Temporal Trends in Bulk Tank Somatic Cell Count and Total Bacterial Count in Irish Dairy Herds During the Past Decade

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ABSTRACT

The objective of this study was to document temporal trends in bulk tank somatic cell count (SCC) and total bacterial counts (TBC) in Irish dairy herds during the years 1994 to 2004. Three milk processors participated in the study, providing data on 2,754,270 individual bulk tank SCC and 2,056,992 individual bulk tank TBC records from 9,113 herds. Somatic cell counts decreased during the years 1994 to 2000, followed by an annual increase thereafter of more than 2,000 cells/mL. A tendency existed for TBC to decrease over time. Across all years, bulk tank SCC were the lowest in April and highest in November; TBC were the lowest in May and highest in December. The significant seasonal pattern observed in herd SCC and TBC was an artifact of seasonal calving in Ireland. In general, herds selling more milk had lower bulk tank SCC and TBC. Herds having the highest SCC (i.e., >450,000 cells/mL) and the lowest SCC (i.e., ≤150,000 cells/mL) both contributed substantially to the mean SCC of the milk pool collected by the milk processors. Derived transition matrices showed that between adjacent years, herds had the greatest probability of remaining in the same annual mean SCC or TBC category.

Key words: bulk tank, dairy, somatic cell, bacterial count

INTRODUCTION

The 1.136 million dairy cows in Ireland produce approximately 5.3 billion kg of milk annually (Central Statistics Office, 2005), of which 10% is consumed locally as fluid milk and the remaining 90% is processed mostly into cheese and butter. The milk industry accounts for 35% of the gross agricultural output in Ireland (Central Statistics Office, 2005), thereby indicating the great importance of milk quality to the Irish agricultural sector as a whole. Export of dairy products

from Ireland is worth approximately €1.7 billion annually (Central Statistics Office, 2005).

Several studies have implicated high SCC as a causative factor of the reduced shelf life of fluid milk (Ma et al., 2000) as well as reduced cheese yield and quality (Kitchen, 1981; Munro et al., 1984; Barbano et al., 1991). Although any adverse effect of high milk SCC on human health has not been shown (Smith and Hogan, 1998), high SCC are thought to be indicative of cows that are stressed or immunologically challenged, or both (Eberhart et al., 1982; Wilson et al., 1997). This may have implications for consumer attitudes toward systems of milk production in the future.

Herds with greater SCC also exhibit an increased risk of antibiotic residue violation (Ruegg and Tabone, 2000) because of their increased antibiotic usage, owing to their greater prevalence of subclinical mastitis. In addition, elevated SCC are associated with lesser cow (Raubertas and Shook, 1982; Ma et al., 2000) and herd (Emanuelson and Funke, 1991; Van Schaik et al., 2002) milk yields, resulting in potential losses in income. Hence, monitoring and control of SCC at a national level as well as on an individual farm basis is vital to identify and monitor trends. It is also a fundamental resource for quality assurance programs. The European Union, of which Ireland is a member state, currently imposes a regulatory limit of 400,000 somatic cells/mL and 100,000 bacterial cells/mL (EEC, 1992, Council Directive 92/46/EEC).

The total bacterial count (TBC) of a bulk tank milk sample is indicative of, among others, herd health status, farm sanitation (e.g., cleanliness of milking equipment), and milk storage temperatures operated on the farm. *Campylobacter*, enterohemorrhagic strains of *Escherichia coli*, *Salmonella*, and *Yersinia* have been observed in bulk milk samples and, unlike SCC, are often implicated in milk-borne disease outbreaks (Steele et al., 1997). Although most bacteria found in raw milk are nonpathogenic and are mostly destroyed by pasteurization, close monitoring of bulk tank TBC is nonetheless crucial to instill consumer confidence in the quality of milk produced.

The objective of the present study was to investigate temporal patterns in milk quality, specifically SCC and

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TBC, in Irish dairy herds during the past decade using data supplied from 3 milk processors. The results will aid in determining trends over time as well as the period of the year when milk quality (i.e., SCC and TBC) deteriorates.

MATERIALS AND METHODS

Data

Data were provided by 3 Irish milk processors. However, information obtained from 1 processor was slightly different and is described separately. All processors evaluated SCC and TBC using the Fossomatic and Bactoscan instruments (Foss Electric, Hillerød, Denmark), respectively.

Data consisting of herd identification, date of collection, milk volume collected, bulk SCC, and bulk TBC were supplied by 2 milk processors for the years 1994 to 2004, inclusive. In total, 6.3 million test-day records consisting of milk volume with or without a corresponding bulk tank SCC (up to twice monthly) or TBC (up to 3 times monthly) were available. In Ireland, milk is collected from farms generally every other day or every third day. Herds with less than 100 test-day observations for milk yield within the year were removed; 6.2 million test-day records from 44,366 different herd-years remained. Of the data available, 1,324,117 test-day records had a bulk tank SCC and 1,057,354 records had a bulk tank TBC. Monthly milk yield was calculated for each herd as the sum of the daily milk collected for each month of each year.

The third milk processor provided only monthly milk supplies per herd for the years 1994 to 2004, inclusive. Information on individual bulk tank SCC (collected no more than twice monthly) and bulk tank TBC (collected no more than 3 times monthly) were supplied. In total, the third processor supplied data on 1,138,661 bulk tank SCC samples and 1,198,981 bulk tank TBC samples across 67,917 herd-years. Only herds with information for at least 6 mo of the year were retained.

Monthly herd milk yield for all 3 processors were collated, as were SCC and TBC test-day samples. Only historical data on herds that were present in 2004 were retained. A total of 9,113 herds were available during 2004 for inclusion in the analysis, which represented approximately 40% of the 23,000 milk suppliers in Ireland at that time (Central Statistics Office, 2005). A total of 99,325 herd-years were included in the analysis; not all herds had data for 11 yr because of the edits previously described. In total, 2,754,270 SCC and 2,056,992 TBC samples were included in the analysis across 99,325 herd-years. Herds also were coded based on quartiles for annual milk volume sold. Threshold

values used to separate herds into quartiles were 122,686, 182,226, and 263,751 L/yr.

Analyses

Correlation analyses among monthly SCC, TBC, and milk volume were performed by using the procedure CORR (SAS Institute, 2005). Because distributions of monthly SCC, TBC, and milk yield were positively skewed, the natural log of the herd-year monthly averages were calculated before correlation analyses were performed.

Temporal Trends. Annual trends in SCC and TBC were assessed by obtaining the annual geometric mean of the 2-cell count variables from a mixed model analysis, with herd included as a random effect in ASREML (Gilmour et al., 2006). Fixed effects included in the model were year and month. Seasonality of monthly trends was tested using a generalization of Hewitt's test for seasonality (Rogerson, 1996).

Proportions of herd test-days that were >250,000 cells/mL also were estimated for each year. A herd-year test-day threshold of 20,000 cells/mL was used for TBC. The number of herds with a monthly geometric mean for SCC of >250,000 cells/mL as a proportion of the total herds was plotted on a monthly basis. A threshold of 20,000 cells/mL as a geometric mean was chosen for TBC.

Contribution to Overall Milk Supply. The effect of any one herd on the overall mean SCC supplied to a milk processor during a given time period will be a function not only of the SCC, but also of the milk volume of that herd supplied during the study period. Schukken et al. (1992b) devised a variable, SCC contribution, to reflect the monthly contribution of an individual herd for SCC, weighted by milk volume supplied, to the overall annual mean SCC across all herds. Hence, the SCC contribution of a particular herd reflects both the SCC of the herd and the quantity of milk supplied relative to other herds within the same year. The SCC contribution for herd k in year j was calculated as

$$\text{SCC contribution}_{jk} = \frac{\sum_{i=1}^{12} (\text{SCC}_{ijk} - \text{THRES}) \cdot \text{PRODUCTION}_{ijk}}{\text{MEAN ANNUAL PRODUCTION}_j},$$

where SCC_{ijk} is the mean SCC for month i in year j for herd k ; THRES is the predefined SCC threshold (set to 250,000 SCC/mL in the present study); PRODUCTION_{ijk} is the herd k milk production in month i of year j ; and $\text{MEAN ANNUAL PRODUCTION}_j$ is the mean production across all herds for year j .

A similar procedure was undertaken for TBC contribution, with a threshold of 20,000 cells/mL. Only herd-years that had records for SCC and TBC for all 12 months were included in the analysis of cell count contribution.

Transition Matrices. A Markov model simulates movement between states over time. In such a model, the probability that an individual (in the present study, an individual is represented by a herd) will move from one state to another is expressed by a transition probability. Transition probabilities for all transitions across time are used to generate a transition matrix. The probability that a herd moves from one state to another is independent of the states visited before the entry into that state. This is known as the Markovian property. The distribution of states, known as the state vector (M), and the changes that occur in this distribution are of primary interest in Markov models. The state vector at any time depends on the previous state vector and the transition matrix (T). Once the current state vector is known and the transition matrix estimated, the state vector in any future time period may be predicted.

In the present study the initial state vector was assumed to be the proportion of herds in 2004 residing in each of 7 predefined SCC categories: $\leq 150,000$, 150,001 to 200,000, 200,001 to 250,000, 250,001 to 300,000, 300,001 to 350,000, 350,001 to 400,000, and $> 400,000$ cells/mL. A transition matrix was derived separately for each set of adjacent years from 2000–2001 to 2003–2004. An average across all 4 elements of the transition matrix was used to derive an average transition matrix representative of the previous 4 yr. Based on the average transition probabilities across these 4-yr groupings and the proportion of herds residing in each of the SCC groups in 2004, a projection of the proportion of herds with an annual geometric SCC mean of $< 250,000$, 250,001 to 400,000, or $> 400,000$ cells/mL in 2009 was calculated. The average transition matrix was used to predict future changes in proportions of herds in the alternative SCC categories in the coming years as

$$M_{n+1} = M_n \cdot T^n,$$

where n is years after 2004. A transition matrix was also derived for TBC in which thresholds were set at $\leq 15,000$, 15,001 to 20,000, 20,001 to 30,000, and $> 30,000$ cells/mL.

RESULTS

The Pearson correlation coefficient between the log transformation of SCC and TBC was 0.16 ($P < 0.001$). Correlations with the log transformation of milk yield

were -0.21 ($P < 0.001$) for SCC and -0.12 ($P < 0.001$) for TBC.

Temporal Trends

Annual milk supply (from herds present in 2004) to the 3 processors increased from 1.6 billion L in 1994 to 2.3 billion L in 2004. Figure 1 summarizes the milk supply pattern during all years of the study, described as a percentage of total annual milk supplied by those herds to the milk processors. A clear seasonal pattern was obvious, and statistical analysis using Hewitt's test for seasonality revealed a seasonality effect ($P < 0.05$). More than half of the milk volume is supplied during the months of April to July, with 75% of the milk supplied during the 6 mo of April to September. Supply trends over the years revealed a relatively smaller peak in recent years. Nonetheless, the milk supply curve became flatter in recent years.

Annual geometric means for SCC and TBC are illustrated in Figure 2. The 95% confidence intervals for annual SCC and TBC were all $< 2,100$ and 360 cells/mL, respectively. Adjacent years were different ($P < 0.01$) from each other for SCC and TBC. A decrease in bulk tank SCC was observed from 1994 to 2000. However, there was a slow increase in SCC from 2000 to 2004; the SCC geometric mean increased from 240,039 cells/mL in 2000 to 250,937 cells/mL in 2004. The SCC from 2001 to 2004 were all greater ($P < 0.01$) than those during 2000. Bulk tank TBC decreased from 1994 to 2003, but TBC in 2004 was greater ($P < 0.01$) than that in 2003. The annual geometric means for SCC derived separately for herds grouped into quartiles based on annual milk sold are illustrated in Figure 3. The greatest SCC were observed in herds that sold the least milk, whereas the least mean SCC were in the herds that sold the most milk. A similar trend was observed for bulk tank TBC.

Figure 4 summarizes the monthly geometric mean SCC and TBC across all the years of the study. The 95% confidence intervals for each time point were all $< 2,300$ cells/mL and 240 cells/mL for SCC and TBC, respectively. All adjacent months had different ($P < 0.01$) SCC and TBC, with the exception of TBC in April and May, which were not different from each other. A seasonal effect ($P < 0.05$) was observed for SCC and TBC, with the highest counts observed during the winter. The lowest cell counts were observed during April and May.

The proportion of herd suppliers in any one month with a monthly SCC geometric mean of $> 250,000$ cells/mL increased in 2004 compared with 2000 (Figure 5). In 2004, more than 70% of herds had a SCC geometric mean of $> 250,000$ cells/mL during November and De-

Figure 1. Percentages of annual milk supplied during each month of the year from 1994 to 2004.

cember. Across all months, the proportion of herds exceeding the monthly SCC geometric mean of 250,000 cells/mL increased by 7 percentage units from 2000 to 2004. In contrast, the proportion of suppliers with a monthly bulk tank TBC geometric mean of >20,000 cells/mL decreased from year 2000 to year 2004 across

11 mo of the year, with September being the exception. Across all months, 9 percentage units less herds had more than 20,000 total bacterial cells/mL in 2004 than in 2000. Across all years, 52% of herd-year tests had a SCC of >250,000 cells/mL, whereas 42% of herd-year tests exhibited a TBC of >20,000 cells/mL.

Figure 2. Annual trend in geometric mean SCC ($-\square-$) and total bacterial count (TBC; $-\bullet-$).

Figure 3. Annual trend in SCC in the first (□), second (◆), third (●), and fourth (△) quartiles for herd-year milk volume.

Contribution to Overall Cell Count

The contribution of each of the categories of cell counts to the annual SCC and TBC is illustrated in Figure 6 for the years 1994, 2000, and 2004. During 1994, herds having the greatest SCC contributed the most to the overall annual SCC of >250,000 cells/mL.

However, their relative contribution decreased in 2000, which was concurrent with a substantial decline in SCC during the same period. However, the contribution of the high-SCC herds to the overall SCC seems to be increasing again, simultaneous with an increase in the annual mean SCC. This increase indicates that the proportion of herds in the highest SCC category may deter-

Figure 4. Monthly trend in geometric mean SCC (□) and total bacterial count (TBC; ●).

Figure 5. Proportion of suppliers whose monthly geometric mean in 2000 (shaded bars) and 2004 (open bars) was greater than (A) SCC of 250,000 cells/mL and (B) total bacterial count (TBC) of 20,000 cells/mL.

mine, to a large degree, the annual mean SCC. Nevertheless, during recent years, the contribution of the lowest SCC category (<150,000 cells/mL) was just as important in maintaining the overall mean SCC of <250,000 cells/mL as the highest SCC category of herds.

A somewhat contrasting pattern was observed for TBC. Despite the large increase in the contribution of the highest TBC category in 2004 compared with 2000, the proportion of herds in the category was smaller in 2004 (41% in 2000 vs. 34% in 2004) and a larger proportion of herds were in the lowest TBC category.

Transition Matrices

The probability of a herd moving from one SCC category to another SCC category among adjacent years is summarized in Table 1 for the years 2000–2001 to 2003–2004. A transition matrix for TBC is summarized in Table 2. In general, the diagonal elements, representing a set of 4 yr for a given SCC category, exhibited the largest probabilities within a row. These diagonal sets of elements represent the probability that a herd will remain in the same category as in the previous year.

Figure 6. Contribution of the alternative categories of cell count to annual (A) SCC and (B) total bacterial count (TBC) during 1994 (shaded bars), 2000 (open bars), and 2004 (cross-hatched bars).

For example, 47% of herds with a geometric mean SCC of <150,000 cells/mL in 2000 remained in that category during 2001. This implies that across adjacent years, the largest proportion of herds remained in the same SCC class. A similar trend was observed for TBC.

The proportion of herds in 2004 whose SCC geometric mean was <150,000, 150,001 to 200,000, 200,001 to 250,001, 250,001 to 300,000, 300,001 to 350,000, 350,001 to 400,000, and >400,000 cells/mL were 9.6, 16.6, 20.9, 19.6, 14.4, 9.8, and 9.1%, respectively. If the

average transition among SCC categories during the previous 4 yr persists for the next 5 yr, then the proportion of herds with a geometric mean of <250,000 cells/mL will decrease by more than 4 percentage units from 47% during 2004 to 43% during 2009. The 4-percentage-unit decrease in the category of <250,000 cells/mL entered the 250,001 to 400,000 cells/mL category (2.9 percentage units) and the >400,000 cells/mL category (1.2 percentage units). Assuming that the linear rate of increase in SCC from 2000 to 2004 persists for another

Table 1. Transition matrix across alternative SCC during the years 2000 to 2001 (2000, 2001 to 2002 (2001), 2002 to 2003 (2002), and 2003 to 2004 (2003))

Year	SCC (cells/mL)	≤150,000	150,001 to 200,000	200,001 to 250,000	250,001 to 300,000	300,001 to 350,000	350,001 to 400,000	>400,000
2000	≤150,000	0.47	0.34	0.14	0.04	0.01	0.00	0.00
2001		0.58	0.27	0.11	0.03	0.02	0.00	0.00
2002		0.49	0.32	0.14	0.04	0.02	0.00	0.00
2003		0.48	0.34	0.12	0.04	0.01	0.01	0.00
2000	150,001 to	0.16	0.32	0.32	0.13	0.05	0.01	0.01
2001	200,000	0.22	0.37	0.24	0.12	0.04	0.01	0.00
2002		0.16	0.34	0.29	0.14	0.05	0.02	0.01
2003		0.15	0.34	0.31	0.15	0.04	0.01	0.01
2000	200,001 to	0.05	0.19	0.30	0.26	0.13	0.05	0.02
2001	250,000	0.07	0.24	0.33	0.22	0.11	0.03	0.01
2002		0.04	0.21	0.31	0.26	0.12	0.04	0.02
2003		0.05	0.19	0.31	0.25	0.12	0.06	0.02
2000	250,001 to	0.02	0.09	0.20	0.29	0.22	0.13	0.05
2001	300,000	0.03	0.11	0.23	0.30	0.20	0.09	0.03
2002		0.02	0.08	0.23	0.31	0.22	0.10	0.05
2003		0.02	0.09	0.24	0.30	0.20	0.10	0.05
2000	300,001 to	0.01	0.04	0.11	0.23	0.29	0.20	0.13
2001	350,000	0.01	0.05	0.16	0.26	0.28	0.17	0.07
2002		0.01	0.05	0.12	0.22	0.27	0.20	0.12
2003		0.01	0.06	0.14	0.26	0.26	0.18	0.10
2000	350,001 to	0.01	0.02	0.08	0.16	0.23	0.27	0.23
2001	400,000	0.01	0.03	0.09	0.16	0.27	0.26	0.19
2002		0.01	0.03	0.07	0.16	0.24	0.26	0.24
2003		0.01	0.04	0.08	0.17	0.26	0.22	0.23
2000	>400,000	0.00	0.01	0.06	0.09	0.15	0.21	0.48
2001		0.00	0.02	0.06	0.10	0.16	0.24	0.42
2002		0.01	0.01	0.04	0.08	0.15	0.24	0.47
2003		0.00	0.01	0.06	0.08	0.15	0.22	0.49

5 yr, then the geometric SCC mean in 2009 is expected to be 262,984 cells/mL. Proportion of herds in 2004 whose TBC geometric mean was <15,000, 15,001 to 20,000, 20,001 to 30,000, and >300,000 cells/mL were 41.0, 25.5, 21.0, and 12.6%, respectively.

DISCUSSION

The objective of this study was to quantify the change, if any, in bulk tank SCC and TBC in Irish dairy herds during the past decade. Although the mean SCC declined from 1994 to 2000, it began to increase again during 2000 at an annual linear rate of more than 2,000 cells/mL. Bulk tank TBC during the period of the retrospective analysis declined. If the trend in SCC observed during the previous 4 yr persists without attention, then SCC will rise because of a transition of herds from having low bulk tank SCC to having moderate to high bulk tank SCC.

The correlations reported among SCC, TBC, and milk yield corroborate a previous report (van Schaik et al., 2002), indicating that greater bulk tank cell counts are associated with lesser milk volumes supplied. In the present study, milk volume may be used as a proxy for herd size, thereby indicating that larger herds have

lower SCC and TBC. This conclusion agrees with previous results using actual herd size (Oleggini et al., 2001). A positive correlation between bulk tank SCC and plate loop count (a variable similar to TBC in the present study) also was reported (Schukken et al., 1992a; Jayarao et al., 2004) using Canadian and US data, respectively.

Significant seasonal trends in milk supplied are a function of the seasonal calving system adopted in Ireland to maximize utilization of pasture grass in the diet of dairy cows (Dillon et al., 1995). In 2003, 55% of calves sired by a dairy breed bull were born in February and March (Department of Agriculture and Food, 2004); 79% of dairy calves were born during January through April (Department of Agriculture and Food, 2004).

SCC

The decline in mean bulk tank SCC during 1994 to 2000 (Figure 2) is encouraging and may be due in part to a dilution effect of greater yields per cow (Emanuelson and Funke, 1991). The average milk yield per cow in Ireland increased from 4,212 kg/cow in 1994 to 5,011 kg/cow in 2000 (Central Statistics Office, 2005). Assuming a similar total production of somatic cells as oc-

Table 2. Transition matrix across alternative total bacterial counts (TBC) during years 2000–2001 (2000), 2001–2002 (2001), 2002–2003 (2002), and 2003–2004 (2003)

Year	TBC	≤15,000	15,001 to 20,000	20,000 to 30,000	>30,000
2000	≤15,000	0.73	0.21	0.05	0.01
2001		0.70	0.24	0.05	0.01
2002		0.83	0.14	0.03	0.00
2003		0.70	0.22	0.07	0.01
2000	15,001 to 20,000	0.27	0.43	0.25	0.05
2001		0.27	0.39	0.30	0.04
2002		0.43	0.39	0.16	0.02
2003		0.29	0.39	0.25	0.07
2000	20,001 to 30,000	0.07	0.27	0.46	0.19
2001		0.14	0.25	0.43	0.18
2002		0.14	0.36	0.39	0.10
2003		0.09	0.27	0.44	0.21
2000	>30,000	0.01	0.07	0.29	0.64
2001		0.02	0.09	0.32	0.57
2002		0.03	0.12	0.35	0.49
2003		0.02	0.09	0.31	0.58

curred in 1994, the dilution effect owing to the increase in national milk yield per cow accounted for half of the proportional decline in bulk tank SCC observed in 2000. Other factors possibly contributing to the decline in bulk SCC during the past decade include increased awareness of farmers of cows with elevated SCC, and the impact of EU policies (EEC, 1992, Council Directive 92/46/EEC) and associated penalties for not achieving quality standards. The EU policies were fully implemented in member countries by 1998.

One factor possibly contributing to increased SCC during the past 4 yr is a reduction in the degree of milk recording and a shift toward less frequent milk recording in Ireland (Irish Cattle Breeding Federation, 2004). If dairy producers do not record milk, then it is difficult to identify cows with consistently elevated SCC, thereby increasing the overall bulk SCC. A further contributing factor may be a deterioration in the operating quality of milking machines. Maintenance of optimal milking machine characteristics is critical in maintaining acceptable herd SCC (Chassagne et al., 2005). In addition, the requirement of better cow-milking throughput, because of the increased farm scale, may result in a lower degree of premilking udder preparation, thus leading to higher SCC.

A similar annual trend was observed in The Netherlands, with a reduction in bulk tank SCC from nearly 600,000 cells/mL in 1976 to 200,000 cells/mL in 1999, followed by an increase to 227,000 cells/mL in 2003 (Sampimon et al., 2005). Sampimon et al. (2005) attributed the recent increase to a relaxation of SCC penalty limits after 2000. Additionally, a slight increase in the geometric mean for bulk tank SCC in recent years was reported in Norway (Østerås and Sølverød, 2005). The geometric SCC mean in Norway increased from 112,000

cells/mL in 2002 to 115,000 cells/mL in 2004, and although small, it is the first increase in SCC since 1988 (Østerås and Sølverød, 2005).

The SCC reported herein is lower than the averages reported in the United States (Oleggini et al., 2001; van Schaik et al., 2002) and Canada (Sargeant et al., 1998), but higher than some European estimates (Milk Development Council, 2004; Pitkälä et al., 2004; Østerås and Sølverød, 2005) and similar to others (Sampimon et al., 2005). The lower SCC reported in the present study compared with those in North America are mainly because of the greater restrictions placed on bulk tank SCC in the European Union compared with North America.

A highly season pattern in SCC during the year (Figure 3) is a function of the seasonal calving system of milk production in Ireland (Figure 1) and changes in SCC across lactation. The SCC tends to be highest in very early and late lactation and at a minimum in mid-lactation (Schepers et al., 1997; Djabri et al., 2002). Although the mean SCC increased from May, the rate of increase intensified from September onward.

The relatively large contribution of herds with very high cell counts to the overall mean cell count of milk collected by the processor agrees with the results of Sargeant et al. (1998), who documented that most of the contribution to SCC was from herds with a bulk tank SCC between 300,000 and 450,000 cells/mL. Sargeant et al. (1998) also highlighted the important contribution of the low SCC herds (<150,000 cells/mL) to the overall mean SCC, which is consistent with results from the present study. Hence, not only should educational resources be expended to reduce SCC in high SCC herds, but emphasis on maintaining low SCC also should be directed toward the low SCC herds.

The greater values within a row on the diagonal of the transition matrix are in agreement with other populations in which the dynamics of bulk tank SCC across herd-years was investigated (Schukken et al., 1990; Schukken et al., 1992b). Tracking population dynamics through transition matrices helps to identify categories of herds at risk for increasing bulk tank SCC in the following year, thereby facilitating a more targeted approach of educational resources toward these farms. Across most years, the probability of a category of herds with increased bulk tank SCC in the following year decreased as bulk tank SCC increased. Hence, educational resources to maintain low bulk tank SCC also should be directed toward herds that currently have low SCC. A similar conclusion was reported by Schukken et al. (1992b) when comparing transition probabilities of herds across months. The authors indicated that incentives may be a means of retaining a larger proportion of herds in the low SCC category.

Transition matrices also facilitate the modeling of categories of a population in future years based on assumptions of trends relative to previous years. Based on the average change in SCC during the past 4 yr, the expected change in population structure in 5 yr had 4 percentage units fewer herds having a geometric mean SCC of <250,000 cells/mL.

TBC

Although the annual trend in bulk tank TBC during the past decade was not consistent, a general tendency was observed for TBC to decrease with time. A linear regression fitted through the annual geometric means revealed an annual decrease of 1,307 cells/mL. Schukken et al. (1992a) also reported a decrease in bulk tank plate loop count during 1985 to 1991. This decrease is most likely an artifact of greater awareness and imposition of EU policies toward improved sanitation at milking time, but also may be a function of dilution through greater milk yield as described previously for SCC.

The mean TBC across all years included in the analyses was within regulatory thresholds specified by the EU. Similarly, the mean TBC across months was always within the specified threshold, although variation around the mean did exist among herds. Total bacterial counts were higher than the standard plate counts reported in studies in the United States (Boor et al., 1998) and Canada (Sargeant et al., 1998).

The trend for greater TBC during winter and early spring is attributable to the dairy production system in Ireland. In seasonal spring calving, as is operated in Ireland, winter and early spring coincide with late and early lactation, respectively. Several studies (Laevens et al., 1997) have reported a greater incidence

of IMI in early and late lactation, thereby increasing the TBC in milk. In addition, the norm in Ireland is to house cows during late autumn until spring. When housed, cows in Ireland are more likely to be exposed to microorganisms and soiled materials compared with when the cows are grazing outdoors, thereby increasing the probability of higher TBC in the bulk tank.

The generally greater probabilities observed on the diagonal elements for the highest and lowest TBC indicate that herds with more extreme TBC are more stable and exhibit a greater probability of remaining in that category during the subsequent year. Transition matrices are useful to elucidate reasons for annual changes in cell counts. For example, the increase in TBC from 2003 to 2004 may be attributed to a smaller proportion of herds remaining in the low TBC category, a greater proportion of herds remaining in the high TBC category, and a larger proportion of herds increasing in TBC compared with the transition from 2002 to 2003. Transition matrices also may be used to simulate impacts on future state vectors following different reactions to alternative scenarios (Schukken et al., 1990).

CONCLUSIONS

The positive correlation observed in the present study between SCC and TBC indicated that a reduction in SCC will, on average, be associated with reduced bulk tank TBC. The bulk tank SCC decreased between 1994 and 2000, but it is on the increase again. To reduce overall bulk tank SCC and TBC, attention should be focused on the category of herds with the largest contribution to the overall milk pool, which are not only the herds having the greatest cell counts, but also those with the lowest cell counts.

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