereby 25% of herds enrolled were estimated to have <36 cows compared with census results showing that 24% of all farms contained <30 cows. The 75th percentile in this study was estimated to be 80 cows and although the census data do not give the exact breakdown, 38% of herds had between 50 and 100 cows and 11% of herds had >100 cows.

In agreement with research conducted in other regions (Oleggini et al., 2001; van Schaik et al., 2002; Ingham et al., 2011), larger herds had the lowest annual mean SCC and TBC. Capital investments in improved herd facilities often require a critical herd size to generate income for improvements (Bailey et al., 1997; Archer et al., 2013). Therefore, it is often more feasible for larger herds to improve herd infrastructure compared with smaller herds. More modern facilities could have an indirect effect on milk quality, and cows on larger herds may benefit from better facilities. Operators of larger herds in Wisconsin were more likely to have regular maintenance of the milking machine, adopt a complete milking routine, use recommended premilking teat preparation practices, and submit samples of bulk milk for microbiological culture compared with operators on smaller herds and, as a result, had a lower prevalence of subclinical mastitis (Rodrigues et al., 2005). Similarly,

as herd size increased in Pennsylvania, management practices changed with respect to type of bedding used, sanitation wash (automatic, manual, or semiautomatic), dry cow treatment, forestripping, teat dipping, and towel type (Jayarao et al., 2004). In the current study, differences in SCC among herd sizes was most apparent from October to December, indicating greater prevalence of subclinical mastitis in late lactation on smaller herds. This difference in milk quality among herd sizes is most likely related to farming practices.

CONCLUSIONS

Annual bulk tank SCC increased slightly from 2007 to 2009 and then declined thereafter, whereas annual TBC remained stable and LPC increased from 2007 and 2011, peaking in 2008. Seasonal trends were observed for monthly SCC, with steady increases from October as the majority of cows entered late lactation, indicating increased prevalence of subclinical mastitis in late lactation. Efforts to reduce bulk tank SCC at this time of the year are warranted. Milk quality differed when herds were categorized based on their herd type and herd size. Seasonal herds had lower SCC from February to September, whereas split-calving herds had a lower SCC thereafter. The average DIM for each herd type differed depending on the month of the year and most likely accounted for the differences in bulk tank SCC. As average DIM increases, opportunities for cows to become exposed to mastitis pathogens increase. Successful education and implementation of well-recognized mastitis control programs on Irish farms could prevent the spread of contagious mastitis and reduce SCC in late lactation. Monthly TBC was greatest at the beginning and end of the year for both split-calving and seasonal herds. Suboptimal housing conditions combined with wetter weather conditions may account for increased TBC at these times. Split-calving herds had lower TBC at the beginning and end of the year than seasonal herds, likely because most split-calving herds have to meet stricter TBC regulations. Hygienic housing conditions and improved teat preparation have the potential to reduce TBC and overcome seasonal influences at the beginning and end of the year. Larger herds had lower SCC and TBC across all months compared with smaller herds. By monitoring milk quality trends in Ireland between 2007 and 2011, we concluded that considerable improvements in milk quality were not seen. Improvements in bulk tank SCC and TBC in late lactation and during winter are warranted. This could be achieved by improving hygiene in the cow's environment, thorough teat preparation, culling chronically infected cows, drying off low-yielding cows, and improving mastitis management.

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