

## A review of the factors affecting the costs of bovine mastitis

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### ABSTRACT

Mastitis is one of the most prevalent production diseases affecting the dairy cattle industry worldwide. Its occurrence is associated with direct and indirect losses and expenditures. When estimating the cost of mastitis to the dairy industry the cost of the control programmes must be added. The direct losses of mastitis are the only costs obvious to the farmer. The difference between the costs of mastitis on one side and the benefits of mastitis control on the other side will give us a picture of the economic efficacy of the mastitis control programme. Continuing education of the farmer is needed for better mastitis control programmes. This article is an attempt to review briefly all relevant factors included in the economics of bovine mastitis and to illustrate the authors' view of some of the costs.

**Key words:** cost, dairy cattle, mastitis, mastitis control, milk production.

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### THE COST OF MASTITIS TO THE DAIRY INDUSTRY

There have been many articles published worldwide on the economics of mastitis. When considering the cost of any disease, it must be remembered that every disease has direct and indirect costs. Bennett *et al.* estimated that the total costs of each disease can be much higher than the direct expenditure<sup>9</sup>. Most of the available estimates take into account only a part of the real cost of mastitis, as estimating the true costs associated with mastitis is notoriously difficult. It is even more difficult to quantify the losses associated with sub-clinical mastitis, because they are not visible to farm owners. To avoid underestimating the consequences of mastitis in evaluations of economic-loss it is important to account for all of the cost factors involved.

The estimation of the economic costs associated with mastitis depends on having the following data:

1. An estimate of the incidence and prevalence of mastitis in the population is a prerequisite for the estimation of its real cost to the dairy industry. There is currently a general demand for regular monitoring, recording and research to establish the incidence and prevalence of mastitis.
2. The severity of the physical effects of mastitis on milk production, which will depend on many factors, such as virulence of the mastitis-causing organisms, stage of lactation, age of the cow and udder defence mechanisms.
3. Identification of the prevention and treatment measures undertaken. It is generally easy to calculate the expenditure on mastitis control.
4. Valuation of the production losses, treatments and expenditures on prevention and control incurred. Production losses caused by mastitis are likely to be influenced by the age, breed and type of the cow, stage of lactation, milk yield before mastitis occurred, milk price, premiums and penalties, mastitis-causing organism, inflammation grade and distribution, diagnosis, treatment cost, prevention cost and analytical model.

### INTRODUCTION

Mastitis is defined as an inflammation of the mammary gland. It is a complex disease involving many factors, which is mainly caused by bacteria and there is no simple model that encompasses all possible facets<sup>25,64</sup>. Despite intensive research and the implementation of various mastitis control strategies over the decades, bovine mastitis has not disappeared and the reduction in the prevalence of sub-clinical mastitis has been minimal<sup>60</sup>. On the other hand, there has been a considerable decrease in the incidence of clinical cases of mastitis worldwide as a result of these control measures.

Bovine mastitis is considered to be one of the most economically important diseases for the dairy industry in developed countries<sup>1,11,16,23,25,27,33,46,60,64,66</sup>. Morin *et al.*, monitored 4 Illinois herds for 12 months and reported mastitis-associated economic losses ranging from US\$161.79 to \$344.16 per lactating cow/year<sup>52</sup>. The magnitude of the economic losses to the dairy industry in the USA due to mastitis was around \$1.3 billion in 1979<sup>11</sup> and around \$2 billion in 1988<sup>48</sup> and 1993<sup>15</sup> (not factored for inflation). The total financial cost of mastitis to the average Scottish dairy herd in 1996 was estimated to be £140/cow/

year<sup>79</sup> of which a loss of £100/cow/year was due to sub-clinical mastitis alone in high Bulk Tank Somatic Cell Count (BTSCC) herds<sup>80</sup>. According to Ott the total production loss due to mastitis in the USA is \$108.00 per cow for herds with average BTSCC of 200 000–399 999 cells/ml and \$295.24 per cow for herds with average BTSCC 400 000 and above or losses of approximately \$1 billion to the USA dairy industry, based only on BTSCC, as measure of sub-clinical mastitis<sup>57</sup>.

There is common confusion between the terms 'loss' and 'cost', so it is important first to clarify the terminology. In this article the following terms will be used as defined:

- a) *Loss* implies a benefit that is taken away (e.g. the production loss experienced because contaminated milk must be discarded); alternatively, it represents a potential benefit that is not realised (such as an evident decrease in the milk yield)<sup>46,66</sup>.
- b) *Expenditures* represent some economic effects of disease that are manifested as extra inputs into livestock production (such as treatment and prevention of mastitis)<sup>9,46,66</sup>.
- c) *Economic cost* is the monetary value of all the economic effects, both losses and expenditures, consequent upon the occurrence of disease<sup>9,46,66</sup>.

This article briefly reviews all the relevant factors influencing the economic cost of bovine mastitis.

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5. Other cost factors – e.g. farm management, culling, replacement and fatalities.

Many techniques and methods have been used to estimate production losses from mastitis in dairy cattle. Methods commonly used are: producer surveys, regression analyses relating milk somatic cell counts, between-herd comparisons, between-cow yield comparisons, within-udder yield comparisons, within-cow yield comparison and studies between identical twins. De Graves and Fetrow stated that none of the techniques used are perfect, due to lack of direct measure of how much milk a cow would have produced if there was no occurrence of mastitis during lactation, and they all have a degree of inherent bias, which, in most cases, tends to underestimate the actual milk yield decrease that has occurred<sup>16</sup>.

The economics of mastitis needs to be addressed at the farm or herd level and depends on local, regional, epidemiological, managerial and economic conditions. At the herd level, as stated by Seegers *et al.*, some compensation or buffer mechanisms can act and this should be taken into consideration in the estimates. An example is a farmer who decides to cull cows with high somatic cell count (SCC), based on the BTSCC and the milk pricing system, rather than on the absolute values of the individual SCC results of the cows. Another example is a farmer who decides to cull an extra cow to decrease the BTSCC and give up selling a heifer<sup>66</sup>.

## LOSSES CAUSED BY MASTITIS

### Direct losses due to mastitis

Direct costs of mastitis to the dairy industry include the costs of treatment (veterinarian's time and drugs), discarded milk (during both the course of treatment and withholding periods) herdsman's time, fatalities and the costs associated with repeated cases of mastitis. In many cases direct losses are the only cost of mastitis realised by the farmers.

#### Treatment cost

(Refs 6, 10, 11, 16, 23–25, 31, 36, 38, 39, 41–43, 48, 49, 60, 66, 67, 74)

The cost of treatment of clinical cases is an important element in the expenditure on mastitis. Very commonly, the size of the veterinarians' bills tends to be seen as 'the cost of disease' in the farmers' eyes. In fact, in general, the treatment of a disease such as mastitis, is only a small proportion of the disease cost<sup>39</sup>.

When estimating the treatment cost, the efficacy and cost-effectiveness should be taken into account. For example, Shim *et al.* comparing 2 treatment protocols

found that the addition of antimicrobials to supportive treatment is more efficacious and cost-effective than supportive treatment alone, projected that cows without mastitis will produce 8265 kg of milk (305-days in lactation)<sup>67</sup>. Cows treated with supportive treatment only produced 7838 (3.064–11.111) kg of milk, while cows with added antimicrobials to the treatment produced 7975 (5.002–11.163) kg, when discarded milk was included<sup>67</sup>. Assuming that none of the unmarketable milk was fed to calves, the cost of mastitis was 3 times higher in the group treated only with supportive treatment<sup>67</sup>.

There are 2 elements of the treatment cost: veterinarians' fees and the cost of drugs. In addition to the financial considerations, the treatment of cows with clinical mastitis is disruptive to the normal milking routine<sup>25,31</sup>.

#### Veterinary time and consultation fees

(Refs 1, 6, 11, 14–16, 23, 25, 28, 31, 36, 38, 43, 49, 52, 67)

The veterinary time and consultation fees can vary considerably in a mastitis control programme. These services are charged on an hourly basis, per-cow-per-year basis, or other methods. They can be applied to the individual cow, a group of cows or a whole herd.

Veterinary time for the treatment of individual cows with clinical mastitis usually involves a minimal level of herd-level consultancy and the cost per cow can be calculated from the invoices. The cost at the farm level may depend on the number of visits by the veterinarian. For example, in the Nordic countries all mastitis cases are attended by a veterinarian. In most other countries, such as South Africa, USA, Australia and New Zealand, the veterinarians attend only some cases of mastitis. In such situations, the calculation of costs on a per cow basis, from data collected at the farm level, needs some modelling.

Group level service includes treatment and prevention of mastitis in a specific group, such as age-categories, heifers or newly purchased cows. In this case, part of the veterinary time is clinical work, and usually there will be some consultancy time as well. Calculation of the estimated cost per cow in such a case is difficult, as it is unknown how much consultancy time has been spent per individual animal. The usual approach is to divide the amount on the invoice by the number of animals attended.

Most of the time when dealing with herd problems is spent on consultancy work, for example dealing with high BTSCC herds or mycoplasma mastitis-affected herds. In this case only a small

amount of time is used as real veterinary clinical work. The calculation of the estimated cost of this element is from the invoices. The fees are usually charged at the farm level and if individual cow-cost is required, then some modelling can be applied, or the amount on the invoices is simply divided by the numbers of cows in the herd.

#### Cost of the drugs

(Refs 1, 2, 10, 11, 14–16, 23, 28, 31, 38, 42, 43, 49, 52, 53)

This part of the mastitis cost is easily calculated from the invoices of purchases of drugs on the farm. A similar calculation may be done for the expenditure on the treatment of individual cases.

#### Discarded milk

(Refs 1, 6, 11, 14–16, 23–25, 31, 36, 38, 39, 42, 43, 52, 53, 66, 67, 74, 78)

The assessment of the cost of discarded milk should include the milk withdrawn during and after the treatment, which depends on the withholding periods of the drugs used and current regulations. The cost of discarded milk is usually estimated easily. In cases where mastitic milk is used for calf-rearing, estimation of the cost of mastitis should be carefully assessed. The system for accounting for the economic costs associated with 'discarded milk' should be transparent. No matter where it ends up the milk is not sold, so it is a loss of income. A possible solution is to budget for the economic costs of mastitis to be debited with the full costs of the milk not sold and the calf rearing budget to be credited with the value of the milk as a replacement for alternative sources of feed. If the estimates of milk losses are calculated on basis of BTSCC, then discarded milk in many cases is not taken into account, leading to underestimates of real mastitis costs<sup>43</sup>. In many dairy countries it is common practice for the farm owners of herds with average high BTSCC to withhold or discard the milk from the cows with highest SCC, aiming to control their bulk milk in acceptable levels.

#### Labour cost

There appear to be 2 main approaches in the literature for dealing with the expenditure on labour for mastitis treatment. The 1st one is to consider the labour time as a direct cost of the disease and include it in the calculations as such<sup>1,11,15,16,36,38,42,43,46,49,52,53,66,78</sup>. The 2nd approach is to calculate the labour cost if a farm specifically employs additional labour to manage treatment, segregation, or other aspects of mastitis control<sup>23–25</sup>. The more usual case is that mastitis control and treatment are handled by existing

farm labour<sup>52</sup> (i.e. no labour reduction would occur if mastitis cases were reduced). In our opinion, the workers' time should be included in the calculations of mastitis cost. The estimation of the time spent per case is variable and will depend on many factors, such as type of mastitis, milk yield, farm size, hired labour and farm owner. For example, peracute cases of mastitis, associated with general illness, requires more time for treating, nursing and frequent stripping than mild subacute mastitis with only changes in the milk.

### Fatality

(Refs 6, 15, 23, 33, 38, 39, 49, 52, 60, 66)

Severe cases of mastitis can lead to the death or euthanasia of the affected cow. The cost of a fatality is greater than simply the value of the cow in the market, as it includes the lost margin from the incomplete portion of its lactation. According to Kossaibati and Esslemont it also included the cost of a replacement heifer<sup>39</sup>. Mortality rate for clinical mastitis is usually low. Wilesmith *et al.* reported between 0.3 and 0.6 % of mastitis cases to be fatal<sup>76</sup>. Worldwide, higher mortality rates caused by mastitis are seen in specific situations with a high prevalence of Gram-negative infections, particularly coliform mastitis. Menzies *et al.* recorded a fatality rate of 14 % and a further 21 % early culling because of the condition in a study involving 264 cases of acute and peracute toxic mastitis in Northern Ireland<sup>47</sup>. By contrast, Bradley and Green reported a mortality rate of 0.6 %, in general, and 2.2 % due to Gram-negative organisms in 6 Somerset dairy herds<sup>12</sup>.

### Repeated cases of mastitis

Some dairy cows suffer repeatedly from mastitis during a single lactation. Kossaibati and Esslemont found that a typically affected cow suffers on average 1.6 cases per lactation<sup>39</sup>. The extra costs of that 0.6 repeat case should be taken into account when assessing losses caused by mastitis. For these repeated cases only the relevant direct costs should be included (i.e. cost of drugs, herdsman's and/or veterinarian's time and discarded milk). For the indirect costs, it is important to calculate only additional losses associated with further decrease in milk yield and increased risk of culling. The rest of the indirect costs usually have been already taken into account.

### Indirect losses due to mastitis

Indirect losses due to mastitis, particularly the subclinical form, are not well-recognised by many farmers. It is generally accepted that subclinical mastitis

accounts for the majority of economic costs of mastitis. Education on this matter is necessary because unrecognised indirect losses can be a reason for difficult implementation of mastitis control measures, as farmers usually hold an opinion that their own losses, due to mastitis, are much lower than the estimates provided for the industry by the experts<sup>13</sup>. Indirect losses include the decreased milk production due to clinical or sub-clinical mastitis, decreased milk quality, increased culling, loss of premiums, penalties, pre-term drying-off, animal welfare aspects and other associated health problems.

### Decrease in milk yield

(Refs 1, 3, 6, 11, 14–16, 23–25, 28, 31, 33, 36, 38, 39, 41, 43, 46, 48, 49, 52, 54, 60, 66, 71, 74)

The main factor in causing economic losses due to both clinical and sub-clinical mastitis is a more or less persistent decrease in milk yield. Usually there will be a short-term depression in yield of variable severity and, in case of no microbial cure and recovery, a longer lasting effect, sometimes carrying over into the next lactation/s. Milk production losses are typically estimated to account for 70 to 80 % of all mastitis losses in a typical herd<sup>16,25,27,38,41,52,64</sup>.

Losses in milk yield (not including discarded milk) need to be assessed within several time-frames. There are the short-term effects on the current lactation and long-term effects, including carry-over effects into the next lactation or beyond, that are usually estimated using several types of comparison or modelling approaches<sup>33,66</sup>.

Estimates of milk yield loss are still under debate and likely to be influenced by the age, breed and type of cow, morphological characteristics of the udder, stage of lactation, pregnancy status, milk yield before mastitis occurred, mastitis-causing organism, inflammation grade, duration and distribution, diagnosis (early or late after the occurrence), treatment, feeding practices, season, recurrence of mastitis during the same or previous lactation, comparison model (what is the control group) and the analytical model.

It is generally accepted that mastitis occurring earlier in lactation will lead to greater milk yield losses. Lescouret and Coulon reported that milk production curves of about one-third of the cows infected early in lactation were little affected and yield recovered in less than 5 weeks. The production curves of the rest of the infected cows were markedly affected or the cows were culled. By contrast, more than half of the cows infected from mid- to late-lactation were not

affected by marked modifications in their milk production curves and recovered in less than 5 weeks<sup>42</sup>. It has been reported that the milk yields of older cows were obviously affected if mastitis occurred early in lactation, while younger cows' yields are sensitive, with carry-over effects seen if mastitis occurred after the peak of lactation<sup>25,62</sup>. Rajala-Schultz *et al.* analysed records of over 24 000 Finnish Ayrshire cows, and reported that milk production declined 4 weeks before the onset of clinical mastitis and dropped further below the curve of 'healthy' cows during the 1st week afterwards. Milk yield never reached the pre-mastitis levels if mastitis occurred in early lactation (before peak)<sup>62</sup>. A decreased milk production before the occurrence of clinical mastitis was presumably due to the effects of sub-clinical infection.

A higher level in milk yield prior to mastitis could be expected to be associated with higher losses in milk (both in absolute value and in percentage)<sup>35,42</sup>

The pathogenesis of mastitis, in many cases, includes damage to secretory tissue and its replacement with fibrous tissue leading to a permanent decrease in milk yield from the affected quarter<sup>7</sup>. In addition, it is probable that part of the decrease of the milk production is due to an increased demand for energy by the immune system, a decreased appetite associated with the inflammatory process and lowered feed intake due to pain and decreased mobility.

Some mastitis-causing organisms were shown to have a more profound impact on milk yields than others<sup>16,25,77</sup>. Mastitis cases caused by *Staphylococcus aureus* generally evolve into persistent but moderate infections, unlike mastitis caused by coliforms. Thus, the mastitis-causing organism may contribute to the residual variation of responses, as well as to the level of intensity. Generally it is estimated that the greater the inflammation the less milk is produced.

There are 3 broad groups of comparison models: (1) between herd comparison, (2) between-cow or within-herd comparison, and (3) between-quarter or within-udder comparison. A comparison of the relative yields of herds with varying levels of mastitis may be used to estimate the decrease in milk production. However, in this type of study, factors other than mastitis may significantly contribute to any difference in milk yield that may be observed. The herds included in the study must be closely matched for factors such as location, breed, age, and plane of nutrition. The between-cow comparison model is also affected by some non-mastitis compounding factors such as age



and breed and the cows must be closely matched for such factors. Within-udder yield comparisons compare a mastitis-infected quarter with an opposing mastitis-free quarter. Generally it is accepted that the contra-lateral quarters of the udder, when both are un-infected, give approximately the same volume of milk. However, while within-udder comparison avoids sources of variation which may confound other estimates of decreased milk production, it is possible that within the infected cow, un-infected quarters partially compensate by producing more milk or both produce less as the cow is sick. There is evidence that mastitis-free quarters may compensate for quarters with mastitis by increasing milk production<sup>30,31,45</sup>. If compensation does in fact occur, then this would cause overestimation of the actual milk loss as a result of mastitis<sup>16,30</sup>. Hortet and Seegers, using a regression-modelling approach to analyse data from 20 papers published worldwide, predicted the average milk-yield loss over the lactation was 300–400 kg (i.e. 4–6 %) per treated case of clinical mastitis in a Holstein Friesian cow producing approximately 7000 kg/lactation. In primiparous cows, the average loss was lower (200–300 kg) and mild patterns of mastitis were more frequent than in multiparous ones. Cases occurring before the peak of lactation were associated with higher average losses (450–550 kg) than cases occurring later. Similarly Seegers *et al.* estimated loss of about 375 kg (5 %) per average clinical case, occurring in the 2nd month of lactation in a Holstein cow<sup>66</sup>.

The estimates need to be used with caution, especially for breeds other than Holstein Friesian or if unusual mastitis-causing organisms are involved in clinical-mastitis cases<sup>33</sup>.

#### Short-term effects

(Refs 6, 25, 33, 34, 62)

For the estimation of short-term effects, it is necessary to bear in mind that an infection can start and the milk yield can be reduced before the mastitis is detected. This may lead to underestimation of the real loss from mastitis<sup>62</sup>.

Hortet and Seegers, using regression models, estimated that short-term losses from clinical cases of mastitis varied from 0 to about 3 kg/cow/day, but suggested that the estimates are lower than expected. They suggested that regression models underestimate short-term losses, because of the difficulty in accounting for variable losses occurring before a clinical diagnosis<sup>33</sup>.

Short-term reduction in milk yield is higher for clinical mastitis in early lacta-

tion compared with mastitis in mid to late lactation. Losses from 0 to 200 kg/cow/month were estimated by Hortet and Seegers in cases of clinical mastitis occurring before the expected peak of the lactation or 0 to 100 kg/cow/month with occurrences in mid- to late-lactation<sup>33</sup>. Houben *et al.*, using records for over 5300 lactations of nearly 2500 black and white cows in Denmark, with approximate calculated production of 7500 kg, reported the estimated effect of clinical mastitis on production of 527 kg of milk for  $\geq 3$  cases of clinical quarters in the 2nd lactation<sup>34</sup>. Rajala-Schultz and Grohn recorded, in cows of 2nd parity, mean milk loss of 294, 348 and 110 kg milk if mastitis occurred before peak, between peak and 120 days and later in lactation, respectively<sup>61</sup>. The losses in older cows were significantly higher. For example, spanning 3 lactations in cows, mean recorded loss was 555, 329 and 357 kg, respectively<sup>61</sup>.

#### Long-term effects

This is an area that needs more attention from research, although available estimates generally indicate there are both long-term decreases in milk production after episodes of clinical mastitis and long-term economic losses associated with chronic mastitis<sup>24,25,42,62,71</sup>.

Deluycker considered that the cows affected by clinical mastitis in the 1st lactation but not in the next do not have a higher, or compensatory increase in milk yield when compared with cows free of mastitis in 2 successive lactations, even if the infection was eliminated<sup>18</sup>. Fetrow *et al.* found that the carry-over effect of mastitis and high SCC from one lactation to the next was generally statistically significant but small, amounting to less than a half of the effects of high SCC in the current lactation. When production measures were adjusted for herd effect (rolling herd average), the carry-over effect was less than 20 % of the direct effect of increased SCC<sup>24</sup>. However, chronic mastitis in 3 or more quarters is associated with long-term economic losses in the following lactation of more than 350 kg in the 2nd and 3rd lactation<sup>33</sup> and up to 381 kg of milk, up to and including 8 months into the 2nd lactation<sup>34</sup>.

#### Elevated somatic cell counts – SCC

The measurement of the SCC in bulk milk is the most universal method of evaluating the occurrence of mastitis in dairy herds. There are significant correlations between the BTSCC of a farm and the economic losses associated with decreased milk production and quality. It is evident that an elevated SCC in milk, regardless of cause, is associated with decreased milk

yield and economic losses<sup>3,8,16,22,24,25,43,50,54,75</sup>.

There is considerable variation in the estimates of the cost of milk loss in studies that have related milk yield to SCC. Thus, lactation losses of 80 kg and 120 kg by primiparous and multiparous cows, respectively for each 2-fold increase in the geometric mean of SCC above 50 000 was estimated by a regression analysis of data from 19 papers<sup>32</sup>. Similarly, Bennedsgaard *et al.*, analysing data from 17 500 lactations in 48 Danish organic herds, reported average losses of 0.2, 0.3 and 0.4 kg of energy-corrected milk/day in the 1st, 2nd and 3rd or later lactations, respectively, with each 2-fold increase in SCC between 100 000 and 1500 000 cells/ml<sup>8</sup>. Losinger estimated loss of US\$810  $\pm$  480 million to the USA economy as a whole caused by reduced milk production associated with an increase in BTCSS during 1996<sup>44</sup>.

#### Milk quality changes

The economic losses that should be included in the calculations due to milk quality changes are poorer milk composition, zoonotic risk and hygienic milk quality changes leading to public health considerations, lower end-product yields and quality, shorter shelf-life of the final products and a decrease in profitability to both producers and processors.

#### Compositional changes

(Refs 1, 6, 14, 16, 31, 33, 36, 46, 52, 60, 66, 71, 74, 75, 78)

Mastitis is responsible for a number of changes in milk composition. While the effects of mastitis on the concentrations of protein and fat in the milk are variable, changes in the actual composition of these components, especially protein, are more consistent and often quite marked<sup>16,36,66</sup>. There is a reduction in the synthesis of the main components of milk, namely fat, lactose and protein, which may lead to a change in the relative proportions of these components in the milk. There are also increased concentrations of blood serum components due to the inflammatory reaction, e.g. proteins, (serum albumin and immunoglobulins), chloride and sodium<sup>6,16,33</sup>. These changes have direct and indirect effects on the manufacturing properties of milk, often decreasing yield<sup>1</sup>, quality<sup>75</sup> and shelf-life of end-product<sup>1,16,31,75</sup>. Furthermore, the presence of small quantities of antimicrobials in the milk due to mastitis treatment is associated with major losses incurred by the manufacturers when starter microorganisms are destroyed or their activity is slowed.

The final products, manufactured from milk with changed composition, will potentially command lower prices on the market and therefore will reduce the

income for the dairy industry and farmers. The current milk-pricing system mainly relies on total-fat and total-protein yields. Since there is little financial incentive for dairy farmers to do so, mastitis control programmes are not stimulated. Also, due to the withdrawal period after treatment of clinical cases, composition changes in bulk milk can, as stated by Seegers *et al.*, be neglected in economic calculations<sup>66</sup>. However, SCC and microbial count play an increasingly important role in many payment systems and therefore a decrease in milk quality, due to mastitis, plays a significant role. The introduction of premiums for milk quality stimulates interest on this matter (examples seen in UK and Australia). The very severe penalties for the presence of antimicrobials in milk are a major incentive for ensuring that effective measures are in place on the farm to prevent contamination.

All costs associated with the compositional changes, at farm level, can be calculated from the statements of milk collecting and processing companies. When the cost of mastitis is estimated on a per cow basis, data collected at the farm level needs some modelling taking into account cow numbers and mastitis occurrence.

#### *Decreased hygienic quality of milk and public health considerations*

When discussing the financial implications of mastitis, its importance in public health and the effects of mastitis on the consumers should not be overlooked<sup>1,16,31,46</sup>. The risk of zoonotic diseases is also an important issue. This risk, however, is not necessarily associated with mastitis. The potential spread of zoonotic organisms via milk, though rare in the era of pasteurisation, remains a risk especially in the niche markets of unpasteurised dairy products, and during pasteurisation failures<sup>60</sup>. A number of mastitis-causing bacteria and fungi are potentially pathogenic to humans, causing in many cases severe or even fatal infections or intoxications (e.g. staphylococcal food poisoning with the thermostable toxins produced by the staphylococcae; *Strep. agalactiae* human septicæmia and neonatal meningitis etc.)<sup>31</sup>. The extensive use of antimicrobials in the treatment and control of mastitis has possible implications for human health through an increased risk of antimicrobial resistant strains of microbes emerging that may then enter the food chain<sup>1,6,60</sup> or through the increased risk of allergic reactions.

The excretion of large numbers of mastitis-causing organisms in milk from in-

fecting cows adds to the total number of bacteria in bulk milk, regardless of degree of care taken with plant hygiene<sup>6,31,46,66</sup>.

The stress to the farmer is considered as a potential public health concern.

The costs associated with the effects of mastitis on milk quality can be estimated from the penalties imposed by the milk processor for failure to meet the quality standards for SCC, microbial content and antibiotic contamination. Some factors of concern for public health, such as exposure to potential pathogens and pathogens resistant to antimicrobials in milk that is used un-pasteurised, or the stress to the farmer are not easily identified or costed.

#### *Culling and replacement cost*

The term culling describes the removal of an animal from a herd. A significant part of the economic cost of mastitis is related to culling losses<sup>1,6,10,11,14,16,23-25,28,33,36,38,39,41,43,46,48,49,52,66,73-75,78</sup>

of cows that have or have had clinical mastitis<sup>1,3-5,16,33,41</sup> or elevated SCC<sup>3,5,66</sup>, and the increased expenditure associated with their replacement<sup>1,6,11,15,31,36,41,46</sup>. Mastitis is usually second only to reproduction as the largest involuntary culling category<sup>4,10,16,27,39,45,66</sup>.

Financial losses at the farm level can be attributed to the loss of future income and genetic potential<sup>1,15,28,31</sup> resulting from culling. Schepers and Dijkhuizen stated that the loss in this case is the difference between the income that a particular animal could earn during her remaining expected life and the expected average income from replacement animals with normal productive qualities and normal probabilities of disposal over the same period of time<sup>64</sup>. However, the loss occurs only when animals have to be replaced before reaching their optimal economic age for culling.

The decision to cull is a complex one. There are different ways of classifying culling according to the motives that lead to the culling decision. The traditional concept distinguishes between voluntary and involuntary culling<sup>51</sup>. A different approach has gained attention that defines biologic and economic culls which allows consideration of all the factors that influence the decision-making process<sup>27</sup>. Lehenbauer and Oltjen stated that the culling strategies are further influenced by short-term fluctuations in cow numbers as well as by planned herd expansion<sup>41</sup>. However, most cows are likely to be removed from dairy herds only after they have displayed several reasons that would lead to culling. Farmers may consider many cow-related factors, such as age, stage of lactation, milk production, health status, disposition, reproductive

performance, economic factors, such as milk price, the price of culled cows and the price, genetic merit and availability of replacement heifers when determining whether or not a cow should be culled. The large effect of clinical mastitis before peak lactation on short-term milk yield may partly explain the increased rate of culling of cows infected early in lactation<sup>25,66</sup>. When mastitis occurs later than 240 days after calving, the effect on culling is not evident<sup>61</sup>. This could be explained by the fact that when the time of next calving is approaching, farmers are prone to wait until the next time the cow calves and see whether she has recovered from mastitis at the start of the next lactation<sup>61</sup>.

As many of the factors of culling and replacement cost are not easily calculated, particularly the loss of genetic potential, it will be necessary to employ complicated dynamic programming model to estimate the cost of this group of factors. The culling of an infected cow is likely to reduce the risk of spread of infection through the herd<sup>73</sup>. The benefits of this effect should be included in the dynamic programming models.

#### *Premium loss and penalties*

(Refs 1, 25, 66, 74, 78)

Penalties and premium losses in many countries, particularly the European Community and Australia, are an important part of the economic losses caused by mastitis. The stringent standards for a number of quality parameters including contamination with antimicrobial substances, microbes, flavour defects, and concentration of milk components as well as somatic cells count are monitored and penalised or compensated for in different countries. Morin *et al.* reported 21–40 % of the cost of mastitis in 4 Illinois herds accounted for milk quality premium losses<sup>52</sup>.

All costs associated with premiums loss and incurred penalties at the farm level are easily calculated from the statements of the milk collecting and processing companies. To estimate the cost at cow level, calculations from the data collected at the farm level will need modelling, taking into account cow numbers and mastitis occurrence. In the final model estimating costs of premium losses and incurred penalties the labour's error<sup>25</sup> should be taken into account, as this will lead to overestimates of the cost of mastitis; for example, milking of a cow before withholding period is finished, etc.

#### *Pre-term drying off*

In many cases, particularly from mid-lactation onward, and when there is a

re-occurring case, pre-term drying off the affected quarter of a cow is advocated. To avoid underestimates of mastitis consequences all those cases should be specifically recorded and accounted for in economic-loss cost evaluations<sup>33,78</sup>.

#### *Animal welfare aspect of mastitis*

The welfare implications of peracute toxic mastitis are obvious. Allore and Erband Payorala stated that more recent researchers have demonstrated significant secondary hyperalgesia in cows following mild clinical episodes of mastitis<sup>1,60</sup>. It has been now accepted that mastitis is associated with hyperalgesia, particularly in acute and peracute cases<sup>26</sup>. Allodynia has been demonstrated for approximately 5 and 40 days in the case of mild and moderate cases of mastitis, respectively<sup>26</sup>. Concentrations of bradykinin, cortisol and other kinins change during clinical mastitis<sup>21,68-70</sup>. Therefore supportive treatment of each case of mastitis can be an issue in the near future, leading to increased costs of mastitis.

According to Milk Hygiene directive 92/46 EEC it is not allowed to deliver milk from cows suffering from recognisable inflammation of the mammary gland<sup>74</sup>.

#### *Associated health problems*

Mastitis is commonly associated with other health problems such as reproductive failure<sup>25,39,46,65,74</sup> and loss of appetite<sup>39,46,66</sup>. There will be some indirect costs due to increased risk of these associated health problems.

Recently there has been a trend when estimating mastitis costs to take into account less food consumed to produce less milk; a factor that was not usually considered<sup>10,28</sup>. However, trying to differentiate between loss due to inflammation of the secretory tissue and that due to a decreased intake because the cow is not feeling well is an unrealistic sophistication. A healthy udder is more efficient at converting nutrients into milk<sup>10</sup>, so to estimate the real cost of mastitis regarding feed intake will need a complicated modelling.

Schrick *et al.* reported that cows with clinical or sub-clinical mastitis before the 1st service had increased days to 1st insemination, increased days open and increased service to conception<sup>65</sup>. This indicates that some of the losses from associated health problems can be calculated using relatively simple modelling.

#### **Cost of mastitis control programmes**

The costs of mastitis control include expenditures which can be measured

directly from invoices or calculated according to standard treatment and prevention costs, and from labour time for monitoring, treatment, prevention<sup>16,36,66</sup>, and other expenditures.

Expenditure on mastitis control is determined by which control methods are employed, namely: educational costs, pre-milking preparation of the udders, teat disinfection, dry-cow therapy and mastitis vaccines, monitoring measures, and maintenance of the milking machine. On the other hand, some authors also include the treatment of clinical cases<sup>27,52</sup>, the pre-partum treatment of heifers<sup>56</sup>, culling<sup>27,52</sup> and the management changes in milking routine<sup>27,52,66</sup>, such as milking infected cows last. For example, Oliver *et al.* reported that pre-partum antibiotic treatment of heifers yielded net revenue of around \$200/heifer/year<sup>56</sup>. Contagious mastitis in the herd is associated with shedding of the mastitis-causing organisms during milking and the risk of cross-infection to other cows in the herd<sup>14,31,52,73,74</sup>. In such cases the mastitis prevalence in the herd will change, and consequently mastitis costs will be increased. A proper transition management with the added cost of feed additives, minerals and vitamins in particular, play an important role in modern mastitis control programmes. A relatively new area in mastitis control strategies is vaccination against different mastitis-causing organisms, and some research on the benefits of this procedure is already available. DeGraves and Fetrow estimated benefit of \$57 per cow if the herd is vaccinated, assuming that 1% of the cows would normally contract coliform mastitis during the season<sup>17</sup>.

#### *Educational costs*

Continuous education of farmers is a necessary tool in the battle against bovine mastitis<sup>25</sup>. Farmers need to be aware of economic cost of mastitis in the herd and the cost benefits of a mastitis control programme that will increase the farm's net income.

The importance of education is demonstrated by the survey conducted by Gill *et al.*<sup>27</sup>. They found that a regular visit by a veterinarian or udder health specialist, more years of ownership or managing a farm, more education, and frequent attendance at dairy extension seminars were associated with lower SCC, while the increase in the total number of people working on the dairy farm was associated with an increased SCC. By contrast, Kuiper *et al.* found that the education factors were not as important as premiums and penalties applied for milk quality<sup>40</sup>.

The costs associated with education of the farmers and the labour can be partially estimated from the invoices for attended courses. Time spent on education is difficult to estimate. Also decreased SCC were associated with the higher education qualifications of the farmers or workers and not necessarily related to knowledge about mastitis, so to try and attribute this to the cost of mastitis seems somehow unrealistic.

#### *Pre-milking preparations of the udders*

(Refs 16, 27, 52, 66)

The costs of this procedure include the time the milker takes for pre-stripping, washing and drying the udders; use of water and teat disinfectant for washing, and paper towels for drying the udders. Pre-milking teat disinfection is a relatively new concept in mastitis control. The majority of authors conclude that this procedure is generally effective and not expensive<sup>35,55,58</sup>. On the contrary, Ruegg and Dohoo reported that the reduced incidence of clinical cases of mastitis does not justify the added expense incurred from pre-milking teat disinfection, with a benefit to cost ratio of 0.37<sup>63</sup>. Further research is needed to evaluate the economic impact of the procedure.

#### *Post-milking teat disinfection*

(Refs 2, 6, 16, 23, 27, 46, 52, 66)

When assessing the cost of teat disinfection there are 3 main elements that should be addressed, namely the cost of the teat disinfectant, the installation and maintenance cost, and labour cost (if included as a cost of mastitis). Gill *et al.* found that the cost of teat disinfectants is quite variable and is influenced by the amount used per cow per year and the cost per litre<sup>27</sup>. On top of this the cost of the emollient used must be added.

Farms that have equipment for back-flushing of the milking units should include the cost of installation, maintenance and any disinfectant used.

#### *Dry-cow treatment and mastitis vaccines*

The cost of commercial dry-cow products (antimicrobials and teat sealants) is somewhat variable, being influenced by the product used<sup>16,16,23,27,46,52,66,78</sup>. The cost will be influenced by the numbers of cows treated at drying off if selective dry-cow therapy is used. If labour cost is considered as an element of the mastitis cost, then it should be added to the calculations.

The same procedure can be used for calculation of the estimated cost of vaccines against mastitis<sup>1,16,60,66</sup> or some of the other immuno-modulatory systems<sup>60</sup> and their application.



## Monitoring measures

(Ref. 23)

### SCC monitoring cost

(Ref. 23)

The cost of herd testing is calculated easily from invoices. Herd testing is done by different companies around the world and these usually record the volume, protein and fat content, and SCC in the milk from each individual cow. For example, herd testing in New Zealand is done by the Livestock Improvement Corporation (LIC) and Ambreed. The information gained from herd testing is vital for effective herd management and decision making. If labour cost is considered as an element of the mastitis cost, then it should be added to the calculations. Zepeda *et al.* estimated that testing and monitoring pays for itself over a short period of time, except when there is very low incidence of mastitis and very low SCC<sup>81</sup>.

### Culturing

(Refs 16, 27, 52)

The cost of detecting and characterising mastitis-causing organisms from infected cows or bulk tank milk is variable and depends on the numbers of samples submitted and the laboratory used for culturing. The cost of materials (sample tubes, alcohol, wipes, cotton wool) should be added to the calculations of the mastitis control programme. If labour cost is considered as an element of the mastitis cost, then it should be also added to the calculations.

Some mastitis control programmes may include more extensive culturing. In this case, individual cows that are likely to be sub-clinically infected are identified either by using the somatic cell count or other methods for sub-clinical mastitis diagnosis, and milk samples are cultured. Cows with culture-positive milk can then be treated, based on the mastitis-causing organism, sensitivity results, age of the cow, stage of lactation and productivity.

### Milking system and milking procedure analysis

Analysis of milking equipment and procedures is highly variable, influenced by the herd size, past history and management level<sup>16,19,23,27,46,52</sup>. However, regular milking machine tests lead to better results and have a high cost:benefit ratio<sup>19</sup>.

### Transition period management

It has been reported that cows suffering from clinical parturient hypocalcaemia have been associated with a nearly 9-fold increased risk for mastitis<sup>20</sup>. The diet of a dairy herd plays an important role in cow productivity, and its general ability to

resist disease<sup>60</sup>. Nutritional relationships to host defence mechanisms have led to the idea of increasing the resistance of dairy cattle to mastitis through nutrition. Not only gross malnutrition, but also merely suboptimal levels of any one micronutrient is sufficient to adversely affect mammary gland immunity<sup>29,37,59,72</sup>.

Mastitis control programmes should ensure that proper levels of all macro- and micro- nutrients are maintained in all cows at all times. The key to ensuring adequate levels of these important micronutrients is direct testing of animals at the herd level to delineate patterns in overall nutrient deficits<sup>72</sup>.

Transition period management includes many other procedures associated with mastitis control, for example teat disinfection and pre- or post-calving treatment of heifers.

The cost of the supplements is easily calculated from invoices. The cost of other procedures is calculated in the same way as for normal treatment or teat disinfection.

## DISCUSSION AND CONCLUSIONS

Bovine mastitis is considered as the most costly production disease to the dairy industry worldwide. Estimating the costs associated with mastitis is notoriously difficult. It is even more difficult to quantify the losses associated with sub-clinical mastitis as they are not visible to the farmer. The economics of mastitis needs to be addressed at the farm or herd level and depends on local, regional, epidemiological, managerial and economic conditions. When considering the cost of any disease, it is necessary to keep in mind that every disease has a direct and an indirect cost. Direct costs and expenses are usually the only ones realised by the farmer. Indirect losses due to mastitis are not realised by the farmer in many cases and are a reason why the implementation of mastitis control measures is difficult, so continuous education on this matter is necessary. Some of the costs and expenditures are easy to calculate and they should be included in research projects dealing with the modelling of the economics of the disease. However, some of the costs are not countable, such as cases of human diseases, farmers' stress etc. To be able to consider the real cost of mastitis to the dairy industry, the prevalence and incidence of mastitis on a national level should first be established. Then estimations of all relevant countable costs and expenditures should be made, and the last step will be to include all of them in 1 large model for mastitis cost estimation.

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