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Antibiotic use in dairy herds in the Netherlands from 2005 to 2012

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ABSTRACT

The aim of this study was to examine the variation in antibiotic use and the effects of external factors on trends in antibiotic use at the herd level by using the number of daily dosages as an indicator for antibiotic use. For this purpose, antibiotic use was analyzed in 94 dairy herds in the Netherlands from 2005 to 2012. The herds were divided into 3 groups of farmers: one group was guided in their antibiotic use from 2008 to 2010 as part of the project, whereas the other 2 groups were not actively guided. The farms were located in 10 of the 12 provinces and were clients of 32 of the 300 veterinary practices that treat cattle. Sales invoices from the veterinary practices provided the antibiotic and cost data for the participating farmers. The number of animal-defined daily dosages (ADDD) indicates the number of days per year that the average cow in a herd is given antibiotic treatment. The average ADDD for all farms from 2005 to 2012 was 5.86 (standard deviation = 2.14); 68% of ADDD were used for udder health, 24% for clinical mastitis and 44% for dry-cow therapy. Variation in ADDD among herds decreased during the study period. The trend in ADDD can be described as having 3 phases: (1) a period of increasing use coinciding with little public concern about antibiotic use (2005–2007), (2) a period of growing awareness and stabilization of use (2007–2010), and (3) a period of decreasing use coinciding with increasing societal concerns (2010–2012). The greatest reduction in use was for drugs other than those used to treat the udder. Drug use for mastitis treatment fell considerably in the final year of the study period, whereas farmers were reluctant to reduce use for dry-cow therapy. Almost 40% of the herds were given less than 2.5 ADDD for dry-cow therapy, which is equivalent to 2.5 tubes per average cow in the herd, and 20% used more than 3 tubes per cow. Use of third- and fourth-generation cephalosporins and fluoroquinolones dropped from 18% of ADDD during 2005 to 2010 to 1% in 2012, with a shift toward penicillins and broad spectrum drugs. The ADDD was 22% lower in 2012 than 2007, the year of the highest usage. The decrease in ADDD over time varied between the 3 groups of farmers. During the second phase of the study, the guided group began to display a reduction in use, whereas the other groups only displayed a significant reduction in the third phase. The reduction in antibiotic use has resulted in lower veterinary costs per cow in recent years.
Key words: antibiotic use, variation and trend, dairy farmer group, treatment category

INTRODUCTION

An increase in the resistance of bacteria to antibiotics, as observed in hospitals, is causing concern among medical practitioners (Schwarz et al., 2001; EFSA, 2009, 2011). The use of antibiotics in animal production is blamed for contributing to the increasing bacterial resistance to antibiotics in humans (Wise et al., 1998; Refsdal, 2000; Oliver et al., 2011). Leverstein-van Hall et al. (2011) have shown that bacteria in human patients, retail chicken meat, and live poultry share the same extended spectrum β-lactamases (**ESBL**) genes and plasmids. Likewise, Reist et al. (2013) and Timofte et al. (2014) reported the presence of ESBL in bacteria found in slaughtered cattle and milk from cows with mastitis. The European Food Safety Authority (EFSA, 2009) has reported on the presence of methicillin-resistant *Staphylococcus aureus* (MRSA) in livestock. Brunton et al. (2012) linked the high prevalence of cefotaximase-producing *Escherichia coli* in dairy calves to the selective pressure induced by the high level of antimicrobial residues in the waste milk fed to calves.

Grave et al. (2010) compared the sales of veterinary antimicrobial agents across 10 European countries in

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2007 based on the total amount of active substances used in all animal sectors. Use of these agents in the Netherlands was reported to be relatively high. The European Food Safety Authority panel on Biological Hazards (EFSA, 2011) concluded that "a highly effective control option would be to stop all uses of cephalosporins, systemically active third- and fourth-generation cephalosporins, or to restrict their use; as co-resistance is an important issue, it is also of high priority to decrease total antimicrobial use in animal production in the European Union."

In the Netherlands, societal and political debate on antibiotic use has intensified since 2008, following a consumer survey showing that information on food safety (e.g., contaminants and medicines) ranked highest among consumer demands (Verhees et al. 2008). The discovery of livestock-associated MRSA in hospitalized Dutch patients (van der Zee et al., 2013) and the detection of the same strains of ESBL in the livestock chain and humans (Leverstein-van Hall et al., 2011; Dierikx et al., 2013) have also fueled public debate.

A Memorandum of Understanding was signed in December 2008 between the Netherlands Ministry of Agriculture, Nature and Fisheries, the Ministry of Public Health, animal sector representatives and the Veterinary Association to monitor antibiotic use in the cattle, pig, and poultry sectors and develop use-reduction strategies. The targets, which included a 20% overall reduction by 2011, increasing to a 50% reduction by 2013 with 2009 as a base year, were added to the Memorandum in 2010. Since 2011, actions to raise awareness of antibiotic use have been undertaken by farmers' organizations, the Veterinary Association and Veterinary Practices, and the Dairy Processing Cooperatives and Companies. The preventive use of antibiotics, including dry-cow therapy, has come under scrutiny. In January 2012, the use of third- and fourth-generation cephalosporins and fluoroquinolones was prohibited unless, following a herd examination, a veterinarian substantiates that no alternative drug is available for the treatment of the particular health problem.

Several studies have discussed antibiotic use in traditional and organic dairy farms (Zwald et al., 2004; Sato et al., 2005; Bennedsgaard, et al., 2010); a literature overview on antibiotic use was reported by Van Werven et al. (2012). Overviews of the use of active substances and treatments in 1,013 herds in major US dairy states were presented by Hill et al. (2009). Pol and Ruegg (2007) developed a method of quantifying drug usage and treatment practices, using the number of defined daily dosages per adult cow per year, providing insight into antibiotic use on 20 traditional and 20 organic farms in Wisconsin. The same indicator was used by Saini et al. (2012), who estimated drug use in 89 Canadian herds.

However, studies on antibiotic use at the herd level are rather limited, illustrating that antibiotic use is an emerging topic. Insight into the methods of antibiotic use and use-reduction strategies would be useful in guiding such a trajectory. Until now, knowledge of the effects of policy initiatives and public opinion on changes in antibiotic use in dairy herds has been scarce. In the studies that have been published, an examination of trends over time was not feasible due to the short duration of the studies.

Discussions in 2004 and 2005 among dairy stakeholders in the Netherlands recognized the necessity of improving the use of veterinary medicine data (Kuipers et al., 2005a). A pilot study was undertaken to examine the data collection and identify useful indicators for monitoring medicine use in dairy herds. Subsequently, data on antibiotic use were collected from a group of dairy farms over an 8-yr period. Against this background, the objectives of our study were to examine the variation in antibiotic use over time with the effects of selected external factors on the trends in antibiotic use at the herd level.

MATERIALS AND METHODS

Source of Data

Data on drug use were collected in a group of 94 dairy farms in the Netherlands from 2005 to 2012 as part of two consecutive projects on medicine use. These data, together with experiences recorded during the same period, provided the source material for the present study.

Sales of drugs to farmers are facilitated by veterinary practices and recorded in their management administration system. Additionally, drugs used by veterinarians during farm visits and the number of hours the veterinarian spent on the farm are also recorded daily in the management administration system. Each month, invoices are prepared and sent to the farmers based on the recorded data. The farmers participating in the study signed an agreement permitting the project team to collect detailed drug usage data from these invoices from the veterinary practices. Initially, some farmers also purchased small quantities of drugs through online veterinary services. Where this occurred, the invoices were copied from the farm records, but this practice ceased during the course of the project. The invoices list the brand names, quantities, and costs of the drugs and other materials alongside costs (professional fees) for the farm visits by the veterinarian. Drugs containing antimicrobial ingredients were selected as input for this study. In addition, the number of teat sealer injectors together with the cost of drugs, materials, and veterinary fees were recorded from the invoices. The accumulated yearly veterinary costs per farm (€) were used as input for this study. The cost data for the whole study period were available for a subset of 45 of the 94 farms.

Farmer Groups

The farmers involved in this study belonged to 1 of the following 3 groups:

1. Guided group of farmers (41). This group comprised 6 subgroups of 6 to 8 farmers each from different veterinary practices. In each veterinary practice, one veterinarian was assigned as the local contact person. Early in 2008, the farmers were recruited by these veterinarians in cooperation with the project team. The aim was to recruit a group of dairy farms that varied in terms of herd size and farmer age. One of the recruited farmers stopped farming during the project period, and this farmer's data were excluded from the analysis. The farms were located in 6 provinces along the north–south axis of the Netherlands, including all of the intensive dairy farming provinces. This group of farmers was actively guided in antibiotic usage in 2008, 2009, and 2010 by the project team. The local veterinarian contact and 2 project team members organized and attended the subgroup meetings twice a year. During these meetings, antibiotic use and trends from 2005 onward were discussed and compared and overviews of antibiotic use of all guided subgroups were provided. The efficiency of data collection, policy developments, and expert reports on antibiotics-related issues were also discussed. In 2011 and 2012, the reports on antibiotic usage in 2010 and 2011, respectively, were emailed to these farmers without discussion.
2. Incidental group of farmers (40). These farmers joined the study in 2008 and 2009 at the request of the project team following contact during meetings or otherwise. The aim was to identify a group of dairy farms that varied in terms of herd size and age of farmers. Two of these farmers stopped farming during the project period and their data were excluded from the analysis. The farmers were associated with 17 different veterinary practices, 4 of which also had farmers in the guided group. The farms were located in 9 of the 12 provinces. No feedback was provided until 2011, which is when the antibiotic usage for 2005 through 2010 was reported to them by e-mail. The data for 2011 were also reported by e-mail in 2012.
3. Environmental group of farmers (13). This group of farmers consisted of participants in a long-term project on farm nutrient management (Kuipers et al. 2005b). They were associated with 13 veterinary practices, which are all different from those involved with the other 2 groups, and were located in 9 of the 12 provinces. Antibiotic use was not a topic that was addressed in this group until the project team calculated the number of daily dosages used in 2011 on each farm. The results were presented to the farmers in 2012.

Antibiotics Indicator

Animal-defined daily dosages (**ADDD**) were used as an indicator of antibiotic use (Jensen et al., 2004; Bondt et al., 2013; WHO, 2014). When applying this indicator to dairy cows, the number of daily dosages indicates how many days per year an average cow in the herd is treated with antibiotics. The average cow weight was set at 600 kg, and each tube used for dry-cow therapy was counted as one daily dose. Antibiotics administered to young stock were included in the calculation of the number of daily dosages per average cow in the herd. Sprays for claw and skin treatments were excluded. The calculations were performed in accordance with the national standard calculation. The number of ADDD (Bos et al., 2013) per cow in year t and herd h was calculated as follows:

$$\mathrm{ADDD}_{th} = \frac{\sum_{i=1}^{n}\left(B_i \,/\, ADD_i\right)}{C_{th}}, \qquad [1]$$

where n = number of drugs i involved in analysis (i.e., 65, including the category of other drugs); B_i = the amount of drug i bought by or sold to herd h in year t in milliliters, tubes, or grams; ADD_i denotes the animal (cow) defined daily dosage of drug i measured in milliliters, tubes, or grams; when drug i was used in calves, the $ADDi$ was multiplied by the factor 0.1 to adjust for the average weight of a cow; and C_{th} is the number of cows present, on average, during year t in herd h. The total usage in year t was

$$\sum_{h=1}^{94} \mathrm{ADDD}_{th}. \quad [2]$$

Antibiotic Treatment Categories

The drugs used were grouped under specific treatments. The treatment categories were classified as tubes for dry-cow therapy, drugs for mastitis, pills for retained placenta (postparturient), drugs for reproduction (metritis), and oral powders for calves. The remaining drugs, together with any incidentally used drugs, were assigned to a category of other drugs. Thereafter, ADDD were calculated per treatment category.

The number of daily dosages (tubes) per cow per year that were used for dry-cow therapy ($\mathrm{ADDD_{dry\text{-}cow}}$) is an important criterion, which depends on the farmer's policy toward dry-cow therapy and several herd characteristics. This can be expressed as follows:

$$\mathrm{ADDD_{dry\text{-}cow}} = \left(\frac{\mathrm{PC}}{100}\right)\times 4 \times \left(\frac{365}{\mathrm{CI}}\right)\times\left(1-\frac{\mathrm{PR}}{100}\right)\times\left(1-\frac{\mathrm{PTT}}{100}\times 1/4\right), \quad [3]$$

where PC = percentage of cows remaining in a herd that receives dry-cow therapy (all teats); CI = calving interval of the herd (days); PR = percentage of cows replaced; and PTT = percentage of cows that have 3 teats instead of 4.

Currently, 3 classes of drugs are specified in veterinary practices in the Netherlands: first-choice drugs are advised; second-choice drugs are permitted; and third-choice drugs are restricted for use and, as of January 1, 2012, may only be used by veterinarians (Royal Dutch Veterinary Association, 2013). Because the brand names of drugs are not universally recognized, the brand names were substituted with the corresponding therapeutic groups (combinations of active substances), whereas the class of drugs to which the active substances belong was also indicated. The ADDD for the various groups of active substances were calculated and expressed as percentages of total use.

Analysis of Variation and Trends

This was a descriptive study similar to that indicated by Hicks and Turner (1999) as ex post facto research, which describes variation and trends in antibiotic data over time. Moreover, we searched, in retrospect, for factors that influence changes in variation and trends.

The farm was taken as the observational unit, and the average ADDD per cow per year was calculated for the period from 2005 to 2012. Most herds were served by different veterinarians. This implies a confounding of the effect of the veterinarian and farm or farmer. However, the 6 guided farmer groups each had a single veterinarian, other than their regular veterinarians, as part of the supporting team that guided that particular subgroup of herds. The influence of this veterinarian can be seen as part of the external effect of guidance.

Some of the drug data for the 94 farms were missing from 2005 to 2007 (data for 14 farms missing in 2005, 7 in 2006, and 3 in 2007), which was due to administrative problems in retrieving the invoices from some of the veterinary practices in these years. To establish whether these missing data caused bias, a 2-sample *t*-test was used to test the equality of means, and the Satterthwaite method was used to test the equality of variances. Means and variances from 2008 to 2012 for the farms with missing values in 2005 to 2007 were compared with the farms with complete data sets. The null hypothesis stated that both groups of farms belonged to the same farm population, which was performed for the 3 separate farmer groups. The ADDD means for the farms with missing values or complete data sets within the 3 farmer groups did not differ significantly for any year within the period of 2008 to 2012, and the only difference in variances was observed for the guided group in 2010 and the environmental group in 2011. Therefore, it was concluded that there was no indication of bias due to missing values.

In the first part of the statistical analysis, the variation and trend in daily dosages per cow per year were analyzed for individual herds. Farm levels of antibiotic use ($\mathrm{herd_i}$) were regressed against time (in years), providing a mean ($\mathrm{m_i}$) and a trend ($\mathrm{b_i}$ = regression coefficient). To illustrate changes in antibiotic use, the mean level of use ($\mathrm{m_i}$) for each individual farm during the first period of the study (2005 to 2010) was compared with that of the last period (2010 to 2012), whereas the regression coefficients for each farm ($\mathrm{b_i}$) from 2005 to 2010 and 2010 to 2012, respectively, were used to demonstrate the trends in use during these periods.

The distribution of ADDD was characterized by the median, standard deviation, skewness, and kurtosis statistics. To establish between-year fluctuations in ADDD, a Pearson correlation was computed between the individual ADDD of the herds in 2 consecutive years. The calculations were performed in Microsoft Excel 2010 (Microsoft Corp., Redmond, WA). Statistical significance was determined at the 1 and 5% probability levels.

In the second part of the analysis, variation and trends in daily dosages were analyzed according to farmer group and antibiotic treatment category. Analyses of variance were performed to test the effects of the farmer group, year, and interaction using the ANOVA procedure of SPSS ver. 19 (IBM Corp., Armonk, NY). Farms were clustered within groups and measured over the years of 2005 to 2012. Observations from the same farm for different years are not independent, so the repeated measurement procedure was used. Multiple comparisons between group means and year means were computed using the Bonferroni test.

Trends in the ADDD for both the farmer groups and antibiotic treatment categories were evaluated by a regression against time (years). Because of external factors influencing the level of antibiotic use, 3 time phases were selected to reflect the changing trends over time (i.e., the periods 2005 to 2007, 2007 to 2010, and 2010 to 2012). The trends in the ADDD within each time phase (t) and treatment category or farmer group (g) were characterized by a regression coefficient (bgt), which was derived as the average of the regression coefficient (b_i) of the individual farms. Within each farmer group and antibiotic treatment category, significant increases or decreases in use per time phase or combination of time phases were determined using a paired t-test. In addition, the relationship between ADDD values and yearly veterinary costs over time was examined using the Pearson correlation for the subset of herds. Significance was set at the 1 and 5% probability levels, and calculations were performed using SPSS. Farmers were questioned about their antibiotic use practices during the guided farmer group sessions.

RESULTS

The group of 94 dairy farms was spread throughout the country and linked to 32 of approximately 300 veterinary practices that treat farm livestock. In 2012, the dairy sector in the Netherlands comprised 18,682 herds with an average herd size of 79 cows. The guided, incidental, and environmental farmer groups had average herd sizes of 110 (range = 46–309), 107 (36–437), and 130 (96–189) cows, respectively. The average age of the farmer upon joining the project was 43 yr (range = 24–62).

Changes in Antibiotic Use on Individual Farms

Changes in antibiotic use between the first and last phases of the study period are illustrated in Figure 1, where the ADDD for each farm is summarized by the mean and regression coefficient against time. The lowest ADDD was 0.37 and the highest was 16.6. The distribution of ADDD was skewed toward higher values (n = 728; mean = 5.86; median = 5.55; Skewness = 0.87 and Kurtosis = 1.59, both significant at $P < 0.01$). The farms were plotted on a graph comprising 4 quadrants that indicate above or below average and increasing or decreasing trends. In the period from 2005 to 2010 (Figure 1a), the farms were mostly positioned in the above average and increasing trend quadrants, whereas during the 2010 to 2012 period (Figure 1b) half of the farms were identified as below average with decreasing trends.

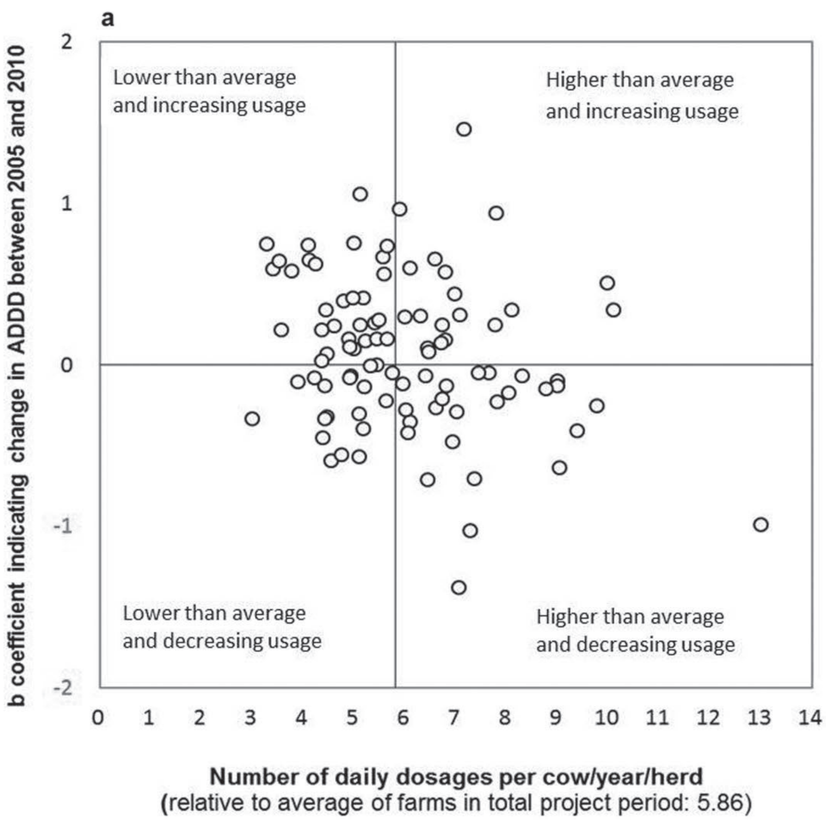
Between-year (Pearson) correlations of ADDD for all herds are listed in Table 1; all correlations were statistically significant ($P < 0.01$). The correlations between consecutive years were highest, ranging from 0.53 to 0.70, indicating that 28 to 49% of the variation in any year was explained by the situation in the previous year. One exception was 2012, when ADDD were observed to be slightly more dependent on ADDD in 2010 than in 2011. This was caused by a very different trend in use reduction among the 3 farmer groups in 2011 and 2012. The fact that more than half of the variation in daily dosages per cow per herd in a particular year cannot be explained by the previous year indicates considerable fluctuation in ADDD between consecutive years.

Variation and Trends in Farmer Groups

Variation Between Farmer Groups and Years. The ANOVA statistics for 2005 to 2012 for the total group of farmers (94) and each of the 3 farmer groups are presented in Table 2. Missing values in the initial years did not significantly affect the analysis. The overall mean and standard deviation were 5.86 and 2.14 ADDD, respectively. The main effects of group ($P = 0.001$) and year ($P = 0.04$) were both significant, but no significant interaction was found between these effects, indicating that the trend over the years was consistent across the groups. Both the guided and environmental groups had significantly lower ADDD than the incidental group. In addition, the ADDD for 2012 was significantly lower than the values from 2007 to 2010.

The standard deviation and coefficient of variation of the ADDD decreased from 2.37 and 0.41, respectively, in 2005 and 2006 to 1.64 and 0.33, respectively, in 2012, which illustrates a reduction in variation toward the end of the study. The average ADDD of the guided subgroups varied from 3.17 to 6.75 (SD = 1.16) in 2005 and 2006 and from 3.59 to 5.20 (SD = 0.72) in 2012, also indicating less variation over time.

Trends and Adaptation. The trends in the ADDD over the years for the 3 farmer groups are illustrated in Figure 2. These results are presented in 3 phases. During the first phase (2005 to 2007), farmers were still increasing antibiotic use when little societal concern for



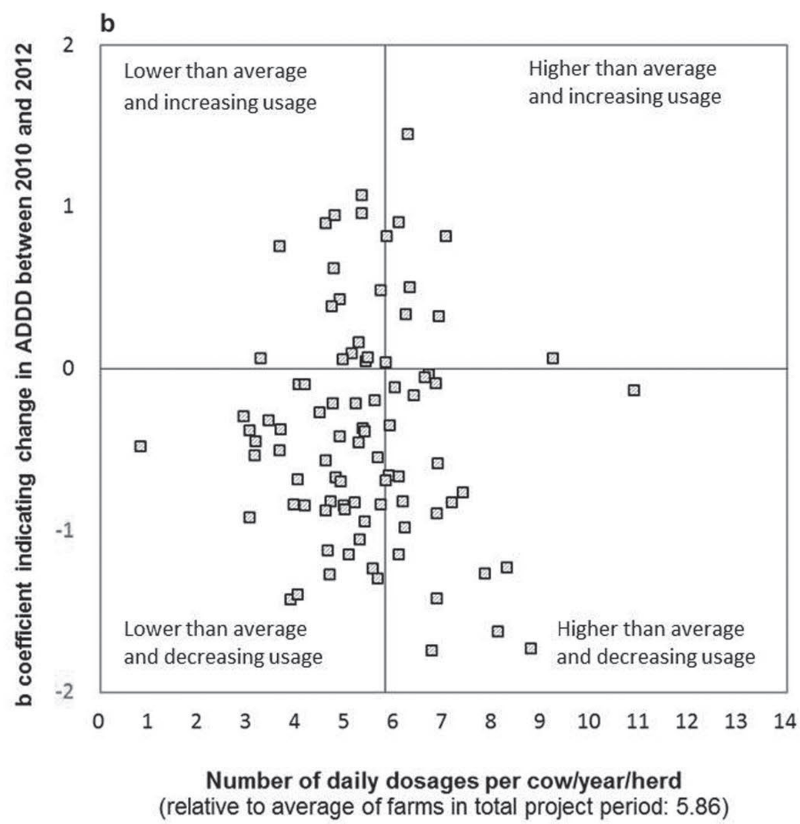


Figure 1. (a) Number and trend of animal defined daily dosages per cow (ADDD) from 2005 to 2010 for each of the 94 herds. (b) Number and trend of ADDD from 2010 to 2012 for each of the 94 herds; b-coefficient is the number of ADDD regressed against time in ±ADDD per year.

Table 1. Pearson correlation coefficients[1] between years for number of animal defined daily dosages (ADDD) per cow per herd from 2005 to 2012

Herd, n	Year	2006	2007	2008	2009	2010	2011	2012
80	2005	0.704	0.649	0.661	0.598	0.548	0.450	0.380
87	2006	1.000	0.683	0.625	0.471	0.461	0.445	0.387
91	2007		1.000	0.660	0.516	0.517	0.491	0.413
94	2008			1.000	0.651	0.549	0.506	0.402
94	2009				1.000	0.638	0.567	0.468
94	2010					1.000	0.635	0.595
94	2011						1.000	0.534
94	2012							1.000

[1]All correlations (r) deviate from zero ($P < 0.01$).

antibiotic use in animals was present. The second phase (2007 to 2010) was a period of growing public awareness and the beginning of a reduction in antibiotic use by some farmers. Indeed, the group of farmers that was coached from 2008 onwards achieved a significant reduction in antibiotic use in this phase (Figure 2). The environmental group comprised participants who were already involved in a sustainability program but did not become actively acquainted with the antibiotic issue until 2012. Nevertheless, this group showed a very significant reduction in antibiotic use in 2011 during the reduction phase (2010 to 2012). A year later, in 2012, the incidental farmers group observed a similar level of reduction in use.

Variation and Trends in Treatment Categories

Number of Daily Dosages per Treatment Category. Approximately 98% of the antibiotic applications in ADDD were covered by 54 drugs. The drugs can be designated as specific treatments. In this study, there were 6 antibiotic treatment categories—mastitis, dry-cow therapy, calves, retained placenta, reproductive tract, and other. In total, 37 drugs were assigned to the first 5 treatment categories. The remaining drugs (17), together with any incidentally used drug, were assigned to the sixth category of other drugs. The 2 main treatment categories were dry-cow therapy and mastitis, which are both related to udder health. These 2 categories accounted for 68% of all ADDD in the period from 2005 to 2012—44% for dry-cow therapy and 24% for mastitis. Most of these treatments were administered through the intramammary route (63%), with only a small proportion (5%) administered systemically for the treatment of clinical mastitis. Only a small proportion of the remaining ADDD were directly attributable to specific treatments, such as medication for young calves, retained placenta, and metritis (Table 3). Most of the remaining drugs (assigned as other treatments) were used for a category of illnesses related

Table 2. Means and SD of number of daily dosages per cow for 3 farmer groups from 2005 to 2012

	Farmers study group							
	Guided (n = 41)		Incidental (n = 40)		Environmental (n = 13)		All study groups (n = 94)	
Year	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2005[1]	5.18	2.21	5.93	2.58	5.98	1.66	5.62	2.33
2006[1]	5.65	1.96	6.48	2.84	5.27	1.88	5.97	2.40
2007[1]	6.07	2.18	6.86	2.90	6.02	2.44	6.41[v]	2.55
2008	5.78	1.68	6.63	2.14	5.88	1.81	6.16[v]	1.93
2009	5.48	1.55	6.55	2.24	6.14	0.80	6.02[v]	1.87
2010	5.40	1.46	6.59	2.33	6.22	1.85	6.02[v]	1.99
2011	5.16	1.78	6.43	2.36	4.78	0.96	5.65	2.07
2012	4.86	1.63	5.21	1.73	4.84	1.44	5.00[w]	1.64
Total	5.45[a]	1.83	6.34[b]	2.43	5.63[a]	1.69	5.86	2.14

[a,b]Means within the row "Total" with a different superscript differ ($P < 0.05$), according to the Bonferroni test.

[v,w]Means within the column "All study groups" with a different superscript differ ($P < 0.05$), according to the Bonferroni test.

[1]In 2005, the Guided, Incidental, and Environmental groups comprised 35, 35, and 10 farms, respectively; in 2006, the numbers were 39, 37, and 11 farms; in 2007, the numbers were 40, 39, and 12 farms; and from 2008 to 2012, the numbers were 41, 40, and 13 farms.

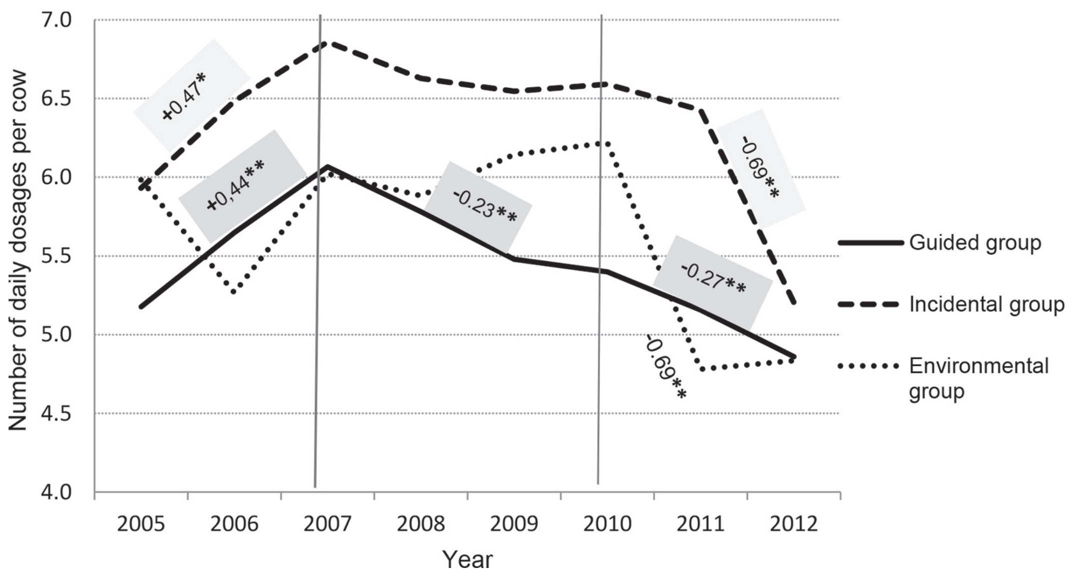


Figure 2. Trend in the number of daily dosages per cow per year for the 3 farmer groups for each of 3 time phases; significant within-group changes in each phase are indicated and expressed by the regression coefficient as ±animal defined daily dosages per cow (ADDD) per year. $^{*}P < 0.05$, $^{**}P < 0.01$, according to the paired *t*-test.

to claw ailments, respiratory tract infections, and digestive tract problems. All drugs in these last categories were administered through the systemic route.

Variation and Trends. The lowest variation was observed in the use of dry-cow therapy tubes, whereas drug usage for calves and the reproductive tract varied considerably among herds (Table 3). The ADDD for dry-cow therapy did not correlate with the ADDD for mastitis and the remaining treatment categories over the 8-yr period (94 farms; n = 728), but the ADDD for the last 2 categories did correlate with each other (r = 0.44). The number of ADDD for mastitis and the remaining categories did explain most of the variation in total ADDD (r = 0.74 and 0.75, respectively). The number of ADDD for dry-cow therapy remained rather constant throughout the study period (at approximately 2.5 ADDD) and, consequently, displayed a relatively low correlation with total ADDD (r = 0.48).

The ANOVA analyses indicated no significant farmer-group or year effect for $ADDD_{dry\text{-}cow}$ from 2005 to 2012.

Table 3. Means, SD, and CV for the number of daily dosages per cow per year for 6 treatment categories, averaged over 8 yr and 94 farms

Treatment	Mean	SD	CV
Mastitis	1.45	1.06	0.73
Dry-cow therapy	2.57	0.94	0.36
Calves	0.19	0.35	1.84
Retained placenta	0.11	0.14	1.28
Reproductive tract	0.05	0.08	1.63
Other	1.50	1.01	0.68

The ADDD for mastitis was subject to a farmer-group effect (incidental group > guided and environmental groups; $P = 0.001$ and $P = 0.01$, respectively), whereas ADDD for remaining categories displayed both a group and year effect (incidental group > guided group; $P = 0.001$, and years 2007 and 2008 > 2012; $P = 0.001$). No significant interaction was found between the main effects.

The decreasing trend in total usage began in 2007 (Figure 3). From that time onwards, regression coefficients for the annual change in ADDD for dry-cow therapy, mastitis, and the remaining categories were −0.050, −0.054, and −0.140, respectively. Thus, the reduction in use for the remaining categories was almost triple that of dry-cow therapy or mastitis. The overall trend in use was influenced mostly by the reduction in use of categories other than udder-related treatments during the second (2007 to 2010) and third (2010 to 2012) phases and a reduction in use for mastitis treatments in the third phase, specifically in 2012. These decreases in ADDD were all significant ($P < 0.01$), according to the paired *t*-test.

An overall reduction of 22% in ADDD was observed in 2012 compared with 2007, the year with highest average use in the farm sample (−17% compared with reference year 2009). Topical antibiotic applications (sprays in aerosols) were not included in the ADDD calculation. In this study, 83% of the farmers used these sprays for 1 or more years. Annually, between 0 and 24 aerosols (210 mL) were purchased per farm. Average aerosol use per herd varied from 0.57 ADDD in 2005

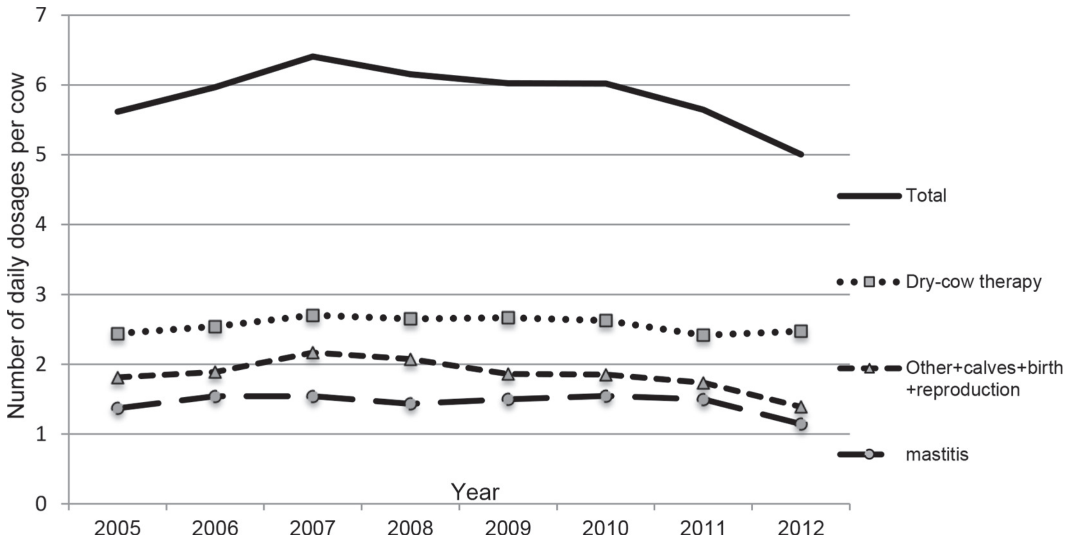


Figure 3. Trend in the number of daily dosages per cow per year for 3 treatment categories and total usage for all farms from 2005 to 2012.

and 2006 to 0.44 ADDD in 2011 and 2012, based on the assumption that each aerosol was used 10 times.

Dry-Cow Therapy Levels

Blanket dry-cow therapy, a replacement rate of 25%, a calving interval of 365 d, and all 4-teat cows result in an $ADDD_{dry\text{-}cow}$ value of 3 using equation [3]. A higher replacement rate (more heifers in the herd) and a longer calving interval would lower the $ADDD_{dry\text{-}cow}$ value. In the Netherlands, the average calving interval from 2005 to 2012 was 417 d, the replacement rate was 28% (CRV, 2013), and 2% of the cows were assumed to have only 3 teats. These average statistics result in an $ADDD_{dry\text{-}cow}$ value of 2.5, implying that, on average, 2.5 tubes per cow were used for blanket dry-cow therapy.

Additionally, for the study farms, the average $ADDD_{dry\text{-}cow}$ values (tubes) per farm were calculated for the period from 2005 to 2012. This indicated that 17% of farms used less than 2 antibiotic tubes per cow, 21% used 2.0 to 2.5, 41% used 2.5 to 3.0, 18% used 3.0 to 3.5, and 3% of farms used more than 3.5 tubes per cow. Although it was expected that 2.5 tubes per cow were used for blanket dry-cow therapy, according to the above estimate based on the national data, it appeared that one-fifth of the study herds used 3 or more tubes per cow.

Active Substances per Treatment Category

The use of active substances in the periods of 2005 to 2010 and 2011 to 2012 are presented in Table 4. These periods were selected because the regulations concerning third-choice drugs had been announced in 2011 and were introduced in 2012. In this study, active substances, such as amoxicillin-clavulanic acid and first- and second-generation cephalosporins-aminoglycoside combinations, were used mostly for mastitis treatments; narrow-spectrum penicillins and procaine penicillin-aminoglycoside combinations were used for dry-cow therapy; and penicillin-aminoglycoside combinations and tetracyclines were used for the remaining treatment categories (Table 4). The use of third-choice drugs (i.e., third- and fourth-generation cephalosporins and fluoroquinolones) was, on average, 18% of total usage during the 2005 to 2010 period. This number was reduced to 14.5% in 2011 and became minimal in 2012. The third-choice drugs were mainly used for mastitis and the remaining treatment categories such as claw diseases (Table 4).

Veterinary Cost and Teat Sealers

Veterinary costs per cow per year, including drug costs plus the fees for farm visits and guidance as assessed in a subset of farms, increased until 2009 and then declined (Table 5). In both the first phase of the study period (2005 to 2007) and the combined second and third phases (2008 to 2012), veterinary costs correlated (highly) with, respectively, the increasing and decreasing trends in antibiotic use ($r = 0.96$ for both periods; $P = 0.16$ for first phase; $P = 0.01$ for second and third phases).

The percentage of farms using teat sealers increased from 8% in 2005 to 53% in 2012, and the average number of teat sealers per cow increased from 0.42 to 1.88

Table 4. Average use per treatment category of active substances (1st, 2nd, and 3rd choice) in all studied dairy herds (94) for 3 periods (% of total use in daily dosages)

Active substances, therapeutic groups	Class of choice	Mastitis 2005–2010	Mastitis 2011	Mastitis 2012	Dry-cow therapy 2005–2010	Dry-cow therapy 2011	Dry-cow therapy 2012	Calves + Birth + Reproduction + Other 2005–2010	Calves + Birth + Reproduction + Other 2011	Calves + Birth + Reproduction + Other 2012
Aminoglycosides	2nd	0.70	0.58	0.63						
Amoxicillin-clavulanic acid	2nd	6.60	6.15	7.56						
Cephalosporins 1–2 generation	2nd	0.16	0.03					0.89[1]	0.80[1]	0.75[1]
Cephalosporins 3–4 generation	3rd	9.36	7.96	0.46	0.21	1.17		7.81	4.34	0.07
Cephalosporins 1–2 generation: aminoglycoside	2nd	1.25	5.85	8.52						
Fluoroquinolones	3rd							0.91	0.96	0.45
Lincosamides	1st	0.33	0.22	0.43				0.01		
Macrolides	1st[2]							2.33[3]	1.89[3]	1.85[3]
Penicillins, broad-spectrum	2nd	3.77	4.03	4.40				0.89	1.24	0.87
Penicillins, narrow-spectrum	1st				23.44	17.95	21.67	1.03	1.61	3.28
Penicillin-aminoglycoside	2nd	0.32	1.07	0.58	5.33	5.37	4.82	5.29	5.38	4.56
Procaine(benzyl) penicillin-aminoglycoside	2nd	2.17	0.62		14.17	18.30	22.91			
Tetracyclines	1st							6.70[4]	7.65[4]	7.47[4]
Trimethoprim-sulfadoxine	1st							2.20	2.12	3.55
Other								4.12[5]	4.71[5]	4.88[5]
Total (%)		24.7	26.5	22.9	43.1	42.8	49.4	32.2	30.7	27.7

[1]For reproduction.

[2]Tulathromycin is the 2nd choice drug; gamithromycin and tildipirosin are also the 2nd choice for nonlactating cattle only.

[3]On average, 0.71% used on calves and 1.51% other usage.

[4]On average, 0.93% used on calves, 1.85% after birth pill, and 4.14% other usage.

[5]On average, 1.49% used on calves and 2.80% other usage.

in the same period within these herds (Table 5). The use of dry-off tubes did not decrease as teat sealer use increased. Consequently, the combination of dry-off tubes alongside teat sealers has become a more common dry-cow therapy practice.

DISCUSSION

Our study describes variations and trends in antibiotic use in commercial dairy herds during an 8-yr period, which makes this study rather unique because few such studies have been performed and almost no comparable data sets are available for analysis. Even so, the limitations of this data set did not enable us to explore the factors behind the variation and trends reported in detail. For instance, the lack of sufficient data impaired our ability to analyze the effect of herd health status on antibiotic use and, likewise, the influence of the veterinary practice (a large number of the farms were linked to different practices). Additionally, the reactions of both farmers and veterinarians to the ongoing public debate on antibiotic use were not experimentally measured. Accordingly, some of our observations are based on field work with the guided and environmental groups rather than on data analysis.

In this section, particular attention is given to the collection and representativeness of the data to place the observed variation and trends of antibiotic use in a wider context. Finally, the role of increasing awareness in dealing with the antibiotic issue is discussed.

Collection and Reliability of Data

In 2005, at the beginning of our work on veterinary drug usage, we learned that drug data that were presented as standalone figures were not really of interest to farmers (Kuipers and Verhees, 2011). The data became more interesting to the farmers after partitioning total use into treatment categories (e.g., how much of a particular drug is used to counteract various problems and diseases). Farmers were also interested in data per individual cow, as found with milk recording data, and how their drug usage compared with that of their fellow farmers. Cow health and drug data are stored on-farm in the farm management computer system. Data input is usually performed by the farmer, the farmer's family, or farm staff. The potential for use of these data for the present study was examined at an early stage. Data from the farm computers of the guided farmer group for the years 2005 to 2007 were downloaded onto the research database. It soon became apparent that the sales data obtained from the veterinary practices displayed similar or higher drug usage than the data obtained from the farm management computers; this was also observed by González et al. (2010). The invoices contain complete and reliable data, whereas databases relying solely on the farmer were occasionally incomplete. In addition, uniformity in record keeping is of the utmost importance in enabling comparisons between farms in the study groups. Various computer systems have different options available for data input, whereas, within a computer system, flexibility of input is possible, which complicates comparisons between farms. For these reasons, we decided not to use the farm-recorded data for our study and chose the data provided through veterinary sales invoices. However, the data from invoices are at the herd level, which may be considered a disadvantage. Nevertheless, working on an aggregated herd basis simplified the administration, calculations, and information material considerably. Drug information on a herd basis is comparable, for instance, to cell count data at the herd level, which both provide a global impression of antibiotic usage and the udder health status of the herd, respectively.

Indicator Daily Dosages

Available indicators for measuring antibiotic use include total active substances and number of daily dosages. Quantities of active substances sold are reported by the drug retail companies but are not defined per animal species. These company reports provide a global indication of total antibiotic use at the national or regional level for policy purposes. On a herd basis, the amount (kg) of active substances has been used as indicator (Carson et al., 2008; Katholm, 2014). Carson et al. (2008) compared the indicators active substances and daily dosages in a study comprising 24 beef farms

Table 5. Veterinary costs and teat sealer use from 2005 to 2012, average of herds

Item	2005	2006	2007	2008	2009	2010	2011	2012
Veterinary costs/per cow year[1] (€)	70	74	76	83	84	84	81	77
Teat sealers in tubes per cow								
Average of all herds	0.03	0.05	0.20	0.49	0.59	0.64	0.89	1.00
Average of herds using teat sealers	0.42	0.64	0.74	1.46	1.42	1.50	1.81	1.88

[1]Calculated on the basis of 45 farms.

in Canada. They concluded that "the relative ranking of use of antimicrobials varied with the chosen metric, and that further investigation into the best measure in relation to antibiotic resistance is warranted." Bondt et al. (2013) stated that "the ideal method for gaining insight into the true exposure to antimicrobial agents is to calculate the number of animal defined daily dosages (ADDD) used per animal per year," as is done in human pharmaco-epidemiology with the number of defined daily dosages per 1,000 inhabitant-days (WHO, 2014). Animal-defined daily dosage is expressed as the average maintenance dose of a specified drug per kilogram of live weight of a specified animal per day, which is used for its main indication (Jensen et al., 2004). On this basis, ADDD has been used as an indicator for antibiotic use in our study. However, it should be noted that ADDD only provides an estimate of the number of days of treatment on an annual basis (Y) by the average cow in the herd because the daily dose actually used may differ in practice from the defined daily dose (Chauvin et al., 2002; Carson et al., 2008; Merle et al., 2014). Occasionally, a farmer or veterinarian may make his or her own interpretation of the best treatment to be applied (Trauffler et al., 2014).

The ADDD was calculated for a 600-kg cow, but the animal-defined dose is given on a per-kilogram basis, which facilitates precise administration to animals of different weights. This technique is especially important in the pig and poultry sectors, where different live weight groups exist and calves require specific dose levels. Because the drugs used for young stock were not separated from those for cows, we included the drugs administered to young stock in the ADDD calculations for cows. Starting in 2012, all farmers in the Netherlands are required to submit their drug usage data to a central database for benchmarking purposes. This data collection (through veterinary practices) is organized by the sector, supported by public regulation. The newly founded Netherlands Veterinary Medicines Authority supervises the monitoring activities and sets benchmarks for national policy goals. Since 2013, the official calculations for dairy farms include the weight of young stock to that of cows (Netherlands Veterinary Medicines Authority, 2013). Consequently, data on the number of young stock per herd are collected and veterinarians are directed to record which drugs are sold for young calves, which enables a separate calculation of ADDD for calves.

Sprays for claw and skin problems (i.e., topical applications) are not included in the ADDD calculations, which is similar to the practice in other European countries. Sprays were also not included in the study of Saini et al. (2012).

Representativeness

Potential biases may have caused the sample of study farms to deviate from the national population of farms with respect to antibiotic use. The fact that the farmers volunteered to participate in this project may suggest that drug use on these farms was somewhat lower than the national average. However, these farms were larger (111 cows) than the national average in 2012 (79 cows per farm) and some reports (e.g., Hill et al., 2009) have indicated higher antibiotic use on larger farms. A separate analysis carried out on data from the present study, supplemented with questionnaire data relating to farm factors and farmer characteristics, did not detect a relationship between farm size and antibiotic use (Kuipers et al., 2013). Saini et al. (2012) also did not find such a relationship. Another factor that may have affected the level of antibiotic use is that organic farms were not included in the study sample. The number of organic dairy farms in the Netherlands is low (approximately 320; 1.7% of all dairy farms). Smolders (2010) reported that on 67 of these farms, the average antibiotic use was 1.9 ADDD from 2006 to 2010. Based on this, the exclusion of organic farms may have had a small upward effect on the level of ADDD in the present study.

To gain more insight into the representativeness of the farm sample, the ADDD for the total group of farms were compared with the ADDD from the national Farm Accountancy Data Network (**FADN**) farms, which are selected to provide a representative sample of the national farm population. These farms are used by each European Union member state to report annually on economic and structural developments in agriculture. A proportion of the national FADN farms are replenished each year. The 31 FADN farms available throughout the period from 2005 to 2009 and the whole group of FADN farms (36 in 2005 increasing to 68 in 2012) had a level of antibiotic usage comparable to the study farms (Figure 4). However, the estimate of 4.2 ADDD for the FADN farms for 2012 is low compared with the previous year and the outcome for the total group of study farms (almost significant at the 5% level). Overall, the sample of farms appeared to provide a reasonable reflection of the antibiotic usage situation on dairy farms in the Netherlands.

Mean and Variation in Use

The mean and standard deviation of the ADDD over the 8 yr of the study were 5.86 and 2.14, respectively. Pol and Ruegg (2007) and Saini et al. (2012) reported ADDD mean values of 5.43 in Wisconsin herds and

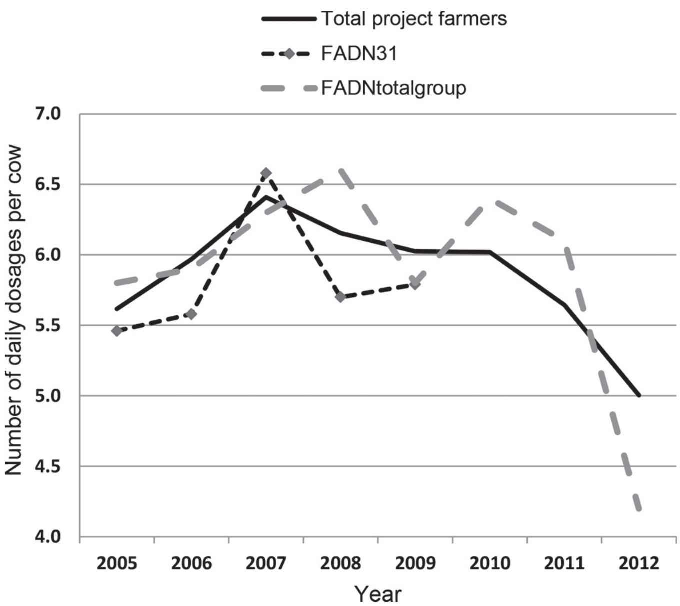


Figure 4. Comparison of trends in antibiotic use on the project farms, the total group of Farm Accountancy Data Network (FADN) farms (36 increasing to 68) in European Union member states from 2005 to 2012, and a group of FADN farms (the same 31 farms) from 2005 to 2009.

5.24 in Canadian herds, respectively. The latter value was calculated by us converting 1,000 cow-day use to annual use. The comparisons are disputable because of different ways of collecting data, time periods, and potential differences in average live weight of cows between countries (or regions). Hill et al. (2009) and Pol and Ruegg (2007) based their data on a single survey covering periods of 12 mo and 5 yr (for intramammary dry-cow products) plus 2 yr (for the other drugs), respectively. Saini et al. (2012) based their data on the collection of used drug injectors and containers by farm workers during a period of 23 mo. They also assumed, as in the present study, an average cow live weight of 600 kg, whereas Pol and Ruegg (2007) worked with an average cow live weight of 680 kg. Moreover, the assignment of several daily defined dosages to drugs sometimes differs, especially for dry-cow therapy. For instance, in Canada (Saini et al., 2012) and Denmark (Katholm, 2014) one daily dose is assigned to blanket dry-cow therapy, whereas in the Netherlands 4 daily doses are assigned. When data from the Netherlands were recalculated on the basis of a single daily dose for blanket dry cow therapy, the mean use was 3.94 ADDD instead of 5.86.

Sales dates on veterinary invoices often do not coincide with the on-farm application dates of the drugs. This is because farmers in the Netherlands are allowed to execute routine treatments themselves, and they may bulk purchase the drug in advance. For instance, teat injectors for dry-cow therapy are inserted by the herdsman. These injectors are often purchased a few times per year in large quantities. As a consequence, on-farm ADDD may fluctuate considerably between years (even more so if expressed quarterly as was initially the case). Other possible causes of fluctuations include the health status of the herd and external factors that influence the farmer and veterinarian. Our data did not permit differentiation between these causes of variation. Nationally, ADDD is calculated on a yearly basis and the Netherlands Veterinary Medicines Authority presents a rolling average. Although ADDD provides the best estimate for the most recent year, a 2-yr average or rolling average provides a more stable indicator for average herd antibiotic use, minimizing the effect of the purchasing behavior of the farmer on the level of use.

During the early years of our study, a large variation in ADDD was evident because farmers were unaware of the antibiotics situation on their farms (Kuipers et al., 2013). This was also experienced by Cabaret (2003). Variation in use decreased considerably during the later phases of the study period, which coincided with a growing political and public awareness, and the resulting sectoral activities related to antibiotic usage influenced the antibiotics usage behavior of both farmers and veterinarians.

Antibiotic Treatment Categories

During 2005 to 2012, 68% of antibiotic use was used for udder health purposes, addressing the prevention of infections during the dry period, treatment of subclinical mastitis at drying-off periods, and treatment of clinical mastitis (Table 3). This percentage was even higher in the study of Pol and Ruegg (2007), whereas Katholm (2014) also reported a value of 68% based on active substances. Taken together, these findings indicate that antibiotic use in dairy herds is largely an udder-related management practice. In our study, 63% of the total number of daily dosages was used via the intramammary route, whereas 37%, including oral powders for calves and intrauterine treatment, was used systemically. Pol and Ruegg (2007) reported similar percentages for intramammary and systemic use, but Saini et al. (2012) found higher systemic than intramammary use. The Netherlands Veterinary Medicines Authority (2013) reported that the systemic route of administration accounted for 33% of the average antibiotic usage on all farms in 2012, similar to the level found in the current study (32% in 2012).

The lowest CV was found for $ADDD_{dry\text{-}cow}$. About one-fifth of farms used less than 2 tubes per average cow in the herd and a similar proportion used more than 3 tubes per cow. This last observation merits further examination because more than 1 tube per teat as dry-cow therapy would be considered excessive. During the guided farmer group sessions, it appeared that most farmers were reluctant to discuss the adaptation of blanket dry-cow therapy (Kuipers et al., 2013). Systematic application of dry-cow therapy has been advocated by the veterinary profession in the Netherlands as a standard practice for the last 20 yr, as is the case in most dairy farming countries. An exception is Denmark, where only 40% of cows received dry-cow therapy in 2009 when the average cell count was 235,300 cells/mL. Since 2010, Danish veterinarians have been required to examine a milk sample before prescribing drugs other than simple penicillin for mastitis treatment. This constrains the use of drugs during lactation and encourages a shift toward curative dry-cow therapy. In 2013, when the national cell count was 212,100 cells/mL, 43% of cows received dry-cow therapy. The use of antibiotics tubes during lactation decreased by 48.5% from 2009 to 2013, whereas the use of tubes for dry-cow therapy increased by 13.4% in the same period (Katholm, 2014). McDougall (2012) reported that, in New Zealand, selective dry-cow therapy was used in about one-third of herds in 2011, whereas approximately 10% of cows and heifers were treated with a teat sealer. Selective dry-cow treatment was introduced in the Netherlands in 2014 as a recommended practice based on the individual cell count of cows before drying off (different levels apply for first lactation and older cows).

Active Substances

The use of third-choice drugs (i.e., third- and fourth-generation cephalosporins and fluoroquinolones) decreased from 18% of total usage from 2005 to 2010 to 1% in 2012. In Australia, third-choice drugs were banned in the 1990s, whereas in New Zealand the usage is under restriction (McDougall, 2012). In Denmark, the restriction on third-choice lactation drugs, in force since 2010, has led to a decrease in the use of third- and fourth-generation cephalosporins, and almost no fluoroquinolones have been used since 2000 (Katholm, 2014).

The reduction in third-choice drugs in the present study was partly replaced by an increase in first- and second-choice drugs. For mastitis, a relative increase in cephalosporin combinations was observed; for drying-off, an increase in procaine penicillin combinations was noted; and for other ailments, an increase in narrow-spectrum penicillins and trimethoprim-sulfadoxine was recorded. Therefore, although a reduction in use of third-choice drugs occurred, there was also an increased use of penicillins and certain broad-spectrum drugs. Pol and Ruegg (2007) also reported the use of penicillins mostly for dry-cow therapy, whereas Saini et al. (2012) found that the most commonly used active substances in Canada, according to the level of use, were cephalosporins, penicillins, penicillin combinations, tetracyclines, trimethoprim-sulfonamide combinations, and lincosamides. However, the cephalosporins consisted mostly of third-generation drugs (especially ceftiofur).

Trends and Awareness

Trends in antibiotic use were presented in 3 phases. During the first phase (2005–2007), farmers were still increasing their antibiotic use. The second phase (2007–2010) saw the first signs of a reduction in antibiotic use by some farmers, and during the third phase (2010–2012) reductions became more apparent. Communication with the guided group of farmers during the second phase, when external pressure on antibiotic use was still relatively low, was 2-fold: written information was sent to participating producers and regular study group meetings were held locally that involved producers, local contact veterinarians, and the project team. These actions were associated with a downward trend in antibiotic use. Raymond et al. (2006) observed a decreasing effect on medicated milk replacer use through information transfer by mail with farmers, whereas Jansen et al. (2010) described communication strategies with farmers who were involved in an udder health improvement program and were hard to reach.

The environmental group of farmers were considered innovators with respect to the environment, but had not yet become engaged in the antibiotic issue. Nevertheless, they seemed to react spontaneously to the public debate by reducing antibiotic use in 2011. In this context, the ongoing public discussion on third-choice drugs may also have affected their adaptation process. The incidental farmer group delayed change until 2012, when they responded, presumably, to societal and professional pressure and the introduction of regulations in 2012 demanding minimal use of third-choice drugs. Lower drug costs per cow will be welcomed by farmers, but a restricted choice in drugs will be seen as a negative development.

It appears that adaptation was easier for mastitis and the other category drugs than for dry-cow therapy injectors. The stable application of dry-cow therapy over time was combined with an increase in the use of teat sealers. The recently introduced guidelines on selective dry-cow treatment create a complex tradeoff between enabling farmers to reduce their antibiotic usage and limiting their ability to address cow health and welfare. Establishment of a final balance in antibiotic applications will take time. However, considerable variation exists in farm practices within and between dairy-producing countries that can provide helpful information. Moreover, future target levels for antibiotic use may be sharpened by governments depending on developments in antibiotic-resistant bacteria and societal pressure.

The combination of awareness-raising and restrictive measures appears to be effective in reducing antibiotic use (−17% in 2012 compared with 2009), although the contribution of the dairy sector to the national reduction goal (−50% by 2013) was modest. In comparison, large reductions in antibiotic sales of more than 50% have been achieved in the pig and poultry sectors within the same period (Mevius and Heederik, 2014).

The involvement of veterinary professionals is essential to achieve a change in the farmer's usage behavior. In the Netherlands, the main communication tools between the veterinarian and farmer are the annual animal health and treatment plans. The animal health plan consists of a series of management and housing practices that may influence dairy cow health and, subsequently, drug usage. This plan provides a check list, whereas the treatment plan lists the most suitable drug per treatment category. These plans require regular consultation between veterinarians and farmers to manage specific animal health problems. Drug use awareness is facilitated by the appropriate presentation of data to farmers and veterinarians. Since 2012, farmers have been informed of their ADDD on a quarterly basis by online website application (http://www.medirund.nl/). The ADDD have accumulated over time as a rolling annual average. An overall warning (benchmark) value is assigned annually by the Medicines Authority. When this value is exceeded, the farmer is contacted by the dairy company and is asked to take appropriate action. Dairy companies are gradually integrating antibiotic use indicators into their quality-assurance schemes (Kuipers and Verhees, 2011).

Further improvement in responsible drug use can be achieved by applying good cow management practices and improving herd conditions. This remains an important area for research and practical application.

CONCLUSIONS

The indicator ADDD was used to evaluate variation and trends in antibiotic use for 3 farmer groups and 6 treatment categories. Large variation in antibiotic use was found between herds, whereas variation in use among herds decreased during the study period. Increasing drug use awareness was an important external factor in reducing antibiotic use and the variation in use. Changes in management practices have the potential to enhance this effect. Maintenance and restoration of udder health is the main reason for antibiotic use, as 68% of all ADDD were used for the udder. A reduction in use was achieved mainly due to a reduction in numbers of daily dosages used as other treatments. Toward the end of the study, a reduction in use for the treatment of mastitis was also noted, but farmers remained reluctant to reduce dry-cow therapy. The decrease in ADDD over time varied between the groups of farmers involved in the study. The guided group began to display a reduction in use at an earlier stage of the study than the other 2 groups. Restrictions on the use of third-choice drugs were successful in minimizing their use. Correspondingly, a shift toward more use of penicillin and certain broad-spectrum drugs was observed. Veterinary costs per cow followed the trend in antibiotic use and, therefore, decreased in recent years coinciding with the downward trend in antibiotic use.

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