ESTIMATED ECONOMIC LOSSES DUE TO *NEOSPORA CANINUM* INFECTION IN DAIRY HERDS WITH AND WITHOUT A HISTORY OF *NEOSPORA CANINUM* ASSOCIATED ABORTION EPIDEMICS

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SUMMARY

In this study, direct economic losses due to *Neospora caninum* infection, based on actual data from *N. caninum* seropositive reference herds and from herds that experienced an *N. caninum*- associated abortion epidemic, were calculated using a stochastic model with random elements. The results demonstrated that 76% of seropositive reference herds had no economic losses, whereas in the remaining 24% of herds, the economic losses went up to maximally €2000 per year. In epidemic abortion herds, economic losses continued after the actual event of the abortion epidemic for at least two more years with average costs of €50 per animal per 2 years. In both herd situations, highest losses were related to premature culling of seropositive cows and to a lesser extent to the effects of abortion (extended calving interval and age of first calving).

INTRODUCTION

Infection with *Neospora caninum* is a major cause of reproductive failure in cattle in many countries (Dubey, 2003), causing potentially considerable economic losses (Chi et al., 2002; Hogeveen & Van der Heijden, 2003). In addition to abortion, effects of bovine neosporosis may include stillbirths and neonatal mortality, early foetal death and resorption manifested as return to service, increased time to conception, increased culling, reduced milk production and reduced value of breeding stock (Trees et al., 1999). There have been studies investigating the effect of *N. caninum* serostatus on culling (Thurmond & Hietala, 1996; Cramer et al., 2002; Tiwari et al., 2005), milk production (Thurmond et al., 1997; Hernandez et al., 2001; Hobson et al., 2002; Romero et al., 2005) and reproductive performance (Jensen et al., 1999; López-Gatius et al., 2005; Romero et al., 2005) in dairy cattle. The results of these studies showed that the effect of *N. caninum* infection is not the same in different situations.

In various countries, among which The Netherlands, control strategies are being promoted (Dijkstra et al., 2005). To the authors' knowledge, these control strategies are not supported by some form of cost-benefit calculations. However, two studies have estimated the production losses due to *N. caninum* (Chi et al., 2002; Hogeveen & Van der Heijden, 2003). These studies were based on a normative model for both the epidemiological effects of *N. caninum* and the

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economic consequences of these effects. Therefore, the objective of the present study was to determine the direct economic losses of *N. caninum* infection related to culling, reproduction performance and milk production based on actual data from randomly selected *N. caninum* seropositive herds and from herds that experienced an abortion epidemic associated with *N. caninum*.

MATERIALS AND METHODS

Selection of herds and testing of animals

From a group of 108 randomly selected Dutch dairy herds of a previous study (Bartels et al., 2006a), all *N. caninum* seropositive herds (N=83) were included in the present study as the 'reference group'. No specific information on *N. caninum* abortion occurrence was available. Another group of 17 dairy herds was included in the study as 'epidemic abortion group'. Owners of these herds had contacted the Animal Health Service (AHS) between April 1997 and November 2000 because of epidemic abortion outbreaks (Wouda et al., 1999). The first contact was between one month and one year after an abortion epidemic. Infection status for *N. caninum* was determined by detection of *N. caninum* antibodies using an AHS in-house ELISA-method (Wouda et al., 1998, Von Blumröder et al., 2004). The results of the ELISA-method were calculated as S/P ratio = {(optical density (OD) test sample - OD negative control)/(OD positive control - OD negative control)}. A cut-off S/P ratio of < 0.5 was defined as negative (N), an S/P ratio of 0.5-1.5 as low positive (LP), and an S/P ratio > 1.5 as high positive (HP).

Economic simulation model

A multi-process Monte Carlo stochastic simulation model was developed to estimate the economic losses of *N. caninum* infection and *N. caninum* associated abortions. The model was built in a spreadsheet (Microsoft Excel) with @Risk add-in software (Palisade Corporation, Newfield NY, USA). The basic process in the model is the animal (cow or pregnant heifer). For every iteration, each animal receives a number of characteristics (parity and with parity one or higher, milk production and calving interval) and a *N. caninum* infection status (Fig. 1). Depending on the *N. caninum* status, abortion might occur. Culling due to *N. caninum* might occur as a consequence of abortion or unrelated to abortion. The following direct economic losses were distinguished: premature culling, increased calving interval (for animals with a parity of one or higher), increased age at first calving (for pregnant heifers), additional inseminations, milk production losses and veterinary and diagnostic costs. Economic losses were calculated over a one-year period and three different herd infection states were distinguished: reference herds, herds in first the year following an abortion epidemic and herds in the second year following an abortion epidemic. Probabilities of events and consequences of events were dependent on the herd infection status. Within each iteration, multiple processes (animals) were run simultaneously to simulate a herd. Results of these individual processes were cumulated to determine the economic losses at the herd level.

Model input on cow characteristics and events

Based on data from the Dutch Dairy Cattle Improvement Organisation (NRS, Arnhem, The Netherlands), the milk production (kg per lactation) of a cow was based on a normal distribution with an average of 8,500 kg (sd 700 kg). The calving interval of a cow was based on a Pert distribution with a minimum, most likely and maximum value of 365, 400 and 450 days respectively. Based on the parity prevalence in the herds studied, parity of a cow had the following probability: parity 0 (pregnant heifer): 18%; parity 1: 25%, parity 2: 18%, parity 3: 14%, parity 4: 10%, parity 5: 6% and parity ≥ 5: 9%.

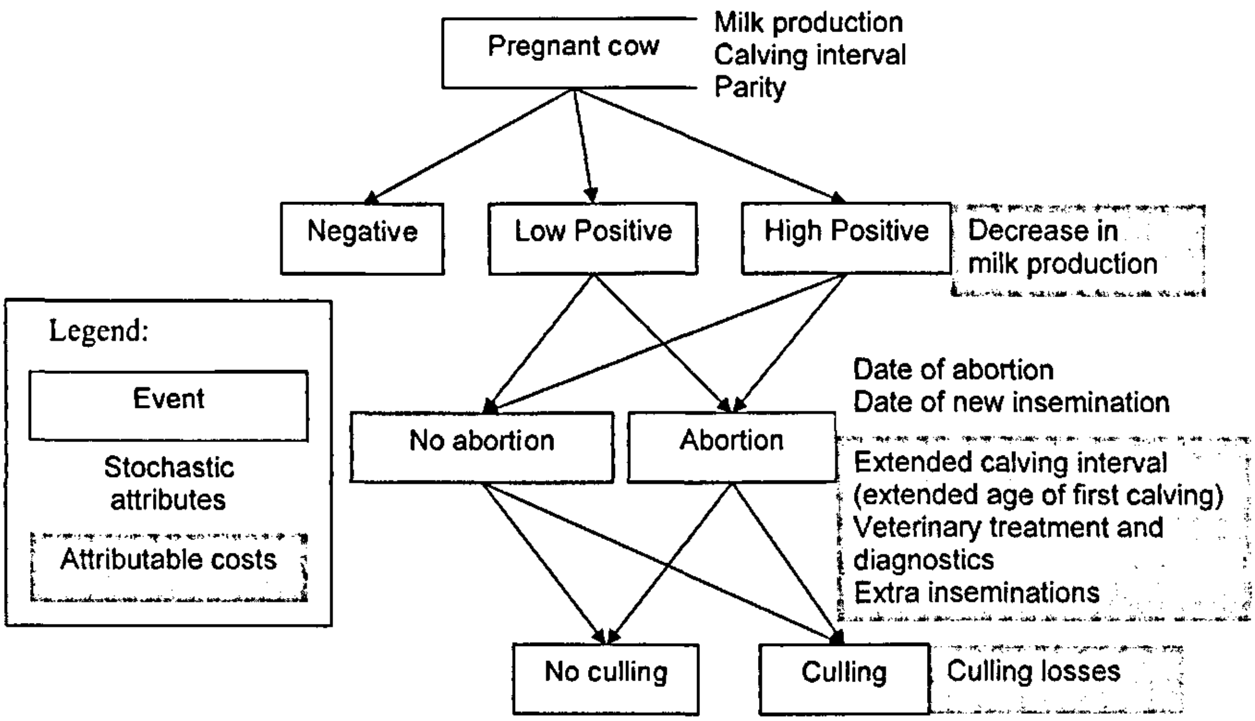

Fig. 1 Schematic overview of the stochastic model to estimate effects of *N. caninum* infection in Dutch dairy herds.

Events (Table 1) were modelled as discrete distributions and were based upon a previous study on the effects of *N. caninum* serostatus on culling, milk production and reproduction performance (Bartels et al., submitted). The prevalence of infection in reference herds (10.8%) was much lower than in epidemic abortion herds (47.0% and 34.4% in the 1st and 2nd year after abortion epidemic respectively). In reference herds, the proportion of HP cows was 40% of the seropositive cows, where as in epidemic abortion herds, HP cows consisted up to 75% of seropositive cows. In that study, significant effects of LP and HP animals compared to N animals were found for culling (all herd types), milk production (epidemic abortion herds in the 1st year after an abortion epidemic) and abortion (epidemic abortion herd types only). The effects of *N. caninum* have been quantified by relative measures such as hazard ratios for culling and odds ratios for abortion. However, the economic simulation model made use of probabilities of events occurring, given the cow status N, LP or HP. Using the model output, the simulation model probabilities have been calculated as follows. In reference herds, the culling data fitted a Cox Proportional Hazards model best. The base line hazard for culling (the probability of a N cow being culled on a particular day, given that it had not been culled up to that day) was multiplied by 365 to calculate the cumulative hazard for culling over a one-year period. Subsequently for HP cows, it was multiplied by the hazard ratio (1.6) found for HP cows. The hazard ratio for LP cows was not significant. In epidemic abortion herds, a parametric survival model with Weibull distribution and accelerated failure time fitted the data best. The cumulative hazards in the first and second year after the abortion epidemic were estimated by visual inspection of the cumulative hazard graph based on the model estimates ('cumhaz' after 'streg', STATA/SE 8.2). For abortion, the base line abortion rate for N cows was calculated using the constant, $\beta 0$, from the logistic regression model as:

$$\text{Prob (abortion | N cow)} = \frac{1}{1+e^{-\{\beta 0 + \beta j Xj + \beta j * serostatus)}} \quad (1)$$

where $\beta_j X_j$ accounted for the estimated effect of parity and production level and β_j* *serostatus* accounted for the effect of serostatus. For LP and HP cows, the estimated parameters for abortion in LP and HP cows were added to Eq. 1 to calculate abortion rate in LP and HP cows respectively.

Table 1. Probabilities (in percentages) of cow characteristics and events for different herd infection status (seropositive reference herds, herds 1 year after an abortion epidemic and herds 2 years after an abortion epidemic) and different serostatus (N = negative, LP = Low Positive and HP = High Positive), used as input data 'for the modelling of economic losses due to *N. caninum* in Dutch dairy herds.

Input data	Category	Serostatus	Herd infection status		
			Reference	Epidemic abortion 1st year	Epidemic abortion 2nd year
Within herd prevalence		N	89.2	53.0	65.6
		LP	6.2	14.0	8.7
		HP	4.6	33.0	25.7
Culling	Heifer	N	4.1	17.0	25.0
		LP	4.1*	25.1	27.7
		HP	4.1*	37.5	51.5
	Cow	N	24.0	5.1	12.8
		LP	24.0*	8.8	21.2
		HP	36.6	11.7	20.6
Abortion rate	Heifer	N	7.6	13.6	10.1
		LP + HP**	7.6*	26.9	16.0
	Cow	N	6.6	6.5	5.6
		LP + HP**	6.6*	14.2	9.1

* Probabilities for LP or HP were not statistically different from negative cows.

** Probabilities for LP and HP were not statistically different from one another.

Model input on economic consequences of N. caninum

Economical losses due to *N. caninum* caused by premature culling were estimated using a calculation of the retention pay-off. The retention pay-off is the difference in expected net revenue (in terms of present value) of the culled cow and a replacing heifer, corrected for the costs to buy or raise this replacing heifer. In the simulation model, different retention pay-off values were used based upon the production level and parity of the cow culled (Houben et al, 1994, updated for the Dutch market situation in 2004). Maximum retention pay-off was €1,332 for a cow in parity 3 with a relative production level of 120 % and the minimum retention pay-off was - €9 for a cow with a relative production level of 85 % and a parity of 3 or higher. The costs for culling of a pregnant heifer were estimated to be €1,000 (normative; based upon the costs to raise a heifer). If a cow aborted and was not culled afterwards, abortion would result in a longer calving interval. This extension of the calving interval was estimated based on the simulated abortion date plus the number of days to a next simulated conception plus the duration of a full pregnancy. Results of Jalvingh and Dijkhuizen (1997, updated for Dutch market circumstances) were used to calculate the economic consequences of a non-optimal calving interval.

Table 2. Description of input variables used in the modelling of the economic losses due to *N. caninum* in Dutch dairy herds.

Variable	Distribution	Values	Reference
Costs for replacement of a culled cow (€)	constant	Retention pay-off	Houben et al., 1994, values updated for 2004.
Costs for replacement of a heifer (€)	constant	1000	Expert opinion
Stage of gestation (days) at abortion	pert	128 (min 128-max 260)	Bartels et al., submitted
Number of extra inseminations after abortion (cow and heifer)	discrete	Prob(1 ins) = 0.1 Prob(2 ins) = 0.8 Prob (3 ins) = 0.1	Expert opinion
Days to new conception after abortion (cow)	pert	71 (min 3-max 105)	Expert opinion
Days to new conception after abortion (heifer)	constant	50	Expert opinion
Costs for extra days to next calving (€)	constant	Optimized calving pattern	Jalvingh and Dijkhuizen, 1997, values updated for 2004
Costs for extra day to 1st calving (€)	constant	1.50	Expert opinion
Costs for additional insemination (€)	constant	18	Expert opinion
Costs of decreased milk production (€/kg)	constant	Milk prod. loss * costs of decreased milk production	Marginal costs to have more cows on the farm
Costs of vet consult (€per hour)	constant	100	Royal Dutch Society for Veterinary Medicine
Costs of laboratory investigations € for serology, € for post mortem	constant	 10 75	Animal Health Service Ltd.

Depending on the length of the calving interval, the costs of an extended calving interval varied from €0.30 to €1.15 per day. The economic losses due to *N. caninum* abortion were calculated by subtracting the damage of the initial calving interval from the damage of the extended calving interval. For pregnant heifers, a similar approach was followed, except that the time from abortion to new conception was taken as a constant. The economic damage of an increased calving age of the heifer was set as a normative value of €1.50 per day. The number of additional inseminations could be one, two or three (discrete distribution). The cost of one additional insemination was set to €18.

An effect on milk production was only found in HP cows in the 1st year after an abortion epidemic (Bartels et al., submitted). Although the effect was significant, the production loss in terms of kg milk per cow was not high (-0.32 (95%CI: 0.01-0.63) kg milk/day for the first 100 days in milk) (data not presented) and rounded off to 1% decrease in production. The economic losses associated with decreased milk production, were calculated by multiplying the milk production losses with the costs of a decreased milk production. The latter costs (€0.07 per kg) were based upon the marginal costs of having more cows in order to fill the milk quota. It was assumed that there were no opportunity costs for additional labour and barn requirements and that the farmer had enough roughage available.

The costs for treatment, veterinary consult and laboratory investigation were based on a number of assumptions. As part of the monitoring of brucellosis-free status, Dutch farmers are obliged to test aborting animals serologically for brucellosis. Expenses for the veterinary visit and sampling of the cow are financed through a nationwide monitoring system. However, when 3 or more cows aborted, it was assumed that herdsmen wanted to have additional advice from the veterinarian (15 minutes at €100 per hour) on treatment and prevention with a likely outcome that more animals were tested and an aborted foetus was submitted for post mortem investigation.

Simulation and sensitivity analysis

Each simulation was run with 5,000 iterations with 65 simultaneous processes (simulating a herd seize of 65 animals). In a sensitivity analysis, baseline output resulting from default values was compared to output based on alternative values. For the sensitivity analysis, a farm in the 1st year after an abortion epidemic was used. The reason for this choice was that in this situation, most effects of *N. caninum* serostatus were incurred and this would provide the largest discriminating effect of the changed parameter. The following parameters were varied such that it was relevant for the Dutch situation: herd size (from 45 to 150 cows); probability of abortion in HP cows (increasing from 10 to 50% compared to LP cows); costs of culling a cow (from 50% to 150 % of the default costs) or a heifer (from 75 to 125% of the default costs); value of decreased milk production (from 170 to 210% of the default costs).

RESULTS

Reference herds with 65 cows had on average 7 seropositive animals (90% CI: 3-11). The mean economic losses of *N. caninum* infection in seropositive dairy herds were €117 per year, as an effect of premature culling of HP cows. However, no economic losses were present on 76% of dairy herds whereas in 5% of situations the costs were €1000 or higher. These costs were applied when the culled animal was a heifer and all costs made to raise the heifer were lost (results not presented). In the situation of an epidemic abortion herd, the number of seropositive animals was on average 31 (90% CI: 24-37) in the first year after an abortion epidemic. Mean economic losses in the first year were €2,053 (90% CI: €454 - €4,174) (Table 3). The highest costs were related to premature culling of *N. caninum* seropositive animals (€1,485 (90% CI: €863 – €3,317)) and extended calving interval or increased age at first calving (combined €376 (90% CI: €0 - €1,175)). The economic losses for reduced milk production were considerably less with €105 (90% CI: €70 - €140) while costs for treatment and diagnostics (€49 (90% CI: €0 – €235)) and extra inseminations for aborted cows (€38 (90% CI: €0 - €105)) were minor. In the second year after an abortion year, the mean number of seropositive animals in a herd of 65 cows was 22 (95% CI: 16-28). There was no longer an effect of *N. caninum* infection on milk production and effects on culling and abortion were less than in the first year after an abortion epidemic. Consequently, economic losses were €1,216 (90% CI: €0 – €2,924) primarily based on costs due to premature culling of seropositive animals. Thus, in addition to the costs at the time of an abortion epidemic, the mean economic losses in the two consecutive years after an abortion epidemic amounted to €3,269 or €50 per animal in the herd. Premature culling of seropositive animals accounted for 78% of these costs, while the extended calving interval and age at 1st calving accounted for 16% of these costs. Reduced milk production (3%), treatment and diagnostics (2%) and extra inseminations (2%) contributed only little to the total costs.

Table 3. Economic losses (€) due to *N. caninum* infection in Dutch epidemic abortion herds in first and second year after an abortion epidemic.

	1st year after abortion epidemic			2nd year after abortion epidemic		
	5th percentile	Mean	95th percentile	5th percentile	Mean	95th percentile
Total	454	2,053	4,174	0	1,216	2,924
Premature culling	86	1,485	3,317	0	1,058	2,618
Extended calving interval	0	161	512	0	72	335
Extended age at 1st calving	0	215	663	0	63	334
Extra inseminations	0	38	105	0	16	60
Reduced milk production	0	104	140	0	0	0
Treatment and diagnoses	0	50	235	0	7	87

Sensitivity analysis

As a default, the herd consisted of 65 animals. When reducing or increasing the number of cows per herd, there was no effect on the average cost per animal. The 95% percentile costs reduced with increasing number of cattle in a herd (Table 4).

Table 4. Effects of changing base line input values on estimated economic losses due *N. caninum* infection in Dutch dairy herds in the first year after experiencing an abortion epidemic.

	Variation	Effect on mean	Effect on 95 percentile
Number of cows compared to	45	3%	+ 11%
65	105	No effect	-18%
Costs for culling compared to	-50%	-18%	-11%
default	+50%	+18%	+13%
Value of culled heifer	-25%	-8%	-13%
(compared to €1000)	+25%	+10%	+13%
Increasing abortion risk for	+10%	+1%	+2%
HP compared to LP cows	+20%	+4%	+4%
	+50%	+14%	+10%
Costs for reduced milk	+70%	+4%	+2%
production compared to	+115%	+6%	+3%
€0.07/kg milk			

The greatest effects on economic losses were found when different assumptions on prices for animals that had to be culled prematurely and replacement costs for replacing heifers were considered. When the abortion risk in HP animals was increased compared to LP animals then the economic losses increased maximally 14% in case of 50% increased abortion risk in HP animals. The effect of changing prices for reduced milk production was small because milk production loss was a minor effect.

DISCUSSION

The objective of this study was to calculate economic losses due to *N. caninum* infection in dairy herds with and without a history of *N. caninum* associated epidemic abortions. The results demonstrated that for 76% of seropositive reference herds, there were no economic losses due to *N. caninum* infection. In the remaining 24% of herds, the economic losses ran up to maximally €2000 in the exceptional situation that two seropositive heifers were culled prematurely. For epidemic abortion herds, the economic losses continued after the actual event of the abortion epidemic for at least two more years. These costs were on average €50 per animal per 2 years and were in addition to the losses at the time of to the abortion epidemic (premature culling, prolonged calving interval and age of 1st calving, milk production losses, treatment and diagnosis).

The economic losses were calculated using a stochastic model. This kind of model provides the possibility to account for naturally existing variation. In addition to a mean outcome value, stochastic modelling provides information about the variation around a mean value (Dijkhuizen & Morris, 1997). The input data for the stochastic model were taken from a study on the effect of *N. caninum* infection in Dutch dairy farms (Bartels et al., submitted). In this study the effect of *N. caninum* infection on culling, reproductive performance and milk production was quantified based on actual data from these farms. There was no effect found of *N. caninum* serostatus on abortion, contrary to the fact that *N. caninum* infection is primarily an abortifacient agent. It was argued that abortion events were underestimated because these events were defined by recorded calving and insemination dates and not by notification of expulsion of a calf foetus. Most likely this underestimation was 'compensated' by the fact that HP cows were culled shortly after an abortion.

Two other studies (Chi et al., 2002; Hogeveen & Van der Heijden, 2003) have looked into the economic losses due to *N. caninum* based on previous studies and expert opinion. Chi et al. estimated the direct production losses (premature voluntary culling, loss of milk yield from abortion and abortion) and treatment costs (veterinary services, medication cost and extra farm labour cost) of *N. caninum* infection in the Maritime provinces of Canada at $2,304 (€1,921) annually per 50 cow herd. They used a partial budget model adapted from a spreadsheet suggested by Bennett (1999). Highest costs were associated with abortion and included an assumed 28% loss in milk yield for each aborting cow (Bennett et al., 1999). Hogeveen and Van der Heijden (2003) had estimated the average annual direct costs at €249 with a maximum of €5,604 for a herd with 50 lactating cows. Their estimates were based on cataloguing the economic effects of neosporosis on partial budgeting while the physiological effects of infection were based on literature information. In comparison with the results from the current study, Hogeveen and Van der Heijden (2003) used 3.5% milk loss in a seropositive cow, a higher percentage of premature culling after abortion and a normative value (180 days) for the extended calving interval after abortion. In the present study, using actual data as input for stochastic models of different herd situations, estimated economic losses due to *N. caninum* infection were much smaller for the most common herd situation (i.e. seropositive herd with no history of an abortion epidemic).

The results of this study can be used as part of a cost benefit analysis on the control of *N. caninum* infection. Currently, control of *N. caninum* infection is focused on separating dogs from cattle, testing of aborting cows and keeping the within-herd seroprevalence low (Dijkstra et al., 2005). For the latter control measure, bulk milk testing has been evaluated (Bartels et al., 2005). In their study, Bartels et al. (2005) demonstrated that a negative bulk milk test result, for 85% of herds correctly predicted a within-herd seroprevalence below 15%. Regular testing of bulk milk might prove an useful monitoring tool, combining sampling ease with low costs for testing. A further study is needed to determine if the costs for regular bulk milk testing outweigh the potential economic losses in dairy herds. For herds experiencing an abortion epidemic, the results of the present study give better insight of the extent of direct costs following the abortion epidemic. For these farmers, knowledge of the potential economic losses will allow them to make better choices among various control options to reduce the effects of high seroprevalence in herds after an abortion epidemic (Dijkstra et al., 2005).

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