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Decision tree analysis of treatment strategies for mild and moderate cases of clinical mastitis occurring in early lactation

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ABSTRACT

The objective of this study was to develop a decision tree to evaluate the economic impact of different durations of intramammary treatment for the first case of mild or moderate clinical mastitis (CM) occurring in early lactation with various scenarios of pathogen distributions and use of on-farm culture. The tree included 2 decision and 3 probability events. The first decision evaluated use of on-farm culture (OFC; 2 programs using OFC and 1 not using OFC) and the second decision evaluated treatment strategies (no intramammary antimicrobials or antimicrobials administered for 2, 5, or 8 d). The tree included probabilities for the distribution of etiologies (gram-positive, gram-negative, or no growth), bacteriological cure, and recurrence. The economic consequences of mastitis included costs of diagnosis and initial treatment, additional treatments, labor, discarded milk, milk production losses due to clinical and subclinical mastitis, culling, and transmission of infection to other cows (only for CM caused by *Staphylococcus aureus*). Pathogen-specific estimates for bacteriological cure and milk losses were used. The economically optimal path for several scenarios was determined by comparison of expected monetary values. For most scenarios, the optimal economic strategy was to treat CM caused by gram-positive pathogens for 2 d and to avoid antimicrobials for CM cases caused by gram-negative pathogens or when no pathogen was recovered. Use of extended intramammary antimicrobial therapy (5 or 8 d) resulted in the least expected monetary values.

Key words: decision tree model, on-farm culture, mastitis, pathogen distribution

INTRODUCTION

Mastitis is a disease of the mammary gland caused by bacterial infection and is the most common and costly health disorder of dairy cows (Ruegg, 2003). Mastitis has a negative economic impact on dairy farms in terms of discarded milk, lost production, reduced milk quality, and treatment costs (Seegers et al., 2003; Gröhn et al., 2004). Although antimicrobial therapy is not necessary for successful treatment of clinical mastitis (**CM**) caused by all pathogens, most cows with cases of CM are treated with intramammary antimicrobials (Pol and Ruegg, 2007; Hill et al., 2009).

Clinical mastitis is often classified according to severity as mild (milk looks abnormal), moderate (milk looks abnormal and the udder or quarter is swollen), or severe (the cow exhibits systemic signs). Although immediate action using systemic treatment is generally recommended for severe cases of CM, selective treatment based on the causative pathogen is often recommended for mild and moderate cases. On-farm culture (**OFC**) programs are one approach used to help farmers rapidly diagnose the pathogen responsible for CM (Neeser et al., 2006; Lago, 2009). On-farm culture programs generally use selective media to differentiate among gram-positive or gram-negative pathogens and apply treatments according to etiology (Neeser et al., 2006; Lago, 2009). Using OFC, microbiological results can be obtained within 24 h, as opposed to waiting at least 48 h to receive results from a diagnostic laboratory. Short-term clinical and bacteriological outcomes have been reported for cows that received selective treatment of CM based on OFC results (Neeser et al., 2006; Lago, 2009). However, economic outcomes of selective treatment based on OFC have not been estimated.

The evaluation of treatment strategies for CM can be at the cow level and is based on biological and economic factors. Biological outcomes from clinical trials using various treatments for CM have been described (Roberson et al., 2004; Hoe and Ruegg, 2005; Suojala et al., 2010) but the economic impact of mastitis treatment protocols has received less attention. In recent years, the use of extended-duration therapy has been recommended and some studies support the concept that extended therapy significantly increases treatment efficacy for some mastitis pathogens (Gillespie et al., 2002; Oliver et al., 2003, 2004a,b; Deluyker et al., 2005). However, the economic impact of mastitis treatments that are administered for extended durations has not been evaluated.

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Decision tree analyses have been successfully used to evaluate economic decision making for treatment of various diseases of dairy cows (Ruegg and Carpenter, 1989; Berry et al., 2004; Dorshorst et al., 2006). Decision tree analysis is a graphical representation of decisions, probabilities, and events, displayed in a logical and time-sequenced manner (Berry et al., 2004). However, the use of decision tree analysis to evaluate the economic outcome of treatments used for mild and moderate cases of CM at the individual cow level has not been previously reported. The objective of this study was to develop a decision tree to evaluate the economic impact of different durations of intramammary treatment for the first case of mild or moderate clinical mastitis occurring in early lactation with various scenarios of pathogen distributions and use of on-farm culture.

MATERIALS AND METHODS

Overview of the Decision Tree Model

Decision tree analysis was performed using TreePlan (Decision Toolworks, San Francisco, CA). The analyses were determined at the cow level for both primiparous and multiparous cows that were experiencing a mild or moderate case of clinical mastitis in a single mammary gland quarter. Cases were assumed to occur at 30 DIM to simulate early lactation cases that would have the maximum potential effect on lactation and were the first case of CM occurring in the current lactation. Economic calculations were based on consequences of CM until the end of a 305-d lactation. Decisions were ordered to reflect the sequence of decisions made by dairy producers. Economic values and probabilities were derived from research literature and expert knowledge (in a few instances where research data was not available).

The decision tree (Figure 1) was constructed using (1) Decision nodes (represented by squares) with branches that represented strategies to be investigated and that were controllable (e.g., use of various OFC programs and use of various treatment durations). Estimated costs were assigned to each decision branch. (2) Probability nodes (represented by circles) with branches that represented uncontrollable events (e.g., distribution of pathogens causing CM, probability of bacteriological cure and probability of recurrence). Estimated probabilities and costs were assigned to each probability branch and summed to 100%. (3) Terminal nodes (represented by triangles) which summed the partial cash flows along a unique path leading to each terminal node.

Decisions Evaluated

Use of OFC. After detection of CM, 3 initial decisions were evaluated: (1) Use OFC and then wait 24 h before initiating treatment (**OFCW**). After detection of CM, an aseptic milk sample was collected for OFC. No treatment was initiated during the first 24 h but milk was discarded. After 24 h, treatment was initiated based on results of OFC. (2) Use OFC but begin treatment before results were known (**OFCT**). After detection of CM, an aseptic milk sample was collected for OFC. Intramammary (**IMM**) antimicrobial treatment was initiated immediately, but the treatment was adjusted based on results of OFC after 24 h. (3) Treat without OFC (**NOOFC**). Treatment was performed without diagnosis of causative pathogen.

Treatment Strategies. The secondary decision evaluated 4 treatment strategies (Figure 1). The strategies that included the use of IMM antimicrobial consisted of the same generic drug administered for different durations. Milk was assumed to be discarded for 3 d after the final treatment. When the initial decision was OFCW or NOOFC the treatment decisions were (1) do not treat the cow with antimicrobials (**NOT**); (2) use IMM antimicrobial treatment for 2 d (**2DT**); (3) use IMM antimicrobial treatment for 5 d (**5DT**); or (4) use IMM antimicrobial treatment for 8 d (**8DT**). When the initial decision was OFCT, similar treatment decisions were used but in this case, because the IMM antimicrobial treatment had already been initiated, the options were to stop treatment (**STOP**) or to continue treatment for 1 (**C1DT**), 4 (**C4DT**), or 7 (**C7DT**) d. Treatment durations >2 d were considered extended-duration treatments.

Probability Events

Distribution of Etiologies. The baseline distribution of pathogens (scenario A) was based on Pinzón-Sánchez (2010) and represented the distribution of pathogens observed on typical large commercial dairy herds located in Wisconsin. Pathogens for scenario A were distributed as 2% *Staphylococcus aureus*, 19% environmental streptococci, 14% CNS, 24% *Escherichia coli*, 6% *Klebsiella* spp., and 35% no growth (Table 1). The underlying pathogen distributions were used to categorize the etiologies as gram-positive pathogens, gram-negative pathogens, or no growth (no pathogen recovered) to represent typical diagnoses used for OFC. Gram-positive pathogens included *Staph. aureus*, environmental streptococci, and CNS; gram-negative pathogens included *E. coli* and *Klebsiella* spp. It was assumed that the diagnosis obtained by using OFC was 100%

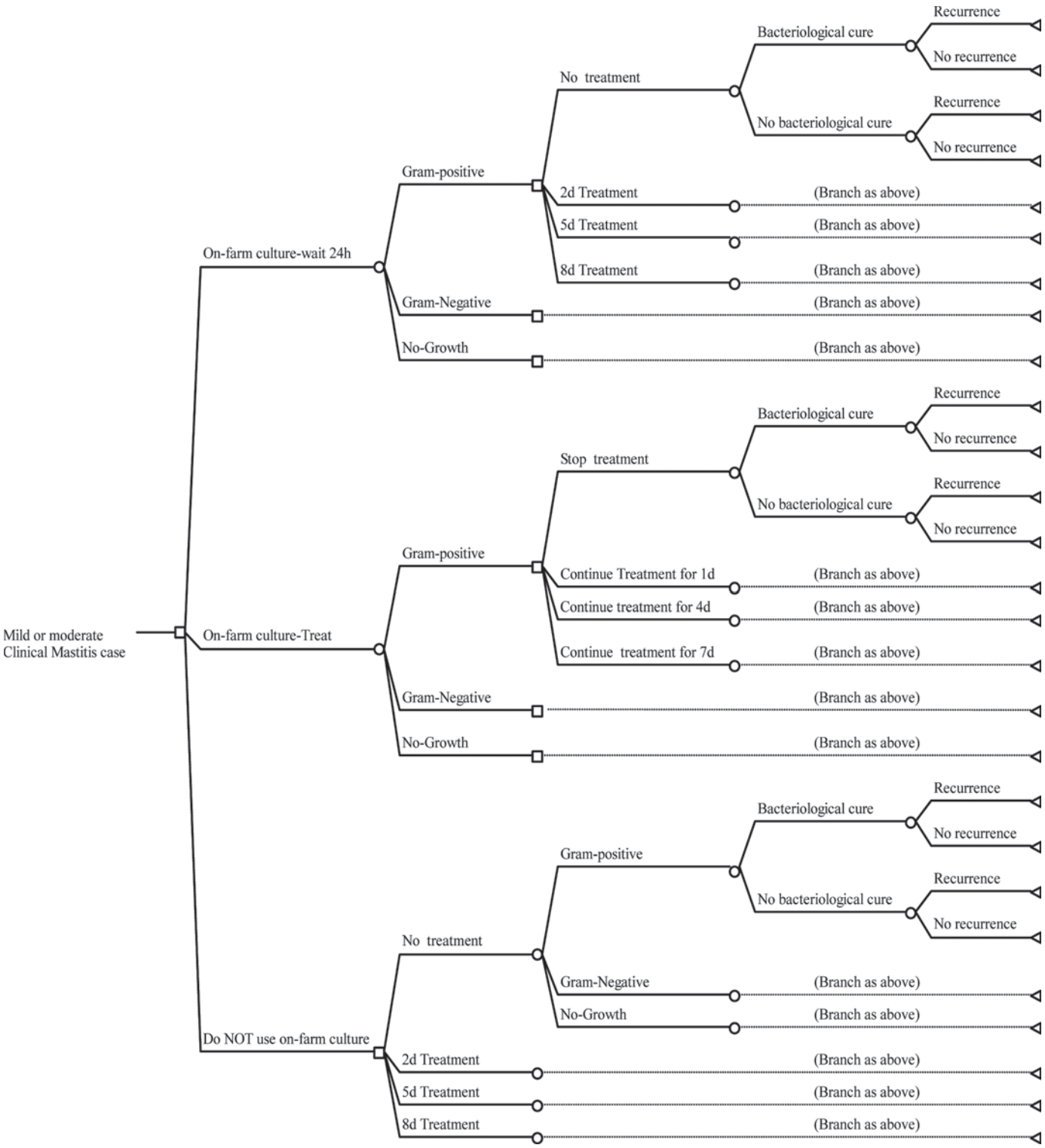

Figure 1. Simplified structure of the decision tree. Decision nodes are represented by squares with branches that represent strategies. Probabilities nodes are represented by circles with branches that represent probability events. Terminal nodes are represented by triangles.

Table 1. Distribution of pathogens for scenarios A (baseline), B (greater prevalence of *Staphylococcus aureus*), and C (greater prevalence of coliform organisms)

	Scenario		
Etiology of clinical mastitis (%)	A (baseline scenario)	B (greater contagious)	C (greater coliforms)
Gram-positive	0.35	0.70	0.15
Staph. aureus	0.02	0.40	0.01
Environmental streptococci	0.19	0.24	0.10
CNS	0.14	0.06	0.04
Gram-negative	0.30	0.15	0.70
Escherichia coli	0.24	0.10	0.60
Klebsiella spp.	0.06	0.05	0.10
No growth	0.35	0.15	0.15

accurate even though Lago (2009) determined that OFC was approximately 80% accurate. It is unlikely that this assumption affected the results of this study because savings attributable to OFC are a result of no treatment administered to gram-negative or no-growth cases, and the error (20%) would have been equally distributed between gram-positive and gram-negative pathogens. For OFCW and OFCT, each decision node was followed by a probability node with 3 branches (gram-positive, gram-negative, or no growth; Figure 1); NOOFC was followed by a decision about treatment strategy (Figure 1). In this branch, the same distribution of pathogens was modeled but treatment was not based on diagnosis of pathogen.

Probability of Bacteriological Cure. Probabilities of bacteriological cure (Table 2) were estimated based on previous research (Smith et al., 1985; Morin et al., 1998; Pyörälä and Pyörälä, 1998; Wilson et al., 1999; Gillespie et al., 2002; Oliver et al., 2004b; Roberson et al., 2004; Deluyker et al., 2005; Hoe and Ruegg, 2005; McDougall et al., 2007; Bradley and Green, 2009; Suojala et al., 2010; van den Borne et al., 2010). The probability of bacteriological cure was estimated for primiparous cows based on treatment strategy and etiology and it was assumed that the probability of bacteriological cure for multiparous cows was always 5% less (Table 2). Because no differences in posttreatment outcomes were reported by Lago (2009), the same probabilities of bacteriological cure were used for cows treated with antimicrobial immediately after detection of CM and those treated 24 h later. The probability of bacteriological cure was estimated by pathogen; thus, weighted averages based on the distribution of pathogens were calculated to determine the overall bacteriological cure for the categorical outcomes of gram-positive and gram-negative pathogens (Table 3).

Probability of Recurrence. The probability of experiencing recurrent cases of CM was estimated based on data collected from 4 commercial dairy herds and varied with the occurrence of bacteriological cure (Pinzón-Sánchez, 2010). For primiparous cows, the probability of recurrence was assumed to be 2% for cases that resulted in bacteriological cure or 25% for cases that experienced persistent infection (no bacteriological cure). For multiparous cows, the probability of recurrence was assumed to be 12% for cases that resulted in bacteriological cure or 35% for cows that experienced persistent infection. Recurrent cases were assumed to have the same etiology and same severity as the first case. All recurrences were assumed to receive 5 d of treatment with a total milk discard of 8 d. The first recurrent case (second case of CM) was assumed to occur 30 d (60 DIM) after the occurrence of the initial CM case. For the first recurrent case, the probabilities of bacteriological cure and recurrence were the same as those assumed for the first case of CM. The second recurrence (third case of CM) was assumed to occur 30 d (90 DIM) after the first recurrent case.

Economic Consequences of Mastitis

The economic consequences of mastitis included costs of diagnosis (OFC), treatment, labor, discarded milk, milk production losses due to clinical and subclinical mastitis, culling, and transmission of infection to other cows (only for CM caused by *Staph. aureus*). Milk production losses included milk loss due to CM, discarded milk, and milk loss due to subclinical mastitis. To allocate milk production losses after occurrence of CM (30 to 305 DIM), the daily potential milk production of a cow (primiparous or multiparous cows) was calculated based on typical lactation curves for Wisconsin dairy cows (Cabrera, 2010). Total potential milk yield from 30 to 305 DIM was estimated to be 9,670 kg and 11,188 kg for primiparous and multiparous cows, respectively. The average US milk price between 2008 and 2009 of \$0.33/kg was used as the baseline (USDA, 2010). Thus, potential income from milk production for stud-

Table 2. Estimated probabilities of bacteriological cure by pathogen and duration of intramammary treatment used for treatment of clinical mastitis occurring in primiparous and multiparous cows

Etiology of clinical mastitis	Treatment duration (d)	Bacteriological cure (%)		Source
		Primiparous	Multiparous	
Staphylococcus aureus	0	0.05	0.00	Gillespie et al., 2002; Deluyker et al., 2005; Oliver et al., 2004b
	2	0.15	0.10	
	5	0.25	0.20	
	8	0.40	0.35	
Environmental streptococci	0	0.30	0.25	Morin et al., 1998; Deluyker et al., 2005; Hoe and Ruegg, 2005; McDougall et al., 2007
	2	0.60	0.55	
	5	0.70	0.65	
	8	0.80	0.75	
CNS	0	0.60	0.55	Oliver et al., 2004b; Hoe and Ruegg, 2005; McDougall et al., 2007; van den Borne et al., 2010
	2	0.75	0.70	
	5	0.80	0.75	
	8	0.85	0.80	
Escherichia coli	0	0.80	0.75	Wilson et al., 1999; McDougall et al., 2007; Bradley and Green, 2009;
	2	0.90	0.85	van den Borne et al., 2010; Suojala et al., 2010.
	5	0.90	0.85	
	8	0.90	0.85	
Klebsiella spp.	0	0.40	0.35	Smith et al., 1985; Pyörälä and Pyörälä, 1998; Roberson et al., 2004; Hoe and Ruegg, 2005
	2	0.50	0.45	
	5	0.50	0.45	
	8	0.50	0.45	
No growth	0	0.95	0.90	Roberson et al., 2004; Pinzón-Sánchez, 2010.
	2	0.95	0.90	
	5	0.95	0.90	
	8	0.95	0.90	

Table 3. Weighted average of bacteriological cure for gram-positive, gram-negative, and no growth, based on distribution of pathogens used in the baseline (scenario A)

Etiology of clinical mastitis	Treatment duration (d)	Bacteriological cure (%)	
		Primiparous	Multiparous
Gram-positive[1]	0	0.41	0.36
	2	0.63	0.58
	5	0.71	0.66
	8	0.80	0.75
Gram-negative[2]	0	0.72	0.67
	2	0.82	0.77
	5	0.82	0.77
	8	0.82	0.77
No growth	0	0.95	0.90
	2	0.95	0.90
	5	0.95	0.90
	8	0.95	0.90

[1]Included *Staphylococcus aureus*, environmental streptococci, and CNS.
[2]Included *Escherichia coli* and *Klebsiella* spp.

ied period was $3,191 and $3,692 for primiparous and multiparous cows, respectively. Farm labor was valued at $13.00/h (Table 4). No costs were included for veterinary labor because treatments of mild and moderate cases of CM are routinely performed by farm personnel rather than veterinarians.

Milk Production Losses Due To CM. After occurrence of CM and for the remainder of the lactation, pathogen-specific milk production losses were estimated for primiparous and multiparous cows based on Gröhn et al. (2004). Because milk losses were estimated by pathogen, weighted averages of milk yield losses were calculated for gram-positive and gram-negative pathogens, based on the modeled distribution of pathogens (Table 5). For primiparous cows, estimated milk losses from 30 to 305 DIM were 288 kg (gram-positive), 823 kg (gram-negative) and 1,017 kg (no growth) (Table 5). For multiparous cows, estimated milk losses from 30 to 305 DIM were 325 kg (gram-positive), 427 kg (gram-negative), and 166 kg (no growth) (Table 5).

Discarded Milk. To avoid double counting milk losses, corrected daily milk production was calculated. Daily milk losses due to CM by etiology were subtracted from potential daily milk production to obtain the corrected daily milk production. Daily corrected milk production was the amount of milk assumed to be discarded. When IMM antimicrobials were used, days of discarded milk were calculated as duration of the treatment plus withholding period (3 d). For cows not treated with IMM antimicrobials, losses due to discarded milk were assumed for 4 d (Lago, 2009; Pinzón-Sánchez, 2010). Days of discarded milk ranged from 4 to 11 d. Cost associated with days of discarded milk varied by duration of treatment, etiology category and DIM.

Milk Production Losses Due To Subclinical Mastitis. When cows experienced bacteriological cure, no additional losses attributable to subclinical mastitis were assumed. When cows did not experience bacteriological cure, milk loss was estimated to be 0.4 kg/d (primiparous) or 0.6 kg/d (multiparous) for every doubling of SCC >50,000 cells/mL (Seegers et al., 2003). The SCC of cows that did not experience bacteriological cure was assumed to be 800,000 cells/mL (Pinzón-

Table 4. Description of assumed costs (baseline) and minimum and maximum scenarios for the initial diagnostic or treatment decision

Description of costs	Baseline $	Minimum $	Maximum $
Milk price per kilogram	0.33	0.22	0.44
Farm labor per hour	13.00	8.00	18.00
Intramammary antimicrobial per tube	3.50	2.50	4.50
Total cost of intramammary treatment per day[1]	6.75	4.50	9.00
Culture plates	2.25	1.25	3.25
Disposable material[2]	0.50	0.50	0.50
Total cost of on-farm culture per culture[3]	6.00	3.75	8.25

[1]Includes 1 intramammary antimicrobial tube and labor (15 min); does not include discarded milk.
[2]Cost of disposable material was not changed for minimum and maximum scenarios.
[3]Includes microbiological media, disposable materials, and labor (15 min).

Table 5. Estimated effects of the first occurrence of pathogen-specific clinical mastitis on milk yield (kg) from 30 to 305 DIM by etiology of clinical mastitis under baseline pathogen prevalence using data from Gröhn et al. (2004)

Etiology of clinical mastitis	Difference in milk yield[1] (kg)	
	Primiparous cows	Multiparous cows
Gram-positive[2]	−288.42	−325.21
Staphylococcus aureus	−718.43	−558.53
Environmental streptococci	90.30	−596.80
CNS	−740.96	76.72
Gram-negative[2]	−823.11	−427.36
Escherichia coli	−670.09	−356.38
Klebsiella spp.	−1,435.19	−711.29
No growth	−1,016.78	−166.12

[1]Positive values indicate milk gain.

[2]Weighted average based on baseline pathogen distribution.

Sánchez, 2010), so milk production was decreased by 1.6 and 2.4 kg/cow per day for primiparous and multiparous cows, respectively. For CM caused by gram-positive bacteria, milk production losses were assumed to persist for the remainder of the lactation, whereas for CM caused by gram-negative bacteria or when no pathogen was recovered (no growth), milk production losses occurred for only 2 mo after occurrence of the case (de Haas et al., 2004). To avoid double counting milk loss, the reduction in milk production began after the end of the milk withholding period. For primiparous cows that did not experience bacteriological cure, the average cost of milk loss due subclinical mastitis was \$141.47 (gram-positive), \$27.85 (gram-negative), and \$27.85 (no growth) (Table 6). For multiparous cows that did not experience bacteriological cure, the average cost of milk loss due subclinical mastitis was \$212.06 (gram-positive), \$41.78 (gram-negative), and \$41.78 (no growth) (Table 6). Because no additive effect is known, losses due to subclinical mastitis were assumed only for the first case of CM (no additional losses were assessed for recurrent cases).

Cost of Diagnosis and Initial Treatment. The cost of performing OFC was estimated to be \$6.00 and included microbiological media (\$2.25), disposable materials (\$0.50) such as swabs and gloves, and 15 min of labor (\$3.25) (Table 4). The fixed cost of purchasing an incubator was not included in cost of OFC because it was assumed that the OFC program was already established on the farm. Initial costs for OFCW included cost of OFC and 1 d of discarded milk, and were \$14.95 and \$18.85 for primiparous and multiparous cows, respectively. Initial costs for OFCT included cost of OFC, 1 d of discarded milk, and 1 d of IMM treatment and were \$21.70 and \$25.60 for primiparous and multiparous cows, respectively. Initial cost for NOOFC included only the cost associated with 1 d of discarded milk and was \$8.95 and \$12.85 for primiparous and multiparous cows, respectively.

Additional Treatment Costs. After the first day, the cost of each additional day of IMM treatment was assumed as \$6.75 and included 1 antimicrobial tube (\$3.50) and 15 min of labor (\$3.25) (Table 4). The total additional cost of each treatment strategy (beyond the first day) was calculated by adding the cost of each treatment strategy and the cost of milk discarded. The additional cost of not treating the cow with antimicrobials (or stopping the treatment after obtaining a pathogen diagnosis) ranged from \$25.39 to \$29.36 for primiparous cows and from \$32.89 to \$42.13 for multiparous cows (Table 7). The additional cost of treating the cow with antimicrobials for 2 d ranged from \$40.60 to \$62.43 for primiparous cows and from \$50.60 to \$83.71 for multiparous cows (Table 7). The additional cost of treating the cow with antimicrobials for 5 d ranged from \$86.79 to \$113.32 for primiparous cows and from \$104.01 to 146.92 for multiparous cows (Table 7). The additional cost of treating the cow with antimicrobials for 8 d ranged from \$133.96 to \$166.41 for primiparous cows and from \$164.70 to \$212.02 for multiparous cows (Table 7). For OFCW and OFCT, pathogen-specific costs of discarded milk were estimated using Gröhn et al. (2004). For NOOFC, the additional cost of milk discard was based on a weighted average depending on the distribution of pathogens included in each scenario.

Cost of Transmission of Staph. aureus. Cows infected with *Staph. aureus* that did not experience bacteriological cure were assumed to remain subclinically infected, and the potential transmission of contagious pathogens to herdmates was estimated. Similar to Swinkels et al. (2005b), non-bacteriologically-cured cows were assumed to remain infected for the remainder of the lactation (275 d), and each infected cow was

Table 6. Estimated cost of production loss ($) due to subclinical mastitis when cows did not experience bacteriological cure[1]

	Cost of production losses due to subclinical mastitis ($)			
	Primiparous		Multiparous	
Treatment	Gram-positive[2]	Gram-negative or no growth[3]	Gram-positive[2]	Gram-negative or no growth[3]
On-farm culture wait 24 h, base treatment on diagnostic result				
Do not treat, discard 3 d	143.09	29.57	214.63	44.35
Treat 2 d, discard 5 d	142.03	28.51	213.05	42.77
Treat 5 d, discard 8 d	140.45	26.93	210.67	40.39
Treat 8 d, discard 11 d	138.86	25.34	208.30	38.02
On-farm culture treat immediately, readjust therapy after diagnosis				
Stop treat, discard 3 d	143.09	29.57	214.63	44.35
Continue 1 d, discard 4 d	142.56	29.04	213.84	43.56
Continue 4 d, discard 7 d	140.98	27.46	211.46	41.18
Continue 7 d, discard 10 d	139.39	25.87	209.09	38.81
No use of on-farm culture				
Do not treat, discard 3 d	143.09	29.57	214.63	44.35
Treat 2 d, discard 4 d	142.56	29.04	213.84	43.56
Treat 5 d, discard 7 d	140.98	27.46	211.46	41.18
Treat 8 d, discard 10 d	139.39	25.87	209.09	38.81
Average milk loss cost	141.47	27.85	212.06	41.78

[1]SCC was assumed to be 800,000 cells/mL and milk production was assumed to decrease by 1.6 and 2.4 kg/cow per day for primiparous and multiparous cows, respectively (Seegers et al., 2003).

[2]For clinical mastitis caused by gram-positive bacteria, milk production losses were assumed to persist for the remainder of the lactation.

[3]For clinical mastitis caused by gram-negative bacteria or when no pathogen was recovered (no growth), milk production losses occurred for only 2 mo after occurrence of the case (de Haas et al., 2004).

Table 7. Additional partial cost ($) of treating a clinical mastitis case including labor, intramammary antimicrobial treatment, and discarded milk (costs from the first day were allocated to diagnosis and initial treatment costs)

	Partial cost of mastitis treatment ($)					
	Primiparous			Multiparous		
Treatment program[1]	Gram-positive	Gram-negative	No growth	Gram-positive	Gram-negative	No growth
On-farm culture wait 24 h, base treatment on diagnostic result						
Do not treat, discard 3 d	29.36	25.68	25.39	42.13	32.89	39.79
Treat 2 d	62.43	56.29	55.82	83.71	68.31	79.82
Treat 5 d	113.32	103.75	102.32	146.92	123.55	140.75
Treat 8 d	166.41	154.11	149.75	212.02	184.48	203.71
On-farm culture treat immediately, readjust therapy after diagnosis						
Stop treat, discard 3 d	29.36	25.68	25.39	42.13	32.89	39.79
Continue 1 d	45.89	40.98	40.60	62.92	50.60	59.81
Continue 4 d	96.04	87.46	86.79	125.57	104.01	120.13
Continue 7 d	148.87	137.56	133.96	190.42	164.70	182.84
	Weighted average[2]			Weighted average[2]		
No use of on-farm culture						
Do not treat, discard 3 d		26.86			38.54	
Treat 2 d		49.32			64.88	
Treat 5 d		96.98			123.95	
Treat 8 d		147.01			186.80	

[1]For all treatment programs, costs for 3-d milk discard are added when animals receive antimicrobials.

[2]Pathogen-specific milk yield loss weighted by the distribution of pathogens.

assumed to infect 0.25 additional cows. To calculate the cost of transmission, the cost of a treating a CM case for a standard 5-d treatment was multiplied by 0.25 and by the prevalence of *Staph. aureus*. The cost of transmission was then added to the total cost of recurrence.

Cost of Premature Culling. The cost of premature culling was based on Dorshorst et al. (2006). It was assumed that the culled animal was immediately replaced by a pregnant heifer with the same production level as the culled animal. The cost of a pregnant replacement heifer was $1,500. The probability that the replacement heifer delivered a female calf was 47%. The value of a male calf was $50 versus $250 for a female calf. Thus the weighted average value of a calf was $144. The estimated salvage value of a culled cow was $600. The total cost of culling (**TCC**) was calculated by subtracting the estimated salvage value and the value of the calf from the value of the replacement heifer (i.e., $1,500 – $144 – $600 = $756). Discounting was used to calculate the cost of culling relative to the expected productive life of a cow. The assumed culling rate in the herd was 30%. The expected number of months for a cow in the herd was calculated as 1 divided by cull rate, and multiplied by 12. Thus, the expected life (**ELM**) of a cow was 40 mo. Using a monthly interest rate (**IR**) of 0.05% (5% annual discount rate), the monthly cost of voluntary culling was estimated using the following equation:

$$\text{Monthly cost of culling} = \text{TCC} \Big/ \frac{1-\left(1+\text{IR}\right)^{-\text{ELM}}}{\text{IR}}.$$

The monthly cost of culling was $20.90; this value was charged to the month of early culling. For example, if a primiparous cow was culled at 60 DIM (2 mo in milk), 38 mo would be considered lost, resulting in premature culling cost of $794 (38 × $20.90). The premature cost of culling a multiparous cow was assumed for a second parity cow. The average calving interval was assumed to be 14 mo. For example, if a multiparous cow was culled at 90 DIM (3 mo in milk), 23 mo would be considered lost (i.e., 40 – 14 – 3 = 23), resulting in premature cost of culling of $480.70. In summary, the cost of culling was calculated by the difference in the value of replacement heifer by the value of salvage and offspring, discounted by month of early culling. The cost of culling was then the prorated monthly value multiplied by the number of months of early culling. For primiparous cows, the cost of premature culling was $794.20 and $773.30 for animals culled at 60 and 90 DIM, respectively. For multiparous cows, the cost of premature culling was $501.60 and $480.70 for animals culled at 60 and 90 DIM, respectively.

Cost of Losing a Mammary Gland Quarter. It was assumed that 10% of cows experiencing a recurrent case resulted in drying off of the infected mammary gland and a subsequent 15% decrease in milk yield for the remainder of the lactation. Milk production loss due to drying off the chronically infected mammary gland was adjusted by DIM.

Costs Due To Recurrence of Mastitis. The costs due to recurrent cases included the total cost of 5-d IMM treatment, potential loss of a mammary gland quarter, and potential transmission (for cases caused by *Staph. aureus*). For primiparous cows, assuming that for the first recurrence 95% of the cases were treated and 5% were culled, the average cost of the first recurrence was $192.22. For multiparous cows, assuming that for the first recurrence 90% of the cases were treated and 10% were culled, the average cost of the first recurrence was $231.91. For primiparous cows, assuming that for the second recurrence 10% of the cases were treated and 90% were culled, the average cost of the second recurrence was $44.86. For multiparous cows, assuming that for the second recurrence 5% of the cases were treated and 95% were culled, the average cost of the second recurrence was $74.75.

Analysis of Model Outcomes

Economic Losses. The decision tree had 144 terminal values that represented the sum of the partial cash flow (total costs) of each possible outcome. The proportional effect of CM on milk income was estimated by dividing each terminal value by the estimated total milk income that would have been generated if the cow did not experience CM.

Expected Monetary Values. The economically optimal path in the decision tree was calculated by comparison of expected monetary values (**EMV**). Expected monetary values were calculated using a process of "averaging out and folding back" and were the sums of the products of the monetary value of each outcome and the probability of that outcome occurring. The optimal treatment strategy was the option with the least negative EMV (i.e., minimum losses). In this model, EMV are negative and represent decrease in milk income; thus, an EMV of −$5 would be more optimal than −$10.

Sensitivity Analyses. Sensitivity analyses were performed using the minimum and maximum values of milk price, cost of farm labor, cost of antimicrobials, and cost of OFC under the baseline prevalence (scenario A; Table 4). Additional sensitivity analyses were performed by creating 2 additional scenarios with differing pathogen distributions. Scenario B was characterized by a greater prevalence of CM caused by

contagious pathogens (*Staph. aureus*), and scenario C was characterized by a greater prevalence of CM caused by coliforms (Table 1).

RESULTS

Economic Losses

Four situations were possible after treatment: (1) cow experienced bacteriological cure and CM did not recur, (2) cow experienced bacteriological cure but the CM did recur, (3) cow did not experience bacteriological cure and CM did not recur, or (4) cow did not experience bacteriological cure but the CM did recur. Proportionally, the least economic losses were observed for cows that experienced bacteriological cure and did not have recurrent cases of CM (best-case scenario) for primiparous cows (4–15% of potential milk income was decreased) and for multiparous cows (3–9% of potential milk income was decreased) (Table 8). The greatest proportion of losses was observed for cows that did not experience bacteriological cure and had recurrent cases of CM (worst-case scenario) for primiparous cows (17–23% of potential milk income was decreased) and multiparous cows (12–23% of potential milk income was decreased) (Table 8). The greatest difference between the best and worst case scenario was for CM caused by gram-positive pathogens (13–15%) compared with CM caused by gram-negative pathogens and no growth (7–9%) (Table 8).

EMV for Scenario A (Baseline Distribution of Pathogens)

For primiparous cows, the least negative overall EMV was for NOOFC (−$323.10), but the differences in overall EMV from the other 2 strategies were less than $2.26 per case of CM (Table 9). For multiparous cows, the least negative overall EMV was for OFCT (−$263.79) but the differences with the EMV from the other 2 strategies were less than $2.83 per case of CM (Table 9).

When the OFCW system was used and the etiology of CM was gram-positive, the treatment strategy with the least negative EMV was 2DT for primiparous cows (−$251.32) and multiparous cows (−$366.97) (Table 9). When the etiology of CM was gram-negative, the treatment strategy with the least negative EMV was NOT for both primiparous cows (−$340.12) and multiparous cows (−$266.35) cows (Table 9). Similarly, when the etiology of CM was no growth, the treatment strategy with the least negative EMV was NOT for primiparous cows (−$383.80) and multiparous cows (−$159.60) cows (Table 9).

When the OFCT system was used and the etiology of CM was gram-positive, the treatment strategy with the least negative EMV was C1DT for primiparous cows (−$241.73) and multiparous cows (−$353.25) cows (Table 9). When the etiology of CM was gram-negative, the treatment strategy with the least negative EMV was STOP for primiparous cows (−$346.87) and multiparous cows (−$273.10) (Table 9). Similarly, when the etiology of CM was no growth, the treatment strategy with the least negative EMV was STOP for primiparous cows (−$390.55) and multiparous cows (−$166.35) (Table 9).

When the NOOFC system was used, the etiology of CM was unknown, and the treatment strategy with the least negative EMV was NOT for primiparous cows (−$323.10) and 2DT for multiparous cows (−$266.62) (Table 9). For primiparous cows the EMV for the strategy 2DT was only $3.65 greater than the EMV for NOT.

For all OFC systems and all etiologies, a large difference was observed in EMV of extended treatments (5DT, 8DT, C4DT, and C7DT) compared with the least negative EMV (Table 9). For primiparous and multiparous cows the difference in EMV ranged from $33.50 to $163.28 greater for extended treatments (Table 9). When OFCW and OFCT were used, the greatest difference was observed for treating gram-negative and no growth for 8 d compared with not treating (Table 9).

EMV for Scenario B (Greater Prevalence of Staph. aureus)

For primiparous cows, the least negative overall EMV was for NOOFC (−$361.44) and the differences with the EMV from the other 2 strategies were less than $6.66 per case of CM (Table 9). For multiparous cows, the least overall EMV was for NOOFC (−$420.57), and the differences with the EMV from the other 2 strategies were less than $9.09 per case of CM (Table 9).

When the OFCW system was used and the etiology of CM was gram-positive, the treatment strategy with the least negative EMV was 2DT for primiparous cows (−$362.53) and multiparous cows (−$517.49) (Table 9). When the etiology of CM was gram-negative, the treatment strategy with the least negative EMV was NOT for primiparous cows (−$378.58) and multiparous cows (−$289.61) (Table 9). Similarly, when the etiology of CM was no growth, the treatment strategy with the least negative EMV was NOT for primiparous cows (−$383.80) and multiparous cows (−$159.60) (Table 9).

When the OFCT system was used, and the etiology of CM was gram-positive, the treatment strategy with the least negative EMV was C1DT for primiparous cows

Table 8. Percentage of milk income lost due to clinical mastitis for remainder of lactation (30–305 DIM) relative to potential income of $3,191 (primiparous cows) and $3,692 (multiparous cows)

			Primiparous cows (%)				Multiparous cows (%)			
			Bact. cure		No bact. cure		Bact. cure		No bact. cure	
On-farm culture system	Etiology	Treatment strategy	No recur	Recur	No recur	Recur	No recur	Recur	No recur	Recur
OFCW[1]	Gram-positive	Do not treat	4.4	8.9	12.3	17.0	4.6	10.4	13.1	19.0
		Treat 2 d	5.4	9.9	13.4	18.0	5.7	11.5	14.2	20.1
		Treat 5 d	7.0	11.4	15.0	19.5	7.4	13.1	15.9	21.8
		Treat 8 d	8.7	13.0	16.6	21.1	9.2	14.8	17.7	23.5
	Gram-negative	Do not treat	9.8	10.7	17.1	18.0	5.2	6.4	13.4	14.6
		Treat 2 d	10.8	11.6	18.0	18.9	6.2	7.3	14.3	15.5
		Treat 5 d	12.2	13.1	19.5	20.4	7.7	8.8	15.8	16.9
		Treat 8 d	13.8	14.6	21.1	21.9	9.3	10.4	17.5	18.5
	No growth	Do not treat	11.8	12.7	18.2	19.1	3.1	4.3	11.0	12.2
		Treat 2 d	12.7	13.6	19.1	20.0	4.2	5.3	12.1	13.2
		Treat 5 d	14.2	15.0	20.6	21.5	5.8	6.9	13.7	14.8
		Treat 8 d	15.7	16.5	22.1	22.9	7.5	8.5	15.4	16.4
OFCT[2]	Gram-positive	Do not treat	4.6	9.1	12.5	17.2	4.7	10.6	13.3	19.2
		Treat 2 d	5.1	9.6	13.1	17.7	5.3	11.1	13.8	19.7
		Treat 5 d	6.7	11.1	14.6	19.2	7.0	12.7	15.5	21.4
		Treat 8 d	8.3	12.7	16.3	20.8	8.8	14.4	17.3	23.1
	Gram-negative	Do not treat	10.0	10.9	17.3	18.2	5.4	6.6	13.6	14.8
		Treat 2 d	10.5	11.4	17.8	18.7	5.9	7.1	14.0	15.2
		Treat 5 d	11.9	12.8	19.2	20.1	7.3	8.5	15.5	16.6
		Treat 8 d	13.5	14.3	20.8	21.6	9.0	10.0	17.1	18.2
	No growth	Do not treat	12.0	12.9	18.4	19.3	3.3	4.5	11.2	12.4
		Treat 2 d	12.5	13.4	18.9	19.8	3.8	5.0	11.7	12.9
		Treat 5 d	13.9	14.8	20.3	21.2	5.4	6.6	13.3	14.5
		Treat 8 d	15.4	16.2	21.8	22.6	7.1	8.2	15.0	16.1
NOOFC[3]	Gram-positive	Do not treat	4.1	8.6	12.1	16.7	4.3	10.1	12.8	18.8
		Treat 2 d	4.8	9.3	12.8	17.4	5.0	10.8	13.5	19.5
		Treat 5 d	6.3	10.7	14.3	18.8	6.6	12.3	15.1	21.0
		Treat 8 d	7.9	12.2	15.8	20.3	8.3	14.0	16.8	22.6
	Gram-negative	Do not treat	9.6	10.6	16.9	17.8	5.2	6.4	13.4	14.6
		Treat 2 d	10.3	11.3	17.6	18.5	5.9	7.1	14.1	15.3
		Treat 5 d	11.8	12.7	19.1	20.0	7.5	8.6	15.7	16.8
		Treat 8 d	13.4	14.2	20.7	21.5	9.2	10.3	17.4	18.4
	No growth	Do not treat	11.6	12.6	18.1	19.0	2.9	4.1	10.8	12.0
		Treat 2 d	12.3	13.3	18.8	19.7	3.6	4.8	11.5	12.7
		Treat 5 d	13.8	14.7	20.3	21.1	5.2	6.3	13.1	14.2
		Treat 8 d	15.4	16.2	21.8	22.6	6.9	7.9	14.8	15.8

[1]Use on-farm culture and wait 24 h for microbiology results to base treatment on diagnosis.
[2]Use on-farm culture and treat immediately, then after 24 h, the treatment is readjusted based on diagnosis.
[3]Do not use on-farm culture.

(−$354.00) and multiparous cows (−$504.59) (Table 9). When the etiology of CM was gram-negative, the treatment strategy with the least negative EMV was STOP for primiparous cows (−$385.33) and multiparous cows (−$296.36) (Table 9). Similarly, when the etiology of CM was no growth, the treatment strategy with the least negative EMV was STOP for primiparous cows (−$390.35) and multiparous cows (−$166.57) (Table 9).

When the NOOFC system was used, the etiology of CM was unknown, and the treatment strategy with the least negative EMV was 2DT for primiparous cows (−$361.44) and multiparous cows (−$420.57) (Table 9).

For all OFC systems and all etiologies, a large difference was observed for EMV of extended treatments (5DT, 8DT, C4DT, and C7DT) compared with the least negative EMV (Table 9). For primiparous cows the difference ranges from $26.58 to $124.15 greater for extended treatments (Table 9). The largest difference was observed for treating no growth for 8 d when using OFCW system (EMV = −$507.75) (Table 9).

EMV for Scenario C (Greater Prevalence of Coliforms)

For primiparous cows, the least negative overall EMV was for NOOFC (−$313.89) and the differences with

Table 9. Expected monetary values (EMV) of different treatment strategies for baseline prevalence (scenario A), high prevalence of contagious pathogens (scenario B), and high prevalence of coliforms (scenario C)[1]

On-farm culture (OFC) system	OFC result	Treatment	Primiparous cows ($)			Multiparous cows ($)		
			A	B	C	A	B	C
OFCW[2]		Overall EMV[3]	−324.33	−368.10	−317.27	−264.20	−429.66	−262.67
	Gram-positive	Do not treat	−264.94	−369.16	−239.86	−392.01	−529.95	−431.76
		Treat 2 d	**−251.32**	**−362.53**	**−222.40**	**−366.97**	**−517.49**	**−401.01**
		Treat 5 d	−285.65	−389.11	−255.31	−406.42	−549.08	−437.79
		Treat 8 d	−321.85	−411.59	−289.98	−447.33	−574.95	−475.95
	Gram-negative	Do not treat	**−340.12**	**−378.58**	**−323.39**	**−266.35**	**−289.61**	**−255.35**
		Treat 2 d	−362.25	−400.41	−345.65	−290.05	−313.41	−279.02
		Treat 5 d	−409.42	−447.41	−392.89	−344.75	−368.22	−333.66
		Treat 8 d	−459.50	−497.44	−442.99	−405.13	−428.25	−394.20
	No growth	Do not treat	**−383.80**	**−383.60**	**−383.59**	**−159.60**	**−159.82**	**−158.44**
		Treat 2 d	−414.18	−413.98	−413.97	−199.47	−199.69	−198.31
		Treat 5 d	−460.60	−460.40	−460.39	−260.16	−260.38	−259.00
		Treat 8 d	−507.95	−507.75	−507.74	−322.88	−323.10	−321.72
OFCT[4]		Overall EMV	−325.36	−364.15	−321.57	−263.79	−422.65	−266.39
	Gram-positive	Stop treat	−271.69	−375.91	−246.61	−398.76	−536.70	−438.51
		Continue 1 d	**−241.73**	**−354.00**	**−212.81**	**−353.25**	**−504.59**	**−387.56**
		Continue 4 d	−275.27	−379.99	−244.94	−392.08	−535.45	−423.71
		Continue 7 d	−311.17	−402.15	−279.31	−432.68	−560.98	−461.55
	Gram-negative	Stop treat	**−346.87**	**−385.33**	**−330.14**	**−273.10**	**−296.36**	**−262.10**
		Continue 1 d	−353.79	−392.02	−337.16	−279.27	−302.53	−268.28
		Continue 4 d	−399.97	−437.99	−383.44	−332.14	−355.68	−321.02
		Continue 7 d	−449.80	−487.77	−433.28	−392.28	−415.46	−381.32
	No growth	Stop treat	**−390.55**	**−390.35**	**−390.34**	**−166.35**	**−166.57**	**−165.19**
		Continue 1 d	−405.74	−405.54	−405.53	−186.28	−186.50	−185.13
		Continue 4 d	−451.85	−451.65	−451.64	−246.37	−246.59	−245.21
		Continue 7 d	−498.94	−498.74	−498.73	−308.84	−309.06	−307.69
NOOFC[5]		Overall EMV	−323.10	−361.44	−313.89	−266.62	−420.57	−261.28
		Do not treat	**−323.10**	−366.74	**−313.89**	−266.97	−432.38	**−261.28**
		Treat 2 d	−326.75	**−361.44**	−322.76	**−266.62**	**−420.57**	−267.70
		Treat 5 d	−368.48	−393.44	−366.89	−317.10	−459.16	−319.05
		Treat 8 d	−412.48	−423.48	−414.00	−371.22	−495.36	−376.31

[1]Least negative EMV is shown in bold.

[2]Use OFC and wait 24 h for microbiology results to base treatment on diagnosis.

[3]Overall EMV = expected monetary value for decision 1 (use of OFC system).

[4]Use OFC and treat immediately, then after 24 h, the treatment is readjusted based on diagnosis.

[5]Do not use OFC.

the EMV from the other 2 strategies were less than $7.68 per CM case (Table 9). For multiparous cows, the least overall EMV was for NOOFC (−$261.28), and the differences with the EMV from the other 2 strategies were less than $5.11 per CM case (Table 9).

When the OFCW system was used and the etiology of CM was gram-positive, the treatment strategy with the least negative EMV was 2DT for primiparous cows (−$222.40) and multiparous cows (−$401.01) (Table 9). When the etiology of CM was gram-negative, the treatment strategy with the least negative EMV was NOT for primiparous cows (−$323.39) and multiparous cows (−$255.35) (Table 9). Similarly, when the etiology of CM was no growth, the treatment strategy with the least negative EMV was NOT for primiparous cows (−$383.59) and multiparous cows (−$158.44) (Table 9).

When the OFCT system was used, and the etiology of CM was gram-positive, the treatment strategy with the least negative EMV was C1DT for primiparous cows (−$212.81) and multiparous cows (−$387.56) (Table 9). When the etiology of CM was gram-negative, the treatment strategy with the least negative EMV was STOP for primiparous cows (−$330.14) and multiparous cows (−$262.10) (Table 9). Similarly, when the etiology of CM was no growth, the treatment strategy with the least negative EMV was STOP for primiparous cows (−$390.34) and multiparous cows (−$165.19) (Table 9).

When the NOOFC system was used, the etiology of CM was unknown, and the treatment strategy with the least negative EMV was NOT for primiparous cows (−$313.89) and multiparous cows (−$261.28) (Table

9). However, for primiparous cows, the strategy 2DT had only $3.65 difference with the NOT strategy.

For all OFC systems and all etiologies, a large difference was observed for EMV of extended treatments (5DT, 8DT, C4DT, and C7DT) compared with the least negative EMV (Table 9). For primiparous cows the difference ranges from $32.91 to $124.15 greater for extended treatments (Table 9). The largest difference was observed for treating no growth for 8 d when using OFCW system (EMV = −$507.75) (Table 9).

Sensitivity Analysis

For both primiparous and multiparous cows, milk price had the greatest effect on the model cost of drug or cost of OFC, because minimal differences in EMV were observed for the extremes of the other variables when compared with EMV from the baseline scenario (Tables 10 and 11).

For primiparous and multiparous cows, the treatment strategies with the least negative EMV were consistently 2DT or C1DT for gram-positives, and NOT or STOP for gram-negatives and no growth, regardless of pathogen distribution.

For primiparous cows when NOOFC system was used, the least negative EMV was NOT (do not treat) regardless of variation in milk price, labor cost, cost of drug, or cost of OFC (Table 10). For multiparous cows when NOOFC system was used, the treatment strategy with the least negative EMV was 2DT except when the labor or drug costs were the maximum or milk price was the minimum value. In these situations, the least negative EMV was NOT (Table 11).

DISCUSSION

As farms increase in size, the herd-level economic impact of treatment decisions often becomes more relevant to farm managers compared with decision making for individual cows on smaller farms. Decision tree analysis is an approach to decision making based on combining scientific knowledge with economic considerations. Rather than simply evaluating clinical or bacteriological cure rates, the use of decision tree analysis at the cow level allowed the comparison of the economic effect of a variety of mastitis treatment strategies that are commonly used by dairy farmers in Wisconsin. The model is an attempt to define the economically optimal treatment strategy for generic treatment of CM while evaluating the benefits and cost of treatment. Although the use of OFC systems was included in this study, the objective was not to determine if use of OFC was economically optimal but to determine the most economically efficient treatment strategy under a variety of potential management situations. The tree included best possible assumptions of the costs and biological outcomes based on published field trial data and in some cases where reliable data was not available assumptions were based on conservative estimates of the authors. The decisions used in the tree were ordered to reflect the sequence of decisions made by dairy producers.

Clinical mastitis is a complex disease that involves different biological factors. Factors related to the cow such as parity, stage of lactation, number of mammary gland quarters infected, and previous history of clinical and subclinical mastitis are known to associated with treatment outcomes (Sol et al., 2000; Constable and Morin, 2003; Deluyker et al., 2005; Bradley and Green, 2009; Pinzón-Sánchez, 2010). The analysis was done separately for primiparous and multiparous cows because of the different shapes of their lactation curves and because parity is an important factor that is usually considered when making treatment decisions. The characteristics of the hypothetical cow were typical of cows that experience mild and moderate cases of clinical mastitis that are expected to result in relatively successful posttreatment outcomes. The modeled cow was relatively early in lactation with a single mammary gland quarter affected and without previous cases of CM. Cows that were experiencing severe cases of mastitis, were in very early or late stages of lactation, were affected with concurrent disease, or were affected with pathogens that are isolated only infrequently from cases of CM were not included in this model.

Most mastitis research has focused on outcomes of treatment of mastitis caused by contagious pathogens such as *Staph. aureus*. However, many modern dairy farms have successfully controlled mastitis caused by contagious pathogens, and the distribution of pathogens causing mastitis is often dominated by environmental pathogens (Makovec and Ruegg, 2003; Milne et al., 2005; Pinzón-Sánchez, 2010). Additionally, 20 to 40% of CM cases have been reported to yield no growth (Roberson et al., 2004; Hoe and Ruegg, 2005; Lago, 2009), probably because the cow's immune system has successfully eliminated the infection (Smith et al., 1985; Sears et al., 1993). The distribution of pathogens modeled in this study was typical of modern US dairy farms. The greater diversity of mastitis pathogens occurring on modern dairy farms has resulted in many farms adopting the use of OFC systems to better target treatments for specific diagnoses (Neeser et al., 2006). In some instances, (such as recovery of no pathogens from CM cases) antimicrobial treatments are not administered and in other instances the duration of treatment may be varied based on diagnosis. Most dairy farms that use OFC limit their diagnoses

Table 10. Results of sensitivity analysis for primiparous cows[1]

On-farm culture (OFC) system	Etiology	Treatment strategy	Baseline	Milk price/kg ($)		Labor cost/h ($)		Cost of drug ($)		OFC cost ($)	
				0.22	0.44	8.00	18.00	2.50	4.50	1.25	3.25
OFCW[2]		Overall EMV[3]	−324.33	−222.65	−426.01	−321.77	−326.89	−323.28	−325.38	−323.33	−325.33
	Gram-positive	Do not treat	−264.94	−185.36	−344.52	−262.75	−267.13	−264.19	−265.69	−263.94	−265.94
		Treat 2 d	**−251.32**	**−178.52**	**−324.13**	**−246.95**	**−255.70**	**−248.82**	**−253.83**	**−250.32**	**−252.32**
		Treat 5 d	−285.65	−207.36	−363.93	−277.63	−293.66	−280.23	−291.06	−284.65	−286.65
		Treat 8 d	−321.85	−237.43	−406.26	−310.19	−333.50	−313.52	−330.17	−320.85	−322.85
	Gram-negative	Do not treat	**−340.12**	**−231.91**	**−448.32**	**−338.36**	**−341.87**	**−339.71**	**−340.52**	**−339.12**	**−341.12**
		Treat 2 d	−362.25	−250.30	−474.20	−358.13	−366.37	−359.96	−364.54	−361.25	−363.25
		Treat 5 d	−409.42	−288.50	−530.34	−401.55	−417.29	−404.12	−414.71	−408.42	−410.42
		Treat 8 d	−459.50	−328.64	−590.36	−447.88	−471.11	−451.20	−467.79	−458.50	−460.50
	No growth	Do not treat	**−383.80**	**−258.84**	**−508.77**	**−382.37**	**−385.24**	**−383.65**	**−383.96**	**−382.80**	**−384.80**
		Treat 2 d	−414.18	−283.59	−544.77	−410.24	−418.12	−412.03	−416.33	−413.18	−415.18
		Treat 5 d	−460.60	−321.29	−599.92	−452.92	−468.29	−455.45	−465.75	−459.60	−461.60
		Treat 8 d	−507.95	−359.61	−656.29	−496.51	−519.39	−499.80	−516.10	−506.95	−508.95
OFCT[4]		Overall EMV	−325.36	−224.80	−425.92	−321.99	−328.73	−323.66	−327.06	−324.36	−326.36
	Gram-positive	Stop treat	−271.69	−192.11	−351.27	−268.25	−275.13	−269.94	−273.44	−270.69	−272.69
		Continue 1 d	**−241.73**	**−172.13**	**−311.34**	**−237.36**	**−246.11**	**−239.23**	**−244.23**	**−240.73**	**−242.73**
		Continue 4 d	−275.27	−200.44	−350.09	−267.25	−283.28	−269.86	−280.68	−274.27	−276.27
		Continue 7 d	−311.17	−230.31	−392.03	−299.52	−322.82	−302.85	−319.49	−310.17	−312.17
	Gram-negative	Stop treat	**−346.87**	**−238.66**	**−455.07**	**−343.86**	**−349.87**	**−345.46**	**−348.27**	**−345.87**	**−347.87**
		Continue 1 d	−353.79	−244.66	−462.91	−349.67	−357.90	−351.49	−356.08	−352.79	−354.79
		Continue 4 d	−399.97	−282.20	−517.74	−392.11	−407.84	−394.68	−405.27	−398.97	−400.97
		Continue 7 d	−449.80	−322.17	−577.42	−438.18	−461.41	−441.50	−458.09	−448.80	−450.80
	No growth	Stop treat	**−390.55**	**−265.59**	**−515.52**	**−387.87**	**−393.24**	**−389.40**	**−391.71**	**−389.55**	**−391.55**
		Continue 1 d	−405.74	−277.97	−533.52	−401.80	−409.68	−403.59	−407.89	−404.74	−406.74
		Continue 4 d	−451.85	−315.46	−588.24	−444.16	−459.54	−446.70	−457.00	−450.85	−452.85
		Continue 7 d	−498.94	−353.60	−644.28	−487.50	−510.38	−490.79	−507.09	−497.94	−499.94
NOOFC[5]		Overall EMV	−323.10	−219.04	−427.15	−322.55	−323.64	−322.66	−323.53	−323.10	−323.10
		Do not treat	**−323.10**	**−219.04**	**−427.15**	**−322.55**	**−323.64**	**−322.66**	**−323.53**	**−323.10**	**−323.10**
		Treat 2 d	−326.75	−224.93	−428.57	−323.86	−329.65	−324.44	−329.07	−326.75	−326.75
		Treat 5 d	−368.48	−259.23	−477.74	−361.88	−375.09	−363.20	−373.77	−368.48	−368.48
		Treat 8 d	−412.48	−295.02	−529.94	−402.16	−422.79	−404.22	−420.73	−412.48	−412.48

[1]Least negative expected monetary values (EMV) for each are shown in bold.

[2]Use OFC and wait 24 h for microbiology results to base treatment on diagnosis.

[3]Overall EMV = expected monetary value for decision 1 (use of OFC system).

[4]Use OFC and treat immediately, then after 24 h, the treatment is readjusted based on diagnosis.

[5]Do not use OFC.

Table 11. Results of sensitivity analysis for multiparous cows[1]

On-farm culture (OFC) system	Etiology	Treatment strategy	Baseline	Milk price/kg ($)		Labor cost/h ($)		Cost of drug ($)		OFC cost ($)	
				0.22	0.44	8.00	18.00	0.22	0.44	8.00	18.00
OFCW[2]		Overall EMV[3]	−264.20	−189.09	−339.32	−261.03	−267.38	−262.67	−265.74	−263.20	−265.20
	Gram-positive	Do not treat	−392.01	−277.82	−506.20	−389.23	−394.79	−390.79	−393.24	−391.01	−393.01
		Treat 2 d	**−366.97**	**−262.79**	**−471.15**	**−361.99**	**−371.95**	**−363.98**	**−369.95**	**−365.97**	**−367.97**
		Treat 5 d	−406.42	−294.84	−517.99	−397.79	−415.04	−400.52	−412.32	−405.42	−407.42
		Treat 8 d	−447.33	−327.84	−566.82	−435.06	−459.59	−438.52	−456.14	−446.33	−448.33
	Gram-negative	Do not treat	**−266.35**	**−189.48**	**−343.22**	**−263.99**	**−268.71**	**−265.46**	**−267.24**	**−265.35**	**−267.35**
		Treat 2 d	−290.05	−208.62	−371.49	−285.32	−294.78	−287.27	−292.84	−289.05	−291.05
		Treat 5 d	−344.75	−251.83	−437.66	−336.26	−353.23	−338.96	−350.53	−343.75	−345.75
		Treat 8 d	−405.13	−298.84	−511.42	−392.90	−417.36	−396.35	−413.91	−404.13	−406.13
	No growth	Do not treat	**−159.60**	**−115.05**	**−204.15**	**−157.54**	**−161.66**	**−158.95**	**−160.25**	**−158.60**	**−160.60**
		Treat 2 d	−199.47	−146.13	−252.81	−194.91	−204.03	−196.82	−202.12	−198.47	−200.47
		Treat 5 d	−260.16	−193.34	−326.98	−251.85	−268.47	−254.51	−265.81	−259.16	−261.16
		Treat 8 d	−322.88	−241.90	−403.85	−310.82	−334.94	−314.23	−331.53	−321.88	−323.88
OFCT[4]		Overall EMV	−263.79	−190.28	−337.31	−259.81	−267.78	−261.60	−265.98	−262.79	−264.79
	Gram-positive	Stop treat	−398.76	−284.57	−512.95	−394.73	−402.79	−396.54	−400.99	−397.76	−399.76
		Continue 1 d	**−353.25**	**−253.65**	**−452.86**	**−348.28**	**−358.23**	**−350.27**	**−356.24**	**−352.25**	**−354.25**
		Continue 4 d	−392.08	−285.29	−498.88	−383.46	−400.71	−386.18	−397.98	−391.08	−393.08
		Continue 7 d	−432.68	−318.07	−547.29	−420.42	−444.95	−423.87	−441.49	−431.68	−433.68
	Gram-negative	Stop treat	**−273.10**	**−196.23**	**−349.97**	**−269.49**	**−276.71**	**−271.21**	**−274.99**	**−272.10**	**−274.10**
		Continue 1 d	−279.27	−201.43	−357.11	−274.54	−284.00	−276.49	−282.06	−278.27	−280.27
		Continue 4 d	−332.14	−243.43	−420.85	−323.66	−340.62	−326.35	−337.92	−331.14	−333.14
		Continue 7 d	−392.28	−290.27	−494.29	−380.05	−404.51	−383.49	−401.06	−391.28	−393.28
	No growth	Stop treat	**−166.35**	**−121.80**	**−210.90**	**−163.04**	**−169.66**	**−164.70**	**−168.00**	**−165.35**	**−167.35**
		Continue 1 d	−186.28	−137.34	−235.23	−181.72	−190.84	−183.64	−188.93	−185.28	−187.28
		Continue 4 d	−246.37	−184.14	−308.59	−238.06	−254.68	−240.72	−252.01	−245.37	−247.37
		Continue 7 d	−308.84	−232.55	−385.14	−296.78	−320.90	−300.19	−317.49	−307.84	−309.84
NOOFC[5]		Overall EMV	−266.62	−188.35	−341.97	−263.11	−268.12	−263.81	−267.89	−266.62	−266.62
		Do not treat	−266.97	**−188.35**	−345.59	−265.82	**−268.12**	−266.05	**−267.89**	−266.97	−266.97
		Treat 2 d	**−266.62**	−191.28	**−341.97**	**−263.11**	−270.13	**−263.81**	−269.43	**−266.62**	**−266.62**
		Treat 5 d	−317.10	−231.33	−402.87	−309.88	−324.32	−311.32	−322.88	−317.10	−317.10
		Treat 8 d	−371.22	−273.80	−468.64	−360.28	−382.15	−362.47	−379.96	−371.22	−371.22

[1]Least negative expected monetary values (EMV) for each option are shown in bold.
[2]Use OFC and wait 24 h for microbiology results to base treatment on diagnosis.
[3]Overall EMV = expected monetary value for decision 1 (use of OFC system).
[4]Use OFC and treat immediately, then after 24 h, the treatment is readjusted based on diagnosis.
[5]Do not use OFC.

to categories such as gram-positive, gram-negative, or no growth; however, the decision tree included the underlying pathogen distribution within these categories to estimate bacteriological cure and production losses. The inclusion of this distribution enhanced the accuracy of the model, taking advantage of recent research describing pathogen-specific bacteriological cure and milk losses (de Haas et al., 2004; Gröhn et al., 2004; Oliver et al., 2004a,b).

Use of OFC programs is a simple and easy technique that, when used correctly, allows producers to identify the possible pathogen causing CM (Neeser et al., 2006; Lago, 2009). Many progressive dairy producers use OFC to determine etiology of CM case and develop selective treatments accordingly. When OFC is used, IMM antimicrobials are often administered to cows experiencing CM caused by gram-positive pathogens and in some instances IMM antimicrobials are not used for CM caused by gram-negative pathogens or when no pathogen is isolated (Lago, 2009). At least 2 different OFC programs are used by farmers (Neeser et al., 2006). The first program is to postpone initiation of treatment for 24 h until microbiological results from OFC are available (OFCW), which has been reported not to have adverse effects on outcomes of mild and moderate cases of CM (Lago, 2009). The second program is to start IMM antimicrobial treatment immediately after detection of CM but to adjust treatment based on microbiological results obtained from OFC after 24 h of incubation (OFCW). Although OFC is often used on larger farms, many farmers have not yet implemented the use of OFC and treatment of CM cases is done without knowledge of causative pathogen. For this reason NOOFC was included in the tree to reflect all possible options.

Using the assumptions that were included in this model, only small differences in overall EMV were observed among all OFC systems (OFCW, OFCT, NOOFC; Tables 9 to 11). Greater differences in EMV were observed based on duration of treatment and the overall differences among OFC systems were primarily a result of the model selecting shorter duration treatments (or no treatment) as the optimal economic pathway used to calculate overall EMV. In reality, the cost saving that occurs when OFC is used is generally associated with reduced milk discard due to fewer IMM antimicrobial treatments. In this model, those savings were not apparent because the model generally recommended no treatment or short-duration therapy. If a farm was using short-duration therapy (or no treatment) as the primary mastitis treatment strategy, this model indicates that OFC is not likely to result in additional economic benefits. In contrast, herds that routinely use extended-duration therapy without regard for pathogen diagnosis could incur considerable savings by adopting OFC. For example, a 1,000-cow dairy with a 40% incidence of CM and a distribution of pathogens similar to that in scenario A would experience 400 first cases of mastitis per year. If the standard treatment was 5 d of IMM antimicrobial without regard to diagnosis (NOOFC), the EMV (loss) for each case occurring in primiparous cows would be approximately $369 (from Table 9) or $147,600 per year (for 400 cases). In contrast, the overall EMV for each case treated using a strategy of OFCW would be $325 or $130,000 per year. In this instance, the use of OFC would result in approximately $18,000 in annual savings.

The treatment strategies used in the model reflect the reality of treatments used on many modern dairy farms. Varying durations of treatment and the inclusion no IMM treatment were based on common practices used in the United States. Most IMM antimicrobials commercially available in the United States are not labeled for treatment of gram-negative pathogens but the generic drug used in the model was assumed to be effective against both gram-negative and gram-positive pathogens, allowed for use for extended-duration therapy, and required 72 h of milk discard. These characteristics are similar to at least one popular IMM antimicrobial marketed in the United States.

Although bacteriological cures are not typically assessed on farms, the inclusion of this outcome in the model allowed us to estimate the economical consequences of CM. Greater probability of bacteriological cure was assumed for primiparous cows as compared with multiparous cows because researchers consistently report that greater parities are associated with a reduced probabilities of cure (Sol et al., 2000; Barkema et al., 2006). Several clinical trials have evaluated bacteriological cure after treatment of CM using different compounds and differing treatment durations. Research data describing bacteriological cure using similar antimicrobial compounds was not available for all the pathogens and all treatment durations included in the model. For this reason, assumptions of bacteriological cure were based on a logical combination of relevant clinical trials that used different active compounds and different durations, and in some instances, were used to assess bacteriological cure after treatment of subclinical mastitis cases (when data from appropriate studies of CM was not available).

With the exception of bacteriologically negative cases (no growth), cows receiving IMM antimicrobials were assumed to have greater bacteriological cure than cows not receiving antimicrobials (Oliver et al., 2004b; van den Borne et al., 2010). Most research of extended therapy used for treatment of CM described outcomes for mastitis caused by gram-positive pathogens (Oliver

et al., 2003, 2004a,b; Gillespie et al., 2002). For CM caused by gram-positive pathogens, the probability of bacteriological cure was assumed to increase with increased duration of treatment (Gillespie et al., 2002; Oliver et al., 2004b; Deluyker et al., 2005). Most IMM antimicrobials commercially available in the United States are not labeled for treatment of gram-negative pathogens, and for CM caused by gram-negative pathogens the probability of bacteriological cure was not influenced by treatment duration. Very little research has described outcomes for cases of CM that have not yielded bacterial growth (Roberson et al., 2004; Pinzón-Sánchez, 2010) and bacteriological cure was not increased with increased duration of treatment for this etiology. Similar or greater proportion of bacteriological cure has been reported for CM caused by *E. coli* treated without use of antimicrobials (Guterbock et al., 1993; Roberson et al., 2004). The greatest bacteriological cure was assumed for cows infected with *E. coli* (van den Borne et al., 2010) and when no pathogen was recovered (Roberson et al., 2004). The least bacteriological cure was assumed for cows infected with *Staph. aureus* (Gillespie et al., 2002; Oliver et al., 2004b).

The probability of recurrence have been reported to be around 20% (Hoe and Ruegg, 2005; Wenz et al., 2005; Pinzón-Sánchez, 2010) and is known to vary with parity. In this model the overall probability of recurrence was estimated as 13 and 23% for primiparous and multiparous cows, respectively. Some previous models used to estimate economic losses of CM did not assume recurrence of CM (Huijps et al., 2008) but this model included the potential occurrence of 2 additional cases of CM. Cows that did not experience bacteriological cure were more likely to experience recurrent cases (Wenz et al., 2005; Pinzón-Sánchez, 2010). Almost no data were found to estimate the probability of recurrence of CM by pathogen, so probability of recurrence was assumed equal for all pathogens. However, recurrence was driven by the probability of bacteriological cure and bacteriological cure was estimated based on etiology. The cost of recurrences (treatment, discarded milk, potential loss of a mammary gland quarter, and potential transmission of contagious pathogens) were similar for first and second recurrence. The overall cost of recurrence appears to be greater for the first recurrence (compared with the second) because the cost of the second recurrence is multiplied by a succession of probabilities (probabilities of cure, recurrence, and treatment). Some possible effects of mastitis were difficult to estimate because the research literature is insufficient. For example, no research was available to document the potential reduction in milk yield when a mammary gland quarter is selectively dried off. Our estimate of a 15% decrease in milk yield may be an overestimate. However, the effect of this assumption was very small because milk yield losses were approximately $40 to $50 and occurred only in 10% of recurrent cases.

Culling decisions are directly affected by diseases (such as clinical mastitis) that result in marked decreases in milk production (DeGraves and Fetrow, 1993; Gröhn et al., 2005; Hadley et al., 2006). Occurrence of previous cases of CM is associated with less probability of cure. Some larger US farms have an abundance of replacement animals and elect to aggressively cull cows that experience recurrent cases of mastitis. Culling most cows that experience a third case of CM during their current lactation is often referred to as the "three strikes and out" rule. This policy was included in this model to reflect current management practices.

Information about pathogen-specific losses attributable to CM is sparse and the estimates used in this model were the best available to estimate milk loss for cases of CM occurring on modern dairy farms. Pathogen-specific milk production losses were estimated based on research conducted by Gröhn et al. (2004). However, these estimates included CM cases of all severities and in various stages of lactation, in contrast to the mild and moderate cases occurring at 30 DIM evaluated in this model. Gröhn et al. (2004) reported milk yield losses for cases of treated mastitis in absence of reporting bacteriological cure so the effect of additional losses caused by subclinical mastitis are not differentiated. The largest estimated milk loss was for CM caused by *Klebsiella* spp., with losses of 1,435 kg for primiparous cows and 711 kg for multiparous cows. Estimated milk losses when CM was caused by *Staph. aureus* were 718 and 558 kg for primiparous and multiparous cows, respectively. Interestingly, Gröhn et al. (2004) reported that primiparous cows affected with CM caused by environmental streptococci produced an additional 90 kg of milk and multiparous cows affected with CM caused by CNS produced an additional 76 kg of milk. Although these estimates are unusual and may reflect characteristics of the underlying herds included in that study, these estimates were used in the decision tree model. Based on the data provided by Gröhn et al. (2004), milk production losses due to CM were greater for primiparous cows than for multiparous cows. The primary reason for this outcome was the large difference (850 kg) in estimated losses for CM cases in which no pathogen was recovered. Gröhn et al. (2004) reported that primiparous cows affected with CM that were diagnosed as no growth resulted in production losses of 1,017 kg in contrast to 166 kg of milk yield loss for multiparous cows. As explained by Gröhn et al. (2004), although losses for multiparous cows became

smaller by d 43 after diagnosis, losses for primiparous cows remained substantial for the remainder of the studied period. Other researchers have suggested that CM cases that yield no bacteria have similar characteristics as gram-negative bacterial infections (Morin et al., 1998).

Somatic cell counts >200,000 cells/mL are an indicator of subclinical infection and are associated with reduced milk production (Hortet and Seegers, 1998). The effects of subclinical mastitis were included in the calculations for this model for cases of CM that did not result in bacteriological cure. The effects of CM on lactation curves for SCC differ among pathogens (de Haas et al., 2002, 2004). As de Haas et al. (2002, 2004) reported that after a case of CM caused by *E. coli* or for culture-negative samples, SCC rapidly decreased. However, for cases of CM caused by *Staph. aureus* or environmental streptococci, SCC remained increased after the occurrence. Based on this information, 2 mo of milk losses due to subclinical mastitis were assumed for gram-negative pathogens and no growth results. Losses due to subclinical mastitis caused by gram-positive pathogens were assumed to persist for the remainder of the lactation.

The great economic impact of CM is well known and has been described previously (Seegers et al., 2003; Halasa et al., 2007; Bar et al., 2008). The largest proportion of economic losses caused by mastitis (reduction of milk production) is generally not evident, and economic losses are usually underestimated by farmers (Huijps et al., 2008). When assessing the direct economic impact of mastitis, costs (i.e., extra resource use) and losses (i.e., reduced revenues) should be aggregated (Seegers et al., 2003). This decision tree model used components to calculate economic losses attributable to mastitis similar to models developed by Huijps et al. (2008) at the farm level and Swinkels et al. (2005a,b) at the cow level. Although both of those models were developed for typical European conditions, this model is specific for US conditions. Inclusion of pathogen-specific estimations to calculate costs of CM is unique and likely improves the precision of the estimates of economic damage caused by CM compared with previous models. Although other studies have reported losses including milk loss due to CM, discarded milk, and due to subclinical mastitis (Shim et al., 2004; Huijps et al., 2008), this decision tree uniquely includes pathogen-specific milk losses. The decision tree included milk production losses due to clinical and subclinical mastitis, discarded milk, cost of drugs, diagnostic, labor, culling, and recurrences; these components are similar to previous studies (Seegers et al., 2003; Huijps et al., 2008). Economic losses from premiums not received by producer due to increased SCC in bulk tank were not included in the model because it was difficult to assign a herd-level value to an individual cow.

The cost per case of clinical mastitis varies widely among studies due to the inclusion of different costs and diverse objectives and populations studied. The total cost of CM in our model ranged from $106 to $867 and included costs of drugs, labor, discarded milk, milk losses due to clinical and subclinical mastitis, culling, and recurrences. For example, a CM case caused by a gram-positive pathogen treated for 2 d, and assuming that the cow did not experience bacteriological cure and recurred, would cost $743 distributed as diagnostic costs (2%), milk loss due to CM (14%), treatment cost (11%), milk loss due to subclinical mastitis (29%), and cost of recurrence (44%). Bar et al. (2008) estimated that average cost of a case of CM was $179 distributed as follows: drugs (11%), discarded milk (11%), labor (5%), milk yield losses (64%), and mortality (7%); however, cost of recurrence was not included. Rodrigues et al. (2005) calculated the partial cost of a case of CM for Wisconsin dairy herds participating in a milk quality program and reported that the average partial cost per case of CM was $91, distributed as discarded milk (60%), cost of treatments (21%), and cost of labor (19%). To make this data comparable to our model and including only the cost included by Rodrigues et al. (2005), the partial cost per case of mild and moderate CM in our model ranged from $25 (no IMM antimicrobial) to $212 (8-d extended treatment) per case depending on the treatment strategy. For example, a 2-d treatment when NOOFC was used was $50 per case for primiparous cows and included treatment cost (27%) and milk discarded (73%), and $60 per case for multiparous cows and included treatment cost (20%) and milk discarded (80%). It is important to note that discarded milk corresponds to the corrected daily milk yield used in our model, thus milk losses due to CM were already decreased.

Discarded milk usually accounts for a large proportion of economic losses attributable to CM (Seegers et al., 2003; Rodrigues et al., 2005; Halasa et al., 2007). The assumption of discarding milk for 4 d, when no antimicrobial was administered was based on the duration of days until the disappearance of clinical signs previously reported (Hoe and Ruegg, 2005; Lago, 2009; Pinzón-Sánchez, 2010). Our model assumed 1 d less of discarded milk when a cow was not treated with antimicrobials (4 d of milk discarded) compared with treatment with antimicrobial for 2d (5 d of milk discarded). When CM was caused by a gram-negative pathogen or no growth, the best treatment strategy was not to treat with antimicrobials. To reduce the loss from discarded

milk, the use of a quarter milker is sometimes recommended.

Extended-duration IMM therapy has been shown to result in increased bacteriological cures for mastitis caused by *Staph. aureus* and some environmental streptococci but the routine use of extended-duration therapy was not economically optimal under any circumstance evaluated in this study. Previous researchers have used partial budgeting to evaluate the economic effect of different treatment strategies for subclinical IMM infection caused by environmental streptococci or *Staph. aureus* (Swinkels et al., 2005a,b). Similar to the results reported herein, Swinkels et al. (2005a) concluded that extended treatment is not economically feasible because of the increased cost of antimicrobials and increased losses due to milk discard. The same authors (Swinkels et al., 2005b) reported that extended-duration treatment of subclinical mastitis caused by *Staph. aureus* was economically justified only in circumstances when the risk of transmission to other cows was great.

When CM is treated without knowledge of etiology, it is difficult to justify the routine use of extended-duration therapy for treatment of the first case of CM. Although the least overall economic loss was typically associated with either a no-treatment option or a 2-d course of therapy, the differences in EMV between no treatment and 2-d treatments were generally very small. Based on existing research, bacteriological cure rates were only marginally improved by 5 d of therapy relative to 2 d of therapy. These small increases (5–10%) in bacteriological cure were not sufficient to offset the larger losses attributable to more days of discarded milk. In light of the limited amount of pathogen-specific research and the uncertainty inherent in models, it is not prudent to conclude that no treatment is preferred but care should be taken to recommend extended-duration therapy only in circumstances where etiologies and clinical experience suggest that a beneficial economic effect will result.

Sensitivity analyses were performed to explore the effect of changes in selected inputs on important model outputs and to identify input variables with a strong effect on the model outputs. Milk price was the only input variable that influenced the model. When milk price was low, the EMV were less negative, indicating that the reduction in milk income was less compared with the baseline. Similarly, when milk price was high, EMV were more negative, indicating that the reduction in milk income was greater compared with the baseline.

CONCLUSIONS

A cow-level decision tree was developed to evaluate the economic impact of selected mastitis treatment strategies. Culture-based therapy allowed for the most judicious use of antimicrobials. For most scenarios, the results of the model suggested that the best strategy was to treat mastitis caused by gram-positive pathogens for 2 d and avoid use of antimicrobials for CM caused by gram-negative pathogens or when no pathogen was recovered. Use of extended therapy (5 or 8 d) resulted in the least EMV. Decision tree analysis is an effective method for determining the most economically optimal treatment strategy for commercial dairy herds and is a useful instructional tool to understand the complex interactions affecting the economics of treatment of CM. The biological assumptions of this model could be strengthened by field studies designed to better characterize posttreatment outcomes in dairy cows. Further study to extrapolate the model for cows with different DIM or with a previous history of clinical and subclinical mastitis is needed.

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