J. Dairy Sci. 104:2280–2289
https://doi.org/10.3168/jds.2020-18973

Monitoring udder health on routinely collected census data: Evaluating the short- to mid-term consequences of implementing selective dry cow treatment

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ABSTRACT

In 2013, the preventive use of antimicrobials in Dutch livestock was prohibited, including a ban on the blanket application of antimicrobial dry cow treatment (BDCT). Since then, selective dry cow treatment (SDCT) has become the standard approach. In this study, we aimed to determine the effect of the ban on BDCT and the extent of the subsequent adoption of SDCT on antimicrobial usage (AMU) and udder health on Dutch dairy farms. In the Dutch cattle health surveillance system, AMU for dry cow treatment (AMU_{DCT}), AMU for intramammary treatment at any point in time (AMU_{IMM}), and udder health indicators are routinely and continuously monitored. This provided the opportunity to study associations among SDCT, udder health, and AMU on census data of approximately 17,000 dairy herds, with about 1.67 million cows in total (>2 yr old) at one moment in time in the period from 2013 until 2017. Six udder health parameters were evaluated using multivariable population-averaged generalized estimating equation models. The year in which the ban on BDCT was introduced (2013) was compared with the period thereafter (2014–2017). Additionally, AMU_{IMM} and AMU_{DCT} were included as independent variables to evaluate whether the extent to which SDCT was implemented on the herd level was associated with udder health. Demographic parameters were included as potential confounders. Since the ban on BDCT, overall declines of 63% in AMU_{DCT} and 15% in AMU_{IMM} were observed. The raw data show an improvement in 5 out of 6 evaluated udder health parameters between 2013 and 2017. Nevertheless, the multivariable model results showed that the period since the ban on BDCT was associated with a small but significant increase in the percentage of cows with high somatic cell count (HSCC) and new HSCC (+0.41% and +0.06%, respectively). Additionally, the probability of belonging to the group of herds with more than 25% of primiparous cows having HSCC during the start of lactation increased slightly, associated with the period after which BDCT was banned (odds ratio = 1.08). The probability of belonging to the group of herds with more than 25% cows having a persistent HSCC during the dry period was not affected and bulk milk somatic cell count showed a slight but significant reduction. The only udder health parameter that notably worsened during the study period was the probability of belonging to the group of herds with more than 25% of multiparous cows with a new HSCC after the dry period, during the start of lactation (odds ratio = 1.23). In herds where the farmer decided not to apply any dry cow therapy (≈20% of all herds), all udder health parameters were poorer compared with herds in which dry cow therapy was applied to some extent. The ban on BDCT and implementation of SDCT in the Netherlands was associated with a considerable reduction in AMU without a major impairment in udder health at the national level. Although negative effects of changed dry cow management were observed in some herds, we conclude that SDCT can be introduced without substantial negative effects on udder health.
Key words: antimicrobial usage, dairy, udder health, somatic cell count, dry cow treatment

INTRODUCTION

In 2008, the Dutch government mandated that the livestock industry reduce antimicrobial usage (**AMU**). A target was set to achieve a 50% reduction in AMU in 2015 relative to that in 2009 (SDa, 2011). Regulations were developed in which the preventive use of antimicrobials in livestock was prohibited (Covenant antibiotic resistance animal husbandry; Dutch Ministry of Agriculture, Nature and Food Quality, 2008).

Received May 28, 2020.
Accepted September 25, 2020.
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In the Dutch dairy industry from 2005 to 2012, approximately 68% of total AMU was related to udder health. The majority of the intramammary treatments (66%) involved dry cow treatment (**DCT**; Kuipers et al., 2016). Before the change in regulations, approximately 90% of Dutch dairy cows were dried off using antimicrobials (Lam et al., 2013), which was considered a crucial part of the 5-point prevention and control program for mastitis (Neave et al., 1969). However, based on the ban on the preventive use of antimicrobials in livestock, blanket dry cow treatment (**BDCT**) was no longer allowed in the Netherlands, beginning in 2013. Scherpenzeel et al. (2014) evaluated the effect of selective dry cow treatment (**SDCT**) in a split-udder trial in cows with low SCC in 97 dairy herds in the Netherlands. The study showed that not applying dry cow antimicrobials in low SCC cows, compared with BDCT, was associated with an increased incidence of clinical mastitis (**CM**) and a higher individual SCC. However, in a modeling study, Scherpenzeel et al. (2016a) concluded that the herd-level effect of implementing SDCT was limited while a huge decrease in AMU could be achieved.

During 2013, the Royal Dutch Veterinary Association developed a guideline on the implementation of SDCT, including cow-level selection criteria to decide whether to apply antimicrobials at drying off (KNMvD, 2013; Vanhoudt et al., 2018). In 2013, SDCT was taken up progressively by the Dutch dairy farmers, and approximately 75% of the farmers had implemented SDCT to some extent by the end of that year (Scherpenzeel et al., 2016b). However, with 25% of the farmers still applying BDCT and other farmers treating the majority of cows with antimicrobials in 2013, about 80% of cows were treated with antimicrobials at drying off (Scherpenzeel et al., 2016b). In 2017, 99% of the farmers were applying SDCT, and the percentage of cows treated with antimicrobials at drying off was reduced to 40% (Holstege et al., 2017).

When BDCT was banned in the Dutch dairy industry, farmers and veterinarians expressed concern that SDCT would lead to deterioration of udder health and consequently to increased AMU for treatment of clinical and subclinical mastitis. Therefore, there was a need to monitor the effect of the antimicrobial restrictions on udder health parameters. Since 2002, a national surveillance system, the Cattle Health Surveillance System (**CHSS**) has been in place in the Netherlands, in which cattle census data are routinely collected and analyzed (Santman-Berends et al., 2016a). The database included data on cow-level SCC, bulk milk SCC (**BMSCC**), and AMU. This provided the opportunity to monitor the effects of the change in DCT policy on udder health parameters during and after the policy's introduction.

The aim of this study was to evaluate the effect of SDCT on udder health parameters from the year of introduction (2013) until 4 years later in Dutch dairy herds.

MATERIALS AND METHODS

Study Population

This study was carried out within the context of the CHSS, which was described in detail by Santman-Berends et al. (2016a). In the CHSS, census data are available from all cattle herds in the Netherlands that consented to use of their herd data for monitoring and surveillance purposes (38,578 cattle herds; 98% of total cattle herds). The current study focused on AMU related to udder health in about 17,000 Dutch dairy herds (98.5% of all dairy herds) that, in total, housed on average 1.67 million cows (>2 yr old) at one moment in time. Data of these herds from January 1, 2013, until December 31, 2017, were available. A dairy herd was defined as a cattle herd that continuously delivered milk.

Available Data

Animal movement data were obtained from the Identification and Registrations system (Rijksdienst Voor Ondernemend Nederland, Assen, the Netherlands), BMSCC (from Qlip Laboratories, Zutphen, the Netherlands), and AMU (from MediRund, The Hague, the Netherlands) for each quarter of each year. Test-day data on cow-level SCC were obtained from the Royal Dutch Cattle Syndicate (CRV, Arnhem, the Netherlands) and Milk Control Society (MCS) Nijland (Nijland, the Netherlands). The test-day data were available for approximately 80% of all dairy herds, the members of these organizations (Table 1).

Definitions and Description of Parameters

In this study, 6 udder health parameters that were extrapolated from SCC data were defined and calculated at herd and quarter of the year level from 2013 until 2017. A high SCC (**HSCC**) was defined as a cow with an SCC >150,000 cells/mL for primiparous cows and >250,000 cells/mL for multiparous cows. Cows with a new HSCC (**NEW_HSCC**) are cows with HSCC at the first test-day after calving or, further in lactation, after having had a low SCC at the preceding test-day. Cows at risk for NEW_HSCC were primiparous cows on their first test-day after first calving, lactating cows with a low SCC in the preceding test-day in their current lactation, or cows with a low SCC on the last test-day in their previous lactation. These parameters are based on the commonly used definitions in the Netherlands (Sampimon et al., 2010; CRV, 2018). Test-day records during the first 4 d in lactation were not evaluated because an elevated SCC in the first days of lactation could have a physiological basis rather than being caused by an IMI (Dohoo, 1993; Barkema et al., 1999). The udder health parameters that were included in this study were categorized in 2 groups. The first group consisted of general udder health parameters and included

- BMSCC: the average SCC (cells/mL) of bulk milk in each individual dairy herd. The BMSCC is evaluated every 14 d in every dairy herd for quality control purposes. These data were averaged per quarter of the year and included as a continuous outcome variable.
- The percentage of HSCC (P_{HSCC}) cows was calculated every test-day (once every 4 to 6 wk) using formula [1], where $Ncows_{HSCC}$ is the number of cows with HSCC and $Ncows_{SCC}$ is the number of cows that were tested for SCC on the test day:

$$P_{HSCC} = \frac{Ncows_{HSCC}}{Ncows_{SCC}} \times 100. \quad [1]$$

This parameter was subsequently averaged for each herd per quarter of the year (HSCC) and included as a continuous outcome variable.

- The percentage of cows with NEW_HSCC was also calculated using [1], but with cows with a NEW_HSCC as the numerator and the number of cows at risk for NEW_HSCC as the denominator. This parameter was also averaged for each herd per quarter of the year and included as a continuous outcome variable.

The second group of udder health parameters consisted of 3 parameters from early lactation in primiparous or multiparous cows which were hypothesized to be directly associated with DCT management.

- Having >25% primiparous cows with HSCC during the first 60 d in lactation (**PRIMI_HSCC**) was calculated using formula [2], where P_PRIMI_{HSCC} is the percentage HSCC primiparous cows in the herd, $Nprimi_{HSCC}$ is the number of primiparous cows with HSCC on the first test-day, and $Nprimi_{SCC}$ described the number of cows at risk; that is, primiparous cows having a first test-day in the specific quarter of the year:

$$P\_PRIMI_{HSCC} = \frac{Nprimi_{HSCC}}{Nprimi_{SCC}} \times 100; \quad [2]$$

PRIMI_HSCC for a herd was expressed per quarter and was allocated the value 1 if P_PRIMI_{HSCC} exceeded the 25% threshold; otherwise, the outcome value was set at 0 (binary outcome).

- Having >25% multiparous cows with new HSCC during the first 60d in lactation (**MULTI_HSCC**) was calculated using formula [2], but applied to multiparous instead of primiparous cows.

Table 1. Available data, their coverage, and source (in the Netherlands) to study the association between the introduction of selective dry cow treatment and the effect on udder health parameters in Dutch dairy herds between 2013 and 2017

Data set	Available parameters	Dairy herds covered (%)	Source
Identification and registration (I&R)	Animal level: Identification (ID) code, birth data, date of entry in the system, date of leaving the system. Movement level: unique herd identification (UHI), ID code, date of entrance, reason of entrance (birth/purchase), date of removal, reasons of removal (sold/slaughter/dead). Herd level: UHI: start date, end date, type of herd (farmer/slaughterhouse).	>98	Rijksdienst Voor Ondernemend Nederland, Assen
MediRund	EAN code (unique European article code), name of product, dosage, amount delivered, active substance, UHI, age group the medicine was supplied to [calves (<56 d), young stock (56 d–2 yr), cows (>2 yr)], type of treatment (oral, intramuscular, intravenous, intramammary, dry cow treatment).	>98	ZuivelNL, The Hague
Bulk milk SCC (BMSCC)	Date of measurement (twice per month), BMSCC result.	>98	Qlip Laboratories, Zutphen
Test-day records	Animal and test-day level: kg of milk, kg of fat, kg of protein. Herd and test-day level: percentage cows with a high SCC or new high SCC[1]	≈80	CRV, Arnhem; and MCS Nijland, Nijland

[1]High SCC is defined as SCC >150,000 cells/mL for primiparous cows and >250,000 cells/mL for multiparous cows.

A newly infected multiparous cow was defined as a cow with (1) a low SCC on the last test-day before calving and a HSCC at the first test-day after calving, or (2) a low SCC on the last test-day before calving, a low SCC at the first test-day after calving, and an HSCC on the second test-day (if that second test-day is within the first 60 d of lactation).

- Having >25% cows with persistent HSCC (**PERS_HSCC**) was also calculated using formula [2], using PERS_HSCC instead of PRIMI_HSCC. A PERS_HSCC was defined as having a HSCC on the last 2 test-days before drying off and a HSCC on the first test-day measure after calving. The denominator was the number of cows at risk; that is, that had an HSCC on the last 2 test-days before drying off.

Antimicrobial usage was monitored based on the results of 2 parameters: AMU for intramammary treatment (**$\mathbf{AMU_{IMM}}$**) in cows (>2 yr old) and AMU for dry cow treatment (**$\mathbf{AMU_{DCT}}$**). For both parameters, for each quarter of the year, the animal defined daily dose per farm over the past year (**$\mathbf{DDDA_F}$**) was calculated according to the method described by Gonggrijp et al. (2016).

Validation and Analyses

Each of the individual data sets were first validated and aggregated to the levels of the herd and quarter of the year before combining them using SAS software version 9.3 (SAS Institute, 2014). Routine checks and preliminary descriptive statistics were conducted to evaluate data quality, and double observations were removed. Biologically impossible values were set to missing (such as having a date of birth before January 1, 1990).

A value per herd per quarter of the year for the 5-yr period was calculated for each of the 6 udder health parameters. This value was either the average of all measurements (BMSCC, HSCC, NEW_HSCC) or a binary score that indicated whether a herd was above or below the predefined threshold value (PRIMI_HSCC, MULTI_HSCC, PERS_HSCC). Multivariable population-averaged generalized estimating equations (**PA-GEE**) models, with the appropriate distribution (i.e., Gaussian, or Binomial) in Stata version 14 (Stata Corp., 2014) were used for analysis. Conditional to the distribution of the dependent variable, an identity, or logit link function was included with an independent correlation structure. Model fit was evaluated using the quasi-likelihood under the independent model criterion (Pan, 2001; Cui, 2007).

The udder health parameters were included as dependent variables. The year in which preventive use of antimicrobials was forbidden and BDCT was banned (i.e., 2013) as well as the first years after the implementation of the new legislation (2014–2017) were included as independent variables to evaluate the association between udder health and the changed DCT strategy. After the ban on BDCT, only cows with indications of IMI were dried off with antimicrobials (Vanhoudt et al., 2018). Thus, AMU became dependent on the udder health situation in herds, leading to large variation in the level of application of DCT among Dutch dairy farmers. We therefore included AMU_{IMM} and AMU_{DCT} as independent variables of interest to capture the variety in AMU and DCT strategy between herds and the effect thereof. Additionally, parameters such as herd size, change in herd size, replacement rate, region, milk production level, season, type of milking parlor (conventional versus automated), and a variable representing the trend in time were included in the model as potential confounders. The AMU for intramammary and dry cow treatment per quarter of the year and per herd, was categorized into 3 categories (no AMU, below median AMU in that specific quarter of the year, or equal to or greater than median AMU in that quarter of the year), and the mean of the total population was included as the reference category. For categorical variables, we chose to use effect coding rather than reference cell coding because we were interested in deviations from the grand total mean of the population instead of differences between specific groups of herds; for example, compare herds with high AMU_{DCT} to the Dutch average instead of comparing herds with above median AMU_{DCT} with herds with an AMU_{DCT} below median.

RESULTS

Study Population

During the analyzed period, on average 17,032 Dutch dairy herds (>98% of the total population) with an average herd size of 99 cows (>2 yr old) gave permission to use their data for monitoring purposes. Of the adult cows in the herds, approximately 31% were primiparous and 69% multiparous. The number of herds declined slightly over time. The average herd size increased from, on average, 92 to 107 cows (>2 yr old) in 2016 and decreased thereafter to an average of 104 cows (>2 yr old) at the end of 2017 (Table 2).

With the ban on BDCT, we observed a decline in AMU for DCT (Table 2). In this period, AMU_{DCT} decreased 36% from an average $DDDA_F$ of 1.83 in 2013 to an average of 1.17 in 2015. Thereafter, AMU_{DCT}

Table 2. Descriptive statistics of Dutch dairy herds included in this study from 2013 to 2017

Variable[1]	2013	2014	2015	2016	2017
No. of dairy herds	17,428	17,254	17,202	16,981	16,293
Average herd size (cows >2 yr)	92	94	99	105	103
AMU intramammary treatment (in $DDDA_F$)	0.79	0.72	0.68	0.62	0.67
Average AMU dry cow treatment (in $DDDA_F$)	1.83	1.28	1.17	1.17	1.18

[1]AMU = average antimicrobial usage; $DDDA_F$ = defined daily dose of antimicrobials used, expressed on an annual level per farm.

remained stable. Additionally, from 2013 to 2017, AMU_{IMM} decreased from a $DDDA_F$ of 0.79 in 2013 to 0.67 in 2017 (15% reduction, Table 2).

General Udder Health Parameters

Descriptive Results. The parameters BMSCC, HSCC, and NEW_HSCC were used to monitor general udder health. During the study period, a slight downward trend was observed for all 3 parameters (Figure 1). The BMSCC decreased from an average of 199,000 cells/mL in 2013 to 170,000 cells/mL in 2017 (Figure 1a). The percentage of HSCC cows decreased from 19.5 to 16.3% and NEW_HSCC decreased from 9.2 to 8.2% in 2013 and 2017, respectively (Figure 1b and 1c).

Multivariable Results. Although no deteriorating effect of the changed DCT policy on udder health was observed when looking at the raw data, the results of the multivariable PA-GEE model showed that the period after the ban (2014–2017) was associated with a slightly but significantly higher percentage of HSCC cows and a borderline significantly higher percentage of NEW_HSCC cows (+0.41% and +0.06%; Table 3). Additionally, BMSCC was slightly but significantly lower in the period after the ban on BDCT (2014–2017) compared with in 2013 (Table 3).

Dairy herds that did not apply DCT in any of their cows showed significantly higher bulk milk and cow-level SCC (Table 3). In these cases, BMSCC was 15,487 cells/mL higher, the percentage of cows with HSCC was 1.65 percentage points higher, and the percentage of cows with NEW_HSCC was 0.70 percentage points higher compared with the Dutch average. The AMU_{IMM} results of showed that dairy herds with the highest AMU_{IMM} also had the highest SCC values in all 3 general udder health parameters, as would be expected (Table 3). In general, AMU_{IMM} and AMU_{DCT} showed a low positive correlation (r = 0.17), indicating that reducing AMU_{DCT} is not necessarily associated with a higher AMU for treatment of mastitis cases.

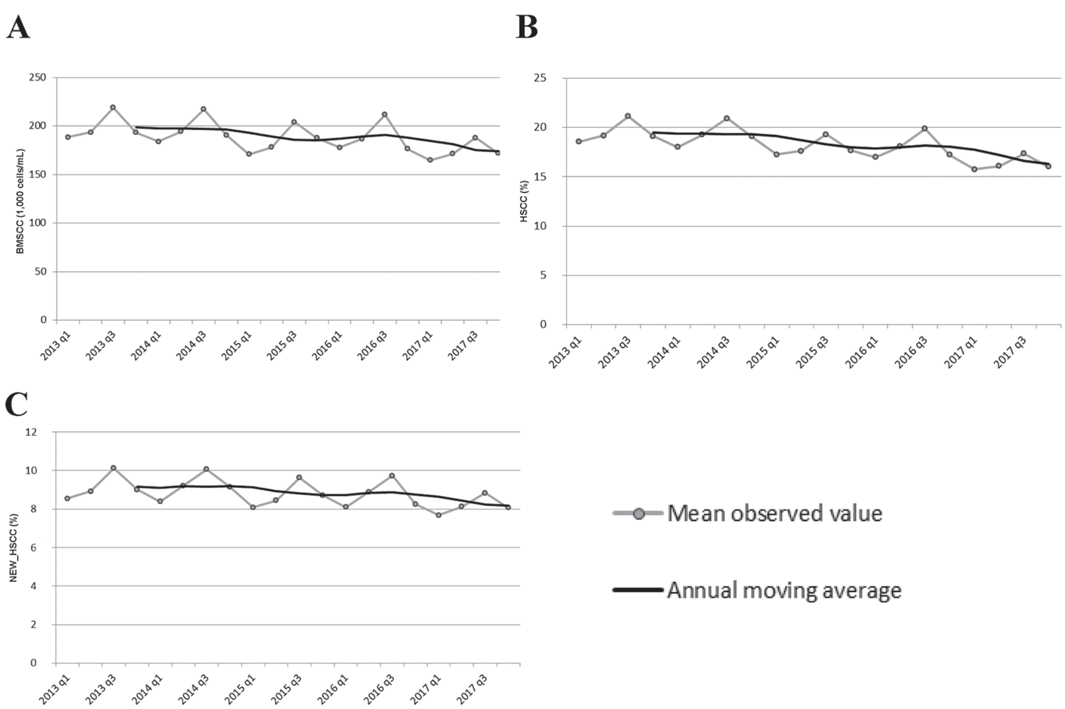

Figure 1. Mean observed value and annual moving average of (a) bulk milk SCC (BMSCC), (b) percentage of high SCC cows (HSCC), and (c) incidence of new high SCC cows (NEW_HSCC) in Dutch dairy herds per quarter of the year (q) from 2013 to 2017.

Udder Health Parameters at the Start of Lactation

Descriptive Results. Similar to the general udder health parameters, PRIMI_HSCC and PERS_HSCC improved during the study period (Figure 2a and 2c). The percentage of herds with PRIMI_HSCC decreased from an average of 32.8% in 2013 to 23.4% in 2017 (Figure 2a). The percentage of herds with >25% PERS_HSCC cows decreased from 2.0% in 2013 to 1.2% in 2017 (Figure 2c). The only parameter that did not improve during the analyzed period was the percentage of herds with >25% MULTI_HSCC. This parameter showed an increase from, on average, 7.4 to 9.2% of the dairy herds from the moment of the ban of BDCT until the first half of 2016. Thereafter, this parameter slightly decreased to an average of 8.0% of the herds (Figure 2b).

Multivariable Results. The results of the multivariable PA-GEE model showed that the ban on BDCT was associated with a limited but significantly higher odds of having >5% PRIMI_HSCC cows (1.08, 95% CI: 1.05, 1.12; Table 4). This adverse effect was also observed for multiparous cows, where the ban on BDCT was associated with odds 1.23 times higher (95% CI: 1.16, 1.30) of having >25% MULTI_HSCC cows. There was no statistically significant association between the implementation of SDCT and the percentage of herds with >25% PERS_HSCC cows (Table 4).

Dairy herds with a higher AMU_{IMM} than the median had 1.06 times higher odds of having >25% PRIMI_HSCC cows. There was no clear association between AMU_{IMM} and having >25% MULTI_HSCC cows during the first 60 d in lactation (Table 4). Nevertheless, dairy herds that did not dry off any cows with antimicrobials (AMU_{DCT} = 0) had 1.59 times higher odds of belonging to the group of herds with >25% MULTI_HSCC cows compared with the Dutch average (Table 4). Also, dairy herds with a higher AMU_{DCT} than the median

Table 3. Results of the multivariable population averaged generalized estimating equation models using a Gaussian distribution of 3 general udder health parameters in Dutch dairy herds in the period from 2013 to 2017

Variable	Parameter	Category[1]	Estimate	95% CI Lower	95% CI Upper	*P*-value
Bulk milk SCC (cells/mL)	Year[2]	2013	Referent			
		2014–2017	−2,203	−3,194	−1,286	<0.001
	AMU dry cow treatment[3]	None	15,487	14,982	15,992	<0.001
		< Median[4]	−2,826	−3,171	−2,481	<0.001
		≥ Median	−12,661	−13,027	−12,295	<0.001
	AMU intramammary treatment	None	−1,681	−2,310	−1,052	<0.001
		< Median	−2,453	−2,843	−2,063	<0.001
		≥ Median	4,134	3,729	4,538	<0.001
Cows with high SCC (%)	Year	2013	Referent			
		2014–2017	0.41	0.31	0.50	<0.001
	AMU dry cow treatment	None	1.65	1.59	1.72	<0.001
		< Median	−0.46	−0.52	−0.38	<0.001
		≥ Median	−1.24	−1.28	−1.19	<0.001
	AMU intramammary treatment	None	−0.10	−0.17	−0.02	0.01
		< Median	−0.53	−0.58	−0.49	<0.001
		≥ Median	0.63	0.58	0.68	<0.001
Cows with new high SCC (%)	Year	2013	Referent			
		2014–2017	0.06	0.00	0.11	0.04
	AMU dry cow treatment	None	0.70	0.67	0.73	<0.001
		< Median	−0.17	−0.19	−0.16	<0.001
		≥ Median	−0.53	−0.55	−0.51	<0.001
	AMU intramammary treatment	None	−0.08	−0.12	−0.04	<0.001
		< Median	−0.18	−0.20	−0.16	<0.001
		≥ Median	0.26	0.23	0.28	<0.001

[1]Ten percent of the dairy herds did not apply any intramammary antimicrobials, 45% used an amount of intramammary antimicrobials below the median, and 45% used an amount equal to or greater than the median. Twenty percent of the dairy herds did not use antimicrobials for dry cow treatment, 40% used an amount of antimicrobials below the median, and 40% used an amount equal to or greater than the median for dry cow treatment.

[2]2013 = banning of blanket dry cow therapy; 2014–2017 = implementation of selective dry cow therapy.

[3]The presented results are relative to the average Dutch dairy herd (reference category) and are corrected for confounders such as herd size, purchase, milk production, location, changing herd sizes over time, replacement, seasonal fluctuation, trends in time, and herd health status.

[4]The median value of AMU varied between quarters of the year. For example, in the most recent quarter of the data (i.e., 2017 q4), the median AMU for dry cow treatment was 1.38 $DDDA_F$ (defined daily dose of antimicrobials used, expressed on an annual level per farm) and the median AMU for intramammary treatment was 0.59 $DDDA_F$.

value in 2017 had substantially lower odds of belonging to the group of herds with >25% MULTI_HSCC cows (Table 4).

Although we did not hypothesize that the ban on BDCT would have a direct effect on persistent infections, we found that herds in which none of the cows were dried off with antimicrobials had 1.55 times higher odds to have >25% PERS_HSCC cows compared with the Dutch average (Table 4). Application of DCT in at least part of the herd (either below or above median use) was associated with lower odds of belonging to the group of herds with >25% PERS_HSCC cows.

DISCUSSION

The changed policy toward preventive use and subsequent ban on BDCT in the Netherlands resulted in a reduction in AMU related to DCT, whereas no increase in AMU_{IMM} was observed in the same period. We did, however, observe a slight worsening of some of the general cow-level SCC parameters and in udder health in the first 60 d of lactation, even though overall herd-level udder health seemed to improve slightly over time.

The improved udder health in the Netherlands could be a result of the Dutch national udder health program, which was launched in 2005 (Lam et al., 2013). Since then, udder health parameters have shown a slow but steady improvement, which created ideal circumstances for a more extensive implementation of SDCT. Even though udder health parameters kept improving overall with time, the multivariable model results showed a significant adverse effect of SDCT in 4 of the 6 evaluated udder health parameters. The magnitude of these effects was fairly limited for the percentage of HSCC (+0.4 percentage points), NEW_HSCC (+0.06 percentage points), and PRIMI_HSCC cows (odds ratio of 1.08). The strongest negative association of implementing SDCT was observed for the parameter describing the percentage of Dutch dairy herds with >25% MULTI_HSCC cows. Between 2013 and 2016, a clear increase in this parameter was observed. From July 2016 on, the percentage of herds with >25% MULTI_HSCC cows started to decline. Whether these effects were the result of implementing and subsequently becoming familiar with the application of SDCT remains unclear. During the study period, some general policy changes could have had an influence on the results. In 2008, the European Commission decided to abolish the milk quota starting in 2015 and allowed an annual increase in the milk quota of 2% per country as a preamble to 2015 (European Union, 2008). Likely as a consequence, the herd size of Dutch dairy farms increased from 92 to 107 cows (>2 yr old) between 2013 and 2016. This expansion in herd size was, in part, achieved by an increased number of lactations per dairy cow (data not shown), which is known to be associated with

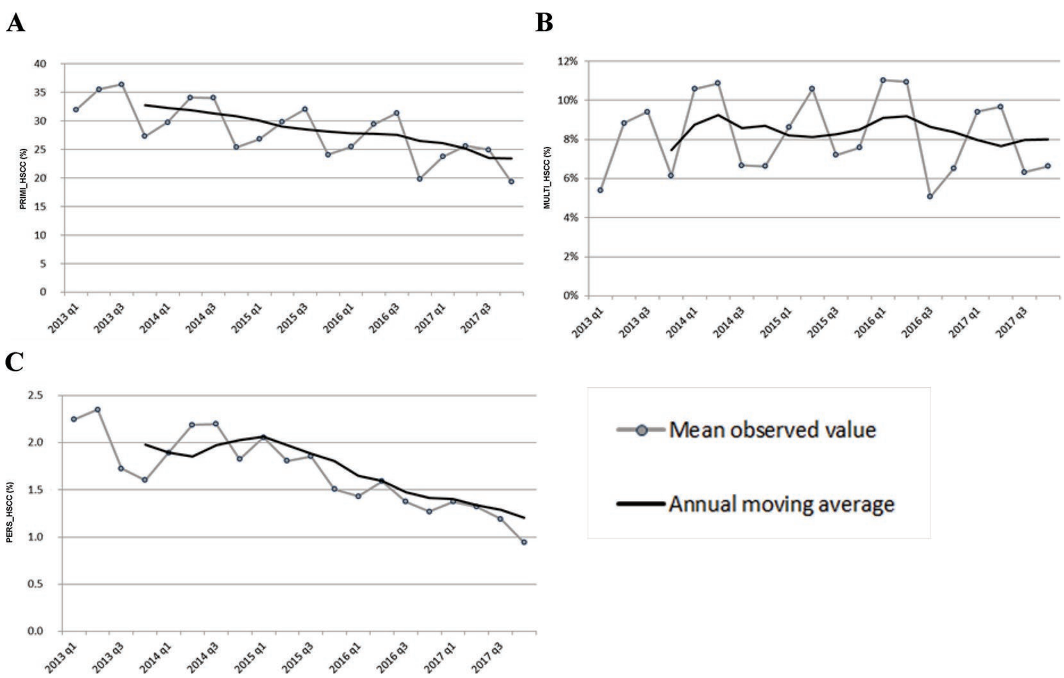

Figure 2. Mean observed value and annual moving average of (a) herds with high (>25%) percentage of primiparous cows with new high SCC during the first 60 d in lactation (PRIMI_HSCC), (b) multiparous cows with new high SCC during the first 60 d in lactation (MULTI_HSCC), and (c) herds with high prevalence of cows with persistent high SCC (PERS_HSCC) in Dutch dairy herds per quarter of the year (q) from 2013 to 2017.

an increased risk of (sub)clinical mastitis during the start of lactation (Steeneveld et al., 2008; Frössling et al., 2017; Hiitiö et al., 2017). Thus, in addition to the implementation of SDCT, this may have influenced the percentage of herds having >25% MULTI_HSCC cows. From 2016 on, national legislation required dairy herds to decrease their herd size because of excess manure; therefore, in 2016 and 2017, many cattle were moved to slaughter (Rijksoverheid, 2015). Chronic subclinical mastitis, expressed by a persistent HSCC, was likely one of the selection criteria for removal, which may have had an effect on the slight reduction in the percentage of herds with >25% MULTI_HSCC cows in the second half of 2016 and in 2017, after this parameter had showed a slight increase in the period before 2016. Because no deviation in other udder health parameters was observed in 2016/2017 compared with 2015, it is unlikely that the changed policy altered the effect of the BDCT ban on udder health to a great extent.

In our study, no clinical mastitis data were available, only cow-level SCC parameters. Nevertheless, in the Netherlands, 2 field studies were conducted in which the clinical mastitis incidence (**CMI**) was measured and the effect of SDCT was evaluated. The first was conducted in 2013, in which the observed CMI was 32.2 cases per 100 cows, and the second was conducted in 2016/2017, in which the CMI was estimated at 27.4 cases per 100 cows (Santman-Berends et al., 2016b; Holstege et al., 2017). Based on these results, it was concluded that the changed AMU policy did not result in an increased CMI. This was better than expected given that the earlier study by Scherpenzeel et al. (2014) predicted an increase in quarter-level CMI after implementation of SDCT. Although the positive effect of DCT on udder health is beyond doubt (Winder et al., 2019) and is confirmed in the current study, improved udder health management may have prevented large negative effects of withholding DCT for low SCC cows. This change in management may have been the result of a changed attitude of Dutch dairy farmers toward udder health and biosecurity resulting from a multiyear strategy to map and improve farmers' attitudes toward udder health and antimicrobial use (Jansen, 2010; Lam et al., 2017). This could not, however, be proven in this study. The mindset of the farmer toward a more restricted use of DCT and its consequences, both at the moment

Table 4. Results of the multivariable population averaged generalized estimating equation models with a binomial distribution of 3 parameters that evaluate udder health during the start of lactation in Dutch dairy herds in the period from 2013 to 2017

Group	Parameter	Category[1]	Odds ratio	95% CI Lower	95% CI Upper	*P*-value
Herds with >25% primiparous cows with new high SCC during start of the lactation	Year[2]	2013	Referent			
		2014–2017	1.08	1.05	1.12	<0.001
	AMU intramammary treatment[3]	None	0.98	0.96	1.01	0.24
		< Median[4]	0.96	0.95	0.98	<0.001
		≥ Median	1.06	1.04	1.07	<0.001
Herds with >25% multiparous cows with new high SCC during start of the lactation	Year	2013	Referent			
		2014–2017	1.23	1.16	1.30	<0.001
	AMU dry cow treatment	None	1.59	1.54	1.65	<0.001
		< Median	1.00	0.98	1.02	0.87
		≥ Median	0.63	0.61	0.64	<0.001
	AMU intramammary treatment	None	1.00	0.96	1.04	0.94
		< Median	0.93	0.91	0.96	<0.001
		≥ Median	1.08	1.05	1.11	<0.001
Herds with >25% persistent high SCC before and after calving	AMU intramammary treatment	2013	Referent			
		2014–2017	1.03	0.93	1.16	0.46
	AMU dry cow treatment	None	1.55	1.46	1.64	<0.001
		< Median	0.96	0.92	1.00	0.08
		≥ Median	0.67	0.64	0.71	<0.001
	AMU intramammary treatment	None	1.04	0.93	1.16	0.40
		< Median	0.89	0.85	0.94	<0.001
		≥ Median	1.08	1.02	1.15	0.006

[1]Ten percent of the dairy herds did not apply any intramammary antimicrobials, 45% used an amount of intramammary antimicrobials below the median, and 45% used an amount equal to or greater than the median. Twenty percent of the dairy herds did not use antimicrobials for dry cow treatment, 40% used an amount of antimicrobials below the median, and 40% used an amount equal to or greater than the median for dry cow treatment.

[2]2013 = banning of blanket dry cow therapy; 2014–2017 = implementation of selective dry cow therapy.

[3]The presented results are relative to the average Dutch dairy herd (reference category) and are corrected for confounders such as herd size, purchase, milk production, location, changing herd sizes over time, replacement, seasonal fluctuation, trends in time, and herd health status.

[4]The median value of AMU varied between quarters of the year. For example, in the most recent quarter of the data (i.e., 2017 q4), the median AMU for dry cow treatment was 1.38 $DDDA_F$ (defined daily dose of antimicrobials used, expressed on an annual level per farm) and the median AMU for intramammary treatment was 0.59 $DDDA_F$.

of introduction and after a few years, was favorable and the perceived negative consequences were limited (Scherpenzeel et al., 2016b, 2018; Holstege et al., 2017). This favorable attitude may also have helped to limit the negative consequences of the changed DCT policy.

In the Dutch situation, where preventive use of antimicrobials is not allowed, DCT with antimicrobials can only be applied if there is an indication of an IMI, which is generally based on SCC measurements before drying off (Vanhoudt et al., 2018). In the Netherlands, selection criteria used for application of DCT varied slightly over time, between farmers and sometimes even between cows within the same herd (Scherpenzeel et al., 2016b; Holstege et al., 2017). Dutch dairy farmers generally do not use bacteriological culturing at drying-off (Griffioen et al., 2016), and mainly use 4- to 6-weekly test-day SCC results to select cows for DCT. In the Nordic countries, only cows with an IMI proven by bacterial identification can be treated with antimicrobials at drying off (Østerås and Sølverød, 2009). In other studies, (on-farm) bacteriological culture results are effective and often used to decide whether to apply antimicrobials at drying off (Cameron et al., 2014; Vasquez et al., 2018). Although Dutch dairy farmers seem to apply different strategies, in which they do not strictly follow standardized criteria, this does not seem to have had a large effect on udder health on a national level.

An obvious limitation of our study is that we did not have a control group. We showed that in a 5-yr period with major changes in antimicrobial use related to DCT, no major worsening in udder health was seen at the national level. This may also be associated with improvements in udder health management in Dutch dairy herds that were implemented and promoted during a 5-yr national udder health improvement plan (Lam et al., 2013). We do not know what would have happened if the ban on BDCT had not been implemented and most of the Dutch dairy herds kept applying BDCT. Theoretically, in a control group that kept applying BDCT, udder health parameters could have improved more than we observed in our study.

Our results showed that the small group of farmers who did not apply any DCT had worse udder health parameters than those who applied SDCT to some extent. This indicates that some cows in these herds would probably have benefited from antibiotic treatment at drying off, reducing negative consequences such as (sub)clinical mastitis and transmission of IMI between cows. This underlines the finding that DCT had an effect on the occurrence of persistent infections and thus that the curative effect of DCT should not be underestimated. Based on the findings described in this study, we believe that from the perspective of prudent antimicrobial use in relation to optimal udder health and cow welfare, a total ban on DCT is undesirable.

In our study, we only had access to routinely collected data, which has its limitations given that we have only a limited amount of background information on the herd level. However, the routinely collected data from almost all Dutch dairy herds in the Netherlands resulted in complete and compelling evidence of a limited effect of the national BDCT ban on udder health.

CONCLUSIONS

The ban of BDCT in the Netherlands did result in a considerable reduction in AMU without a major worsening of udder health. Nevertheless, some slight but negative effects were observed, specifically in an increased proportion of herds with >25% multiparous cows that developed a HSCC after calving. Based on our results, we conclude that SDCT can be implemented without substantial impairment of udder health. A total ban on AMU_{DCT} would be undesirable but implementation of SDCT instead of BDCT is achievable without substantially jeopardizing udder health.

ACKNOWLEDGMENTS

The Cattle Health Surveillance System is financed by the Ministry of Agriculture, Nature and Food safety (LNV, the Hague, the Netherlands) and the producer organizations for dairy (ZuivelNL, the Hague, the Netherlands) and veal (SBK, Zeist, the Netherlands). The authors have not stated any conflicts of interest.

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