

Economic perspectives on blanket and selective dry cow therapy

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Dry cow therapy (DCT) is an efficient measure to control intramammary infections (IMI) in dairy herds. In a blanket-DCT practice (BDCT), all cows receive antibiotics at dry-off. In a selective-DCT practice (SDCT), treatments are targeted only at infected cows. Our objective was to compare the economy of SDCT and BDCT under Finnish production conditions. Economic analysis is needed to show numerically whether the farms currently applying BDCT can switch to SDCT without the dairy farmer's economic losses. We applied a partial budgeting approach and built a stochastic calculation model to show the margin for costs that are equal in both DCT policies. Data for modeling were generated by running 100,000 Monte Carlo simulations. The parameters for the model were extracted from the literature and from official statistics. SDCT is a competitive management practice, especially with herds succeeding in keeping their IMI risk low. Therefore, the focus in farm-level decision-making should be on the herd's udder health status. In those herds with high IMI prevalence, the problem must be tackled primarily by means other than BDCT, which does not support the goal of reducing the use of antibiotics and which, when used routinely, is also contrary to existing EU legislation.

Key words: intramammary infection, dry cow therapy, partial budgeting, simulation

Introduction

Dry cow therapy (DCT) is an efficient and widely used measure to eliminate and prevent intramammary infections (IMI) in dairy herds (Halasa et al. 2009a,b). Antibiotic DCT can be implemented 1) as a blanket-DCT practice (BDCT) in which all quarters of all cows are treated with a long-acting antimicrobial at dry-off, or 2) as a selective-DCT practice (SDCT) in which antimicrobial treatments are targeted only at infected or presumably infected cows. Moreover, non-antibiotic internal teat sealants (ITS) can be used to protect untreated cows or quarters during SDCT practice (Kabera et al. 2021a). Non-antibiotic ITS and antibiotic DCT may also be used concurrently (Rabiee and Lean 2013, Winder et al. 2019a).

Both the growing concern about increasing antibiotic resistance and pressure to reduce antibiotic use have led to regulatory action. Current European Union (EU) legislation, Regulation (EU) 2019/6, represents a substantial change in the authorization, monitoring, and control of veterinary medicinal products (EU 2018). Legislation came into effect on 28 January 2019 and became applicable in all EU Member States from 28 January 2022. According to its Article 107, antimicrobial medicinal products shall not be applied routinely nor used to compensate for poor hygiene or poor farm management, inadequate animal husbandry, or lack of care. Moreover, antimicrobial medicinal products shall not be used for prophylaxis other than in exceptional cases, for administration to an individual animal or to a restricted number of animals when the risk of an infection or of an infectious disease is very high, and the consequences are likely to be severe (EU 2018). Thus, the legislation makes regular, preventive use of antibiotics illegal.

According to European Medicines Agency reports, sales of the various veterinary antimicrobial classes, expressed as mg sold per population correction unit (PCU), are, among all European countries, lowest in the Nordic countries (EMA 2021). Regarding DCT, the national mastitis control programs in Finland and other Nordic countries have always recommended SDCT (NMSM 2009, Rajala-Schultz et al. 2021). According to an online survey in the beginning of 2017, 13% of all Finnish dairy farmers applied BDCT. The BDCT practice was more common on large automatic milking system (AMS) farms than on small farms with a conventional milking system (Vilar et al. 2018). In Germany, in the UK, and in the US, among others, the share was at that time about 80% (Bertulat et al. 2015, USDA 2016, Fujiwara et al. 2018).

On Finnish farms, the selection of cows that need DCT is performed by evaluating both subclinical and clinical udder health history (Vilar et al. 2018). The recommended two main indications for DCT are high SCC, especially near dry-off and typically in more than one measurement, and clinical mastitis during the preceding lactation.

The microbiological analyses of presumably infected quarters commonly supplement other udder-health information and support treatment decisions (Vilar et al. 2018, Rajala-Schultz et al. 2021). On Finnish SDCT farms, selection criteria seem to be quite optimal, because the proportion of DCT-treated cows was equivalent to the proportion of cows with SCC $\geq 200,000$ cells ml⁻¹ near dry-off and the post-calving proportions of mastitis treatments between selectively DCT-treated and -untreated cows were similar (Niemi et al. 2021, 2022).

If the herd-level mastitis incidence is low or if herd-information lacks comprehensive milk sample analysis to obtain adequate information on causal pathogens, routine DCT administration to all cows is interpreted as preventive. Current legislation only allows metaphylaxis, and therefore, on those farms that have no severe udder health problems or are not fighting against an ongoing contagious mastitis outbreak, the appropriate management adjustment is to adopt the SDCT approach. Thus, current practice in most Finnish herds is already in line with the EU legislation, and there is no need to change the practice due to the stricter regulation.

Dairy farmers have an interest in striving for responsible milk production, including prudent use of antibiotics, to maintain long-term production possibilities (Young et al. 2010, Jones et al. 2015, Fischer et al. 2019). However, dairy farmers are entrepreneurs who also strive to achieve good financial results through their business, and thus, economic considerations play a great role in their decision-making (Lahnamäki-Kivelä and Kuhmonen 2022). Regarding DCT, the question is whether a contradiction exists between reducing antibiotic use and achieving a good economic result. Research on the subject from both an animal health perspective (Cameron et al. 2015, Winder et al. 2019b, Rowe et al. 2020a, b) and from an economic perspective (Scherpenzeel et al. 2018, Hommels et al. 2021, Rowe et al. 2021) is available, but more research is necessary to cover a wider range of operating environments with varying regulations, treatment practices, and price ratios. If there is no contradiction between the One Health -approach and the farmer's goals, the result will hopefully encourage milk producers to switch from BDCT to SDCT even in countries where it is not yet a legal obligation. If, however, a discrepancy exists between these two, corrective measures are essential in the milk production chain to ensure compliance with the regulations and to reduce antibiotic use without putting the costs onto milk producers alone.

Our objective was to compare the economy of SDCT and BDCT under Finnish production conditions. Economic analysis is necessary to show numerically whether the farms currently applying BDCT can switch to SDCT without dairy farmers' economic losses. However, the switch from BDCT to SDCT is required to reduce antimicrobial usage in dairy farming and to guarantee compliance with newly enacted EU legislation. If financial incentives for the switch are not created in the prevailing market, measures are needed to promote the prudent use of antibiotics. Thus, the results will benefit dairy farmers, other actors in the dairy chain, and administrative decision-makers.

Material and methods

Partial budgeting is a planning and decision-making framework used to analyze the costs and benefits of alternative management decisions faced by farm businesses (see Kay et al. 2020). Partial budgeting focuses only on the changes in costs and revenues, which simplifies the comparison of differing options. DCT practice affects some revenue and cost items, while some items, like capital and electricity costs, are independent of DCT. Thus, partial budgeting is an appropriate approach to economic comparison of diverse DCT practices. We built a stochastic calculation model in the framework of partial budgeting to show a margin for costs that are equal in both DCT policies, i.e., a margin for fixed costs relative to the DCT practice. The higher the margin, the better financial opportunities for a dairy farmer to cover the costs that are fixed with respect to the DCT policy.

The results were calculated on an annual basis assuming that one dry-off procedure occurs for each cow during the course of one year. In the BDCT practice, all cows received antibiotic DCT for all quarters at dry-off. In the SDCT practice, antibiotic treatments were selectively allocated at cow level so that if the prior number of lactational IMI cases or the composite somatic cell count (SCC) exceeded the treatment threshold set by the dairy farmer or the veterinarian, then all quarters received antibiotic treatment.

In the calculation model, the return consisted of milk return minus milk return losses during antimicrobial treatment and during a subsequent withdrawal period. Variable costs were associated with feed, labor, veterinary services, medicines, and microbiological analysis of milk samples. Fixed values were used for variables expected to have minimal variation over time or within the Finnish dairy sector. Stochastic variables were those whose value the milk producer cannot predict with certainty when making a decision on DCT (e.g. milk price) and variables that may vary within or between herds (e.g. veterinary costs).

We constructed the data for the economic analysis using Monte Carlo simulation in IBM SPSS Statistics 27.0 software (IBM Corp, Armonk, NY). What we simulated were the single parameters that we used in the calculation (unless the parameters were constant). The parameters were simulated to be equal for both DCT strategies, or they were DCT-specific. Milk yield was simulated to vary by herd size (60 vs. 120 dairy cows) and milking system (AMS vs. milking parlor) as well. All the simulations were run using 100,000 iterations that produced a dataset with 100,000 rows, each row depicting an individual cow in a virtual herd. Cows that received treatment at dry-off or that acquired IMI after calving were randomly selected among these 100,000 cows based on probability values. The result, the margin for fixed costs per cow per year, was then calculated for each cow by deducting variable costs from revenues. The calculation was carried out so that all the cows were assumed to be managed either according to the BDCT or SDCT policy and the parameters were selected accordingly. Moreover, the parameters were selected to represent a herd with 60 or 120 dairy cows and with AMS or a milking parlor. Hence, the results indicate the margin for the fixed costs per cow separately for farms implementing SDCT and for farms implementing BDCT and having variable farm size and milking system.

Herd-level milk production estimates in the economic analysis were based on Niemi et al. (2020). Model estimates from the multiple linear regression for annual herd-average milk production per cow served in our estimation of the average yield in herds implementing SDCT or BDCT. The model parameters were DCT approach, herd-average SCC, herd size, and milking system (Niemi et al. 2020). The median SCC for the estimations was 163,000 cells ml⁻¹ in the SDCT herds and 157,000 cells ml⁻¹ in the BDCT herds. Herd size was set at 120 dairy cows for AMS and at 60 dairy cows for milking parlor.

At the end of 2020, Finnish farms with AMS had an average of 1.6 milking stalls (Manninen 2021). Thus, a dairy farm with AMS was assumed to have two milking stalls and a herd size roughly equivalent to their capacity. Dairy farms with 60 dairy cows and a milking parlor represent farms that were large enough to switch from pipeline milking to a milking parlor, but slightly too small to invest in AMS. Standardization of herd size and milking system in the comparison highlighted the effect of DCT on milk yields. The effect of DCT became visible in the prevalence of IMI in the subsequent lactation and, further, in the long-term milk yield losses due to IMI. In the data simulation, a normal distribution was created with the mean (i.e. estimated DCT-specific yields) and standard deviations derived from Niemi et al. (2020). The distribution was truncated to the range corresponding to the range in Niemi et al. (2020) (Table 1). The quantity of discarded milk was derived from the daily milk yields and from the simulated withdrawal periods. The daily yield was the annual yield divided by 305 days.

Each cow's feed consumption was linked to her milk yield. Initially, a typical Finnish dairy cow ration was optimized with the Lypsikki model (Nousiainen et al. 2011) for this study's yield levels. This optimization produced the ratios of feeds (grass silage, grain, protein feed, minerals) on a cost-minimization based on given prices, live weights, and energy-corrected milk (ECM). Results indicated that the total feed consumption was roughly the same, 0.6 kg dry matter per kg ECM, on the milk-yield levels studied and a live weight default of 650 kg. At the average protein and fat content of milk in Finnish dairy herds (ICAR 2021), this means 0.64 kg of dry matter per kg milk (Table 1).

Labor input was included in the calculation for the work required for dry-off procedures and treatment of IMI during lactation. In both BDCT and SDCT herds, the work encompassed administering antibiotic therapy and running an antibiotic residue test of milk after calving. Residue testing is not mandatory but is recommended. Virtually all farms follow the recommendation, as the dairy processors test all the milk collected and finding residues at that stage would cause the farm significant financial losses. Examination of SCC measurements and clinical mastitis history in order to select cows to be treated results in more workload in SDCT herds than in BDCT herds. The labor input required for treating IMI during lactation includes taking milk samples, contacting the veterinarian and assisting the vet with medication of the cow, ensuring proper withdrawal of the antibiotic milk during and after the treatment, and, after the treatment, running an antibiotic residue test. The estimated times that performance of these tasks requires are presented in Table 1. Estimates are based on the working-time measurements by Peltonen and Karttunen (2002) and dairy producers' current estimates of the time required for the various dry-off procedures and treatment of IMI during lactation in barns with AMS.

Annual price variation during the years 2000 to 2020 determined the distribution of milk price and feed price (Statistics Finland 2021). Testing the normality of the distributions with the Kolmogorov-Smirnov test in SPSS indicated that normal distribution could be accepted for the feed, but the milk price was closer to a beta distribution. Parameters of the distributions we derived from the annual price series 2000–2020 at the 2020 price level (Table 1). The mean feed price, 0.15 euro per kg dry matter, reflects the average price of the feed combination used in the model (Table 1).

Table 1. Parameters for a stochastic calculation model for farms implementing selective versus blanket dry cow therapy

Variable	Distribution	Fixed value / Parameters ¹⁾ and range of distribution	
		Selective dry cow therapy	Blanket dry cow therapy
Output			
Milk, kg year ⁻¹ 120 dairy cows, AMS ²⁾	Normal	10,243; 1,109 (7,070–13,200)	10,472; 881 (7,730–11,500)
Milk, kg year ⁻¹ 60 dairy cows, parlor	Normal	9,475; 1,026 (6,540–12,200)	9,704; 816 (7,170–10,660)
Input			
Feed, kg dry matter kg ⁻¹ milk	Fixed	0.64	0.64
Labor, min cow ⁻¹			
Dry cow therapy	Fixed	13	10
IMI during lactation ³⁾	Fixed ³⁾	23; 28	23; 28
Prices			
Milk, € l ⁻¹	Beta	1.35; 4.65 (0.33–0.45)	1.35; 4.65 (0.33–0.45)
Feed, € kg ⁻¹ dry matter	Normal	0.15; 0.03 (0.1–0.2)	0.15; 0.03 (0.1–0.2)
Labor, € h ⁻¹	Fixed	18	18
Dry cow therapy, € cow ⁻¹	Fixed	9	9
IMI during lactation			
Milk sample, €	Fixed	15	15
Veterinarian ⁴⁾ , €	Normal	93; 14 (70–120)	93; 14 (70–120)
Drugs, €	Normal	38; 22 (8–85)	38; 22 (8–85)
Probabilities			
Dry cow therapy		0.21	1.00
IMI during subsequent lactation		0.24	0.18
Duration, days			
Treatment during lactation (probabilities)	Categorical	3; 5 (0.50; 0.50)	3; 5 (0.50; 0.50)
Withdrawal period after treatment during lactation (probabilities)	Categorical	4; 6 (0.50; 0.50)	4; 6 (0.50; 0.50)

¹⁾Parameter keys: Normal (mean, SD), Beta (α , β), Categorical (probability 1, probability 2); ²⁾Automatic milking system; ³⁾Varies with respect to length of medication: 3, 5 days; ⁴⁾Includes travel costs

On mainly family-owned Finnish farms, family members constitute the main labor force. Therefore, the farmer’s wage claim, which is also used in agricultural profitability accounting, served as a starting point for pricing labor (Luke 2021). However, due to the demanding work, the average wage claim was increased by 12.5%. The price of the work was fixed, because no sudden changes in it are likely within a family (Table 1).

The price of DCT per cow is approximately the same regardless of the drug product used. Thus, a fixed price in the model included both the prescription and the medicine cost (Table 1). Supplies for antibiotic-residue testing in milk are commonly paid by the dairy processor, and thus their price is not included in the calculation. The price of the PCR test for a milk sample remains quite constant, since the majority of Finnish dairy farmers send their milk samples to the same laboratory. Therefore, we used a fixed price for testing milk samples (Table 1). The cost of a veterinarian’s visit varies, depending on the distance between the farm and the veterinary clinic. A normal distribution was formed from the fixed portion of the fees (basic procedure) and the portion varying by the travel distance (Table 1). As our data did not enable us to distinguish between subclinical and clinical mastitis, we used the price of medication as an indicator of inflammation severity. We assumed the cost to be normally distributed around the mean price of drugs for a typical IMI (Table 1).

The probability of SDCT in the model was determined from the data in Niemi et al. (2021). In cows with SCC \geq 200,000 cells ml⁻¹ 60 d before dry-off, all quarters were assumed to be treated according to current Finnish SDCT practice (Table 1). The results from logistic regression for the odds of having milk SCC \geq 200,000 cells ml⁻¹ on the first test day 5–45 days in milk, based on 6,825 cows from 239 dairy herds were, in turn, used to derive the probability of contracting IMI after calving (Table 1). Probabilities were derived from the odds ratios and the number of observations in each DCT and SCC category, following Rita and Virtala (2013).

The duration of antibiotic IMI treatment during lactation was assumed to be 3 or 5 days, both having equal probability (Table 1). Those two duration periods are typical in Finland with antibiotics that are used to treat IMI. Withdrawal times with those antibiotics are 4 or 6 days. The probabilities of the number of days were assumed to be equal (Table 1).

Because Niemi et al. (2021) indicated that BDCT was associated with lower SCC after calving, we conducted a sensitivity analysis to investigate situations in which SDCT farms could reduce the risk of high SCC during the subsequent lactation to be closer to that of BDCT farms. The initial probability of IMI after calving is 0.24 on SDCT farms, and 0.18 on BDCT farms (Table 1). The sensitivity analysis provides the economic performance for SDCT herds when the post-calving IMI probabilities are 0.22 and 0.20.

Results

Our stochastic calculation model produced distributions of the margin for the fixed costs relative to the DCT practice in herds implementing SDCT and BDCT as their drying-off practice. Table 2 presents the quartiles of the distributions for each practice and each virtual herd having a certain herd size and milking system. The quartile breaks down the data into quarters so that 25% of the margins are less than the lower quartile (Q1), 50% are less than the median (Q2), and 75% are less than the upper quartile (Q3).

Within the same herd size and milking system, the distribution of the margin in the BDCT herds is to the right of the distribution of the SDCT herds (Table 2). The difference in the median (Q2) is €23 to €29 per cow per year in favor of BDCT, given that the probability of post-calving IMI follows the figures in Niemi et al. (2021). The difference in the lower quartile is larger, but the upper quartiles are almost equal in both the BDCT herds and SDCT herds. If the SDCT herds could have their current risk of post-calving IMI (0.24) reduced to 0.22 or 0.20, SDCT would be a very competitive alternative to BDCT at a risk of 0.18 (Table 2).

Table 2. Quartiles of annual margin for the fixed costs per dairy cow in herds implementing selective dry cow therapy (SDCT) and blanket dry cow therapy (BDCT) by herd size and milking system (probability of post-calving intramammary infection in parentheses).

Margin for fixed costs, €/dairy cow/year ¹⁾						
Quartiles	120 dairy cows, AMS ²⁾				60 dairy cows, milking parlor	
	SDCT (0.24)	SDCT (0.22)	SDCT (0.20)	BDCT (0.18)	SDCT (0.24)	BDCT (0.18)
Q1	2,398	2,424	2,448	2,452	2,214	2,268
Q2	2,727	2,754	2,778	2,750	2,518	2,547
Q3	3,090	3,120	3,147	3,084	2,854	2,857

¹⁾ Margin for costs that are equal in SDCT and BDCT; ²⁾ Automatic milking system

Table 3 shows that the lowest mean and the minimum margin for the fixed costs is in the herds with 60 dairy cows, a milking parlor, SDCT in use, and a probability of a post-calving IMI of 0.24. The highest mean and the maximum is reached in the herds with 120 dairy cows, AMS, SDCT in use, and a probability of a post-calving IMI of 0.20. The skewness indicates that the distributions are rather symmetrical, as are the distributions of most of the parameters in the model. The positive skewness is greater in the SDCT herds than in the BDCT herds, due to the greater variation in milk yields and the highly skewed milk price (Table 3).

Table 3. Descriptive statistics of an annual margin for the fixed costs per dairy cow in herds implementing selective dry cow therapy (SDCT) and blanket dry cow therapy (BDCT) by herd size and milking system (probability of post-calving intramammary infection in parentheses).

Margin for fixed costs, €/dairy cow/year ¹⁾						
Descriptive statistics	120 dairy cows, AMS ²⁾				60 dairy cows, milking parlor	
	SDCT (0.24)	SDCT (0.22)	SDCT (0.20)	BDCT (0.18)	SDCT (0.24)	BDCT (0.18)
Minimum	1,206	1,350	1,196	1,206	1,068	1,240
Maximum	4,853	4,194	4,888	4,922	4,412	3,893
Mean	2,757	2,774	2,784	2,810	2,546	2,568
SD	497	441	502	502	459	410
Skewness	0.272	0.162	0.264	0.271	0.271	0.158

¹⁾ Margin for costs that are equal in SDCT and BDCT; ²⁾ Automatic milking system

The virtual herd having 60 dairy cows and a milking parlor represents a typical herd implementing SDCT. Correspondingly, the virtual herd having 120 dairy cows and AMS represents a typical herd implementing BDCT. The distribution of the margins for the fixed costs in those herds are presented in Figures 1 and 2. Figure 1 shows that 90% of the annual margins in the SDCT herds ranges from €1,835 to €3,346 per dairy cow. The corresponding range in the BDCT herds is from €2,085 to €3,532 per dairy cow.

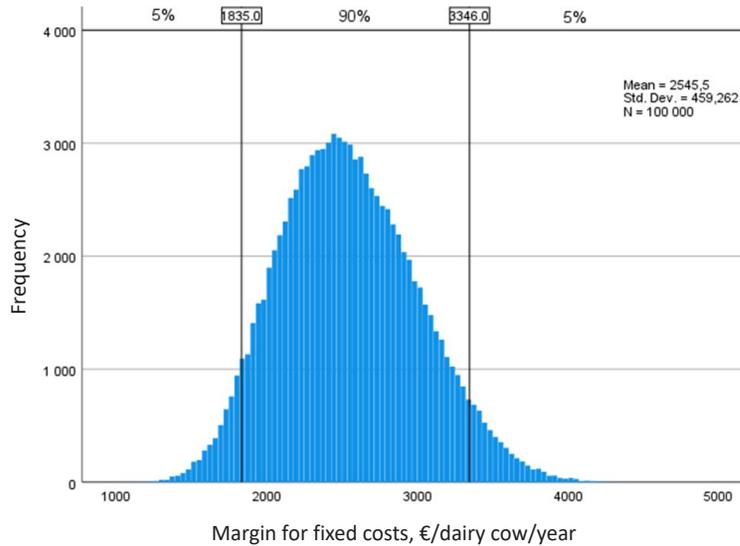


Fig. 1. Distribution of margin for fixed costs in herds with 60 dairy cows, parlor milking, and selective dry cow therapy (probability of post-calving intramammary infection 0.24).

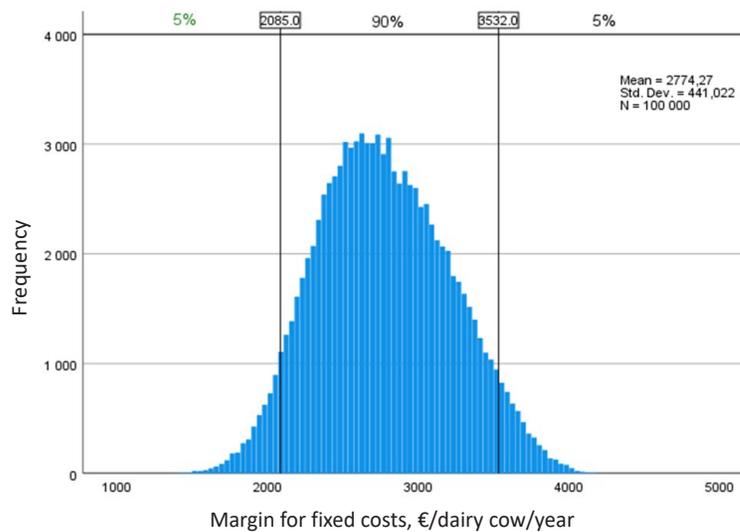


Fig. 2. Distribution of margin for fixed costs in herds with 120 dairy cows, automatic milking system, and blanket dry cow therapy (probability of post-calving intramammary infection 0.18).

Discussion

Our stochastic calculation model indicated that the choice between SDCT and BCDT does not result in a significant difference in the margin for the fixed costs. The relatively largest differences in the margin components between DCT practices were in the incidence of mastitis in the subsequent lactation and in the labor demand of DCT. The former affected marketable milk amount and veterinary costs, the latter the costs of DCT.

From a farmer's viewpoint, the benefit of BDCT is the smaller labor demand per cow at dry-off, because all quarters and all cows are treated with antibiotic DCT regardless of the cows' udder health status. There exists, therefore, no need to review such cows' SCC and mastitis-treatment records nor to analyze milk samples before selecting cows for treatment. However, because Finnish dairy farmers find bacteriological examination of milk samples advantageous for both an individual cow and for the entire herd, in both BDCT and SDCT herds, they regularly carry out milk sampling at least from some of their cows before treating them at dry-off (Vilar et al. 2018). By knowing the pathogens present in the herd, it is possible to intervene in the chains of infection and control, for example, the spread of *Staphylococcus aureus*.

Because we assumed in our model that no milk samples are needed in BDCT before the antibiotic treatment, both labor demand and BDCT cost are underestimated compared to the reality on Finnish farms. In SDCT herds, we assumed that the cows to be treated were selected according to their SCC and IMI history without analyzing any milk sample. This means that also the actual cost of SDCT is higher than our results indicate. Exact figures for this deviation are impossible to estimate, as we know only that approximately 80% of SDCT farms and 60% of BDCT farms take milk samples from some of their cows at dry-off, but the precise number of milk samples tested is unknown (Vilar et al. 2018). Since this computational shortfall affects both DCT practices to the same extent, we assume that it slightly overestimates the level of the margins for the fixed costs but does not significantly affect the economic advantage between these two practices. The parameters based on average daily milk yield may, in turn, underestimate the withdrawal losses due to IMI if IMI coincides with the highest milk yield of lactation. However, we can assume that the possible error for SDCT and for BDCT is equal, and therefore does not significantly affect the difference between the two management systems, nor the conclusions one can draw from the results.

A model is a simplification of reality intended to promote our understanding of an issue. If too many details are included in the model, it may become so complicated that it fails to promote the development of understanding that one seeks (Bellinger 2004). Some simplifications were also made in our calculation model because exact parameters were missing from the farms from which the other biological parameters of the model were originated. According to our understanding, the estimates of those parameters would not have brought the model closer to reality but have led to increased inaccuracy. Thus, we ignored the possible effect of IMI on premature culling and reproductive performance.

The strength of our calculation model is that the parameters related to animal health and milk production came mainly from recent studies based on extensive Dairy Herd Improvement (DHI) information from 241 Finnish dairy farms and 7,461 dairy cows (Niemi et al. 2020, 2021). Many other economic analyses of DCT have had to use older parameters or parameters from quite diverse sources, which weakens the reliability of their results. For instance, Scherpenzeel et al. (2018) and Rowe et al. (2021) assumed that each new case of subclinical mastitis reduced milk yield by 0.87 kg d⁻¹. This assumption was based on data collected from Dutch dairy farms in 2004 and 2005 (Halasa et al. 2009c), although this figure was applied to modern US dairy farms (Rowe et al. 2021). Hommels et al. (2021) studied large US dairies and based their estimation on milk production losses due to clinical mastitis on data collected in New York State during a research period from 1999 to 2001. In our study, the production parameters originated from the same farms as did the figures on probability of SDCT and IMI during subsequent lactation.

Based on the DHI data utilized by Niemi et al. (2022), only 14% of the SDCT farms treated more than half their cows. In this study, we used the mean, 21%, as the proportion of cows to be treated. Thus, the results give a simplified picture of the economic impact of SDCT practice, because the proportion of cows to be treated may range widely depending on the herd's udder health status. In general, the lower the proportion of cows to be treated and the lower the incidence of IMI during subsequent lactation, the greater are the economic benefits of SDCT. The optimum proportion of cows to be treated can be determined with linear programming models like those that Scherpenzeel et al. (2018) have utilized. Regarding the One Health approach and prudent antibiotic use, any proportion less than 100% used in BDCT is an advantage.

In this study, the financial difference between SDCT and BDCT practice was very small. Regardless of the DCT practice, herd-specific differences in the margins for the fixed costs are probably much greater, because profitability shows a wide range within Finnish dairy farms (Luke 2021). However, this study provides an indication of the economic effects of different DCT practices when the effects have been defined on a uniform basis.

The economic results are highly dependent on local prices and requirements related to antimicrobial use. Moreover, different methods may produce different results depending on their coverage and uncertainty factors involved in the analysis. However, the results of this study are mainly in line with those of other studies, if we look at the final conclusions, not at only the differences in financial values.

Based on a randomized controlled field trial carried out in the Netherlands between June 2011 and March 2012, Scherpenzeel et al. (2018) concluded that the optimal percentage of cows to be dried off with antimicrobials depends on a herd's subclinical and clinical udder health situation. The optimum was determined using a linear programming model with the goal of minimizing costs associated with antimicrobial use at drying off. In their study, SDCT was economically more beneficial than BDCT for all types of herds evaluated. The lower were the bulk tank SCC and incidence of clinical mastitis, the greater were the profits of SDCT. Thus, economics is not an argument against reduction in dry cow antimicrobial use (Scherpenzeel et al. 2018).

The study of Rowe et al. (2021) was methodologically very close to ours, but their data originated from sources that varied greatly in time and place. They concluded, however, that when SDCT is implemented appropriately, it may be a cost-effective practice for US herds under a range of economic conditions. Economic benefits of SDCT will be greatest in herds where SDCT implementation results in substantial reductions in antibiotic use, if antibiotic treatments are relatively expensive, and if SDCT does not lead to higher mastitis incidence in the subsequent lactation (Rowe et al. 2021).

Hommels et al. (2021) showed that it is economically feasible to reduce antibiotic use associated with DCT in large US dairy herds. Compared with BDCT, the use of antibiotics around the dry period in the economically optimal SDCT was reduced by approximately 30%, although the need for antibiotics to treat clinical mastitis after calving was considered. The method was a linear programming model which aimed at minimization of the total cost of mastitis around the dry period, under a varying constraint for the maximum percentage of cows dried off with antibiotics. A sensitivity analysis was performed on milk price, dry-off antibiotic price, and risk ratio of mastitis in the subsequent lactation. For all situations studied, BDCT was more expensive than SDCT.

Based on herd-level SCC, IMI prevalence varies substantially among Finnish farms (Niemi et al. 2020). A risk of post-calving IMI is likely associated with the improper selection of cows for DCT. In addition, it is associated with many other farm-specific factors that are affecting the herd's overall udder health (Green et al. 2007, Green et al. 2008, Dufour et al. 2011). Matters related specifically to the dry period are for example drying-off hygiene, body-condition score at dry-off, dry-period accommodation, and calving-area hygiene (Green et al. 2007, 2008). Current results show that SCDT becomes a more economical choice than BDCT, if a farm manages to reduce its IMI incidence from 24% to 22% or less. Scherpenzeel et al. (2018) reported that the optimum percentage of DCT-treated cows was 20% for a herd with an average level of clinical mastitis and a bulk-tank SCC between 150,000 and 250,000 cells ml⁻¹, which proportion corresponds to the proportions of SDCT-treated cows investigated in the current study. The recent North American herd-level SDCT-percentage estimates were 16.2% (95% CI 11.0.0, 22.7) for farms with an average bulk-tank SCC of less than 250,000 cells ml⁻¹ (Kabera et al. 2021b) and 22% for primiparous cows and 89% for multiparous cows on farms with good udder health (Hommels et al. 2021).

In our study, the distribution of the margin for the fixed costs in the BDCT herds was on the right compared to the distribution in SDCT herds. The difference in the median was €23 to €29 per cow per year in favor of BDCT. Thus, unlike Scherpenzeel et al. (2018) and Hommels et al. (2021), we cannot state that BDCT was more expensive than SDCT. However, the proportional difference in the margins was only 1% in favor of BDCT. As the current average herd size in Finland is approximately 50 cows (Luke 2022), this difference is not very substantial even at herd level.

Conclusions

Antimicrobial resistance is a serious global concern that calls for non-antibiotic IMI prevention. In the Finnish production environment, financial differences between SDCT and BDCT are minimal, meaning that compliance with current EU regulation does not, as a rule, entail financial losses for the producer. SDCT is a competitive management practice, especially on farms succeeding in keeping their IMI risk low. The focus in farm-level decision-making should be on the herd's udder-health status. In those herds with high IMI prevalence, the problem must be tackled primarily by means other than BDCT, because BDCT does not support the goal of reducing antibiotic use, and, when used routinely, is contrary to existing legislation.

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