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Study of the economic impact of cryptosporidiosis in calves after implementing good practices to manage the disease on dairy farms in Belgium, France, and the Netherlands

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ABSTRACT

Cryptosporidium spp. are widespread parasitic protozoans causing enteric infections in humans and animals. The parasites cause neonatal diarrhoea in calves, leading to a high mortality rate in the first three weeks. Losses are significant for farmers, but the cost of cryptosporidiosis remains poorly documented. In the absence of a vaccine, only preventive measures are available to farmers to combat the infection. This study, conducted between 2018 and 2021, aimed to evaluate the economic impact of *Cryptosporidium* spp. on European dairy farms and monitor changes in costs after implementing disease management measures. First, a field survey was carried out and questionnaires administered to 57 farmers in Belgium, France, and the Netherlands. The aim of the survey was to assess the losses associated with the occurrence of diarrhoea in calves aged between 3 days and 3 weeks. The economic impact of diarrhoea was calculated based on mortality losses, health expenditures, and additional labour costs. To refine the cost estimation specifically for *Cryptosporidium* spp., stool samples were collected from 10 calves per farm. The prevalence of *Cryptosporidium* spp. was determined, and the economic impact of diarrhoea was adjusted accordingly. The assumption was made that a certain percentage of costs was attributed to cryptosporidiosis based on the prevalence. These protocols were repeated at the end of the study to observe changes in costs. In the three years, the cost of diarrhoea for the 28 farms that stayed in the panel all along the study improved from €140 in 2018 to €106 on average per diarrhoeic calf in 2021. With a stable prevalence at 40%, the cost of cryptosporidiosis per infected calf decreased from €60.62 to €45.91 in Belgium, from €43.83 to €32.14 in France, and from €58.24 to €39.48 in the Netherlands. This represented an average of €15 saved per infected calf. The methodology employed in this study did not allow us to conclude that the improvement is strictly due to the implementation of preventive measures. However, with 11 million calves raised in the Interreg 2 Seas area covered by the study, it provided valuable insights into the economic burden of *Cryptosporidium* spp.

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1. Introduction

Cryptosporidium spp. are parasitic protozoans prevalent worldwide that cause enteric infections (Widmer et al., 2020; Ebiyo and Haile, 2022). These parasites are considered to have the potential to infect a broad range of host species including mammals (Cama and Mathison, 2015). Indeed, *Cryptosporidium* infection is ubiquitous and has a high prevalence in animals and humans. In humans, it can have serious consequences for young children and immunocompromised or immunodeficient adults (Helmy and Hafez, 2022). In animals, cryptosporidiosis was first reported in cattle in the early 1970's (Panciera et al., 1971). In 2023, the disease remains the most frequently diagnosed cause of diarrhoea in pre-weaned calves in Great Britain (APHA/SCUC, 2022). A longitudinal study done in US farms showed that animals become infected by the first weeks of life (Santín et al., 2008). Young infected calves spread millions of parasites a day and show stunted growth (De Graaf et al., 1999). The disease is characterised by high morbidity leading to a higher mortality rate (Singh et al., 2006). The financial consequences of cryptosporidiosis are dreaded and always entail a huge loss of money. In fact, there are at least 15 studies in the literature that refer to these costs but without ever quoting an amount.

The European dairy sector plays a vital role in the European Union's (EU) economy. According to Eurostat (2022), in 2020 the EU was the world's largest producer of cow milk, with a total production of nearly 160 million tonnes. Countries such as France and the Netherlands are among the leading dairy producers in the EU. The sector contributes around €10 billion annually to the positive EU trade balance and is therefore a key European industry (EDA, 2018). The economic importance of the dairy sector translates into thousands of direct and indirect jobs, a substantial contribution to agricultural incomes, and a significant share of agri-food exports. Nonetheless, dairy farms are particularly vulnerable to crises since the end of the milk quotas and the drop in milk price. Thus, the health and well-being of calves on dairy farms are of crucial importance to ensure the sustainability and prosperity of this sector.

Today, it is therefore necessary to characterise the economic weight that this endemic disease represents for dairy farms. This observation is shared by Japan, where a study was launched in 2020 on the link between production losses and *Cryptosporidium* spp. infections in the cattle industry (El-Alfy and Nishikawa, 2020). The aim is to raise awareness of the economic and health urgency of managing this parasite, both for farmers and the farming community, and for public authorities, given that livestock is a reservoir for zoonotic parasites transmissible to humans (Radostits et al., 2007; Follet et al., 2011). Currently, there are no vaccines to protect calves. Moreover, the lack of effective treatment to cure sick animals explain the reason why farm practices and preventing strategy merged to tackle this parasite.

The main objective of the present study was to evaluate the costs generated by the presence of *Cryptosporidium* spp. in calves on dairy farms and to monitor changes in these costs after implementing disease management measures on a network of pilot farms in Belgium, France, and the Netherlands. By highlighting the costs linked with cryptosporidiosis in dairy farms, this research contributes to informed decision-making aimed at improving animal and farmers' health and welfare, the economic sustainability of the dairy sector and lowering the impact on human and environmental health.

2. Materials and methods

The methodology involved 3 stages: a field survey of farmers to determine the general cost of diarrhoea, a sampling of stools to determine the prevalence of *Cryptosporidium* spp. on farms and refine the cost of cryptosporidiosis, and the implementation of *Cryptosporidium* spp. preventive measures to monitor the evolution of the costs.

2.1. Field survey and economic impact of diarrhoea

As pathogens are not bound by national borders and trade between farms and breeding centres can be a vector for pathogens, including *Cryptosporidium* spp., to spread far and wide, the European scale seemed more appropriate for the study. In order for the results of this study to be adapted to different kinds of farm model in each country, it was essential to recruit farms of different sizes and with different production systems. The data needed for the expertise were collected using a questionnaire from a network of pilot dairy farms facing or having faced cryptosporidiosis problems in northern Europe. Each farmer was surveyed individually, and the similar questionnaire completed in all three countries by the veterinarian in charge of the farm in Belgium and France, and by the livestock adviser in the Netherlands.

Even if detection tools exist, these were not always used on farms in the frame of this study. Then it was difficult for farmers to identify the pathogenic agent. Moreover, it was not defined if diarrhoea was due to a single pathogen or a consequence of co-infection. This led us to ask questions about the impact of diarrhoea in general and the husbandry practices related to its management over a full accountable year. The survey focused on the earliest age of calves, between 3 days and 3 weeks, when they are the most vulnerable (Sanford and Josephson, 1982; Smith, 2012; Qi et al., 2020). We allowed ourselves to make a connection between diarrhoea and *Cryptosporidium* spp. because the pathogen has been identified as one of the main enteric pathogens causing neonatal diarrhoea throughout the world (Trotz-Williams et al., 2005; Singh et al., 2006; Blanchard, 2012; Cho et al., 2013). The likelihood that almost all calves on a farm become infected with *Cryptosporidium* spp. in the first few weeks of life is high (Thomson et al., 2017).

The method used to calculate the economic impact of diarrhoea in calves is based on the works of Fourichon et al. (2005), Gunn and Stott (1997), and Singh et al. (2014). It was worked out as the sum of the following components: (A) losses due to mortality, (B) health expenditures, and (C) additional labour cost.

(A) *Losses due to mortality.* Losses due to mortality were direct losses linked to the inability to create value from dead animals. Mortality is the cost of a dead calf, whether it is a male or a female and without considering any loss in weight. The total loss represented the number of dead calves due to diarrhoea in the first 3 weeks of life, multiplied by the average live calf sale price of the year for a standard weight in the country concerned. These data were provided by the farmer in the questionnaire. This direct loss was calculated for all breeders, whether they sold their calves or kept them for fattening.

(B) *Health expenditures.* Health costs represent all expenses to manage calves ill with diarrhoea, i.e. veterinarian fees and medicine costs. Veterinarian costs included interventions, travel costs, flat-rate fees, self-tests etc. Medicine included oral rehydration solutions, perfusions, acidosis treatments, stomach-coating medication, antibiotics, halofuginone, probiotics, vitamins, and other medications used to fight diarrhoea. Each treatment cost was calculated by multiplying the price of the product by the number of doses used during the sick period for all the treated calves. Whenever a price was missing, it was approximated by an average calculated from the prices given by respondents from the same country, considering that tariffs in the agricultural sector are relatively homogeneous within the same region. This average was only calculated if the responses were sufficient in number (10 responses) or close enough in value (5% standard deviation). For the price of treatment, we also looked at an online veterinarian pharmacy and, for France, used the rates charged by the veterinary practice SELAS CVE.

(C) *Additional labour cost.* Another cost to look at was the additional labour necessary to take care of sick calves. The time spent with sick calves included feeding, administration of medication and fitting a coat or heat lamp. Ten days were considered before the calves became immune. However, in calculating the extra work, a period of 5 days was taken as the average period during which increased attention was required with the calf (Olson et al., 2004), particularly for the administration of medication. This time was assessed by multiplying the number of sick calves by the frequency of visits with each sick calf every day for 5 days and the duration of these visits. The related labour value was obtained by multiplying this time by the average hourly wage in force in the country of the farm provided by European Dairy farmers' network.

This economic impact was therefore calculated for a given farm on a yearly basis.

2.2. Sampling animals and evaluation of the cryptosporidiosis costs

To get closer to the real cost of cryptosporidiosis as part of the overall cost of diarrhoea, the prevalence of *Cryptosporidium* spp. was researched on the farm. The survey was therefore completed by a collection of stool samples for 10 calves and 10 mothers per farm, according to the methodology described in Pinto et al. (2021). Thanks to these samplings, the estimated costs for diarrhoea could be refined according to the prevalence of *Cryptosporidium* spp. in the farms. For each farm, once the prevalence of *Cryptosporidium* spp. has been estimated, this percentage was applied to the economic impact calculated for diarrhoea. Considering that x% of diarrhoea cases were due to *Cryptosporidium* spp., so x% of costs were assumed to be linked to cryptosporidiosis.

As a full accounting year was required to assess the costs, they referred to 2018. However, manure collection was carried out in 2019. The economic data for 2018 will therefore be compared with the best data available for *Cryptosporidium* spp., i.e. 2019, on the assumption that the farm's health status has changed little between these 2 years.

2.3. A two-step approach

In the context of the Interreg 2 Seas project H4DC (Health for Dairy Cows; H4DC, 2023), a first round of surveys and samplings were conducted in 2019. Then a set of farm practices modifications was implemented on these pilot sites. In parallel, a review of the scientific literature on risk factors for *Cryptosporidium* spp. highlighted several prevention measures that can reduce the pressure of the disease (Brainard et al., 2020). In addition to general farm biosecurity measures, the pilot farms were asked to implement specific management measures concerning calving place, colostrum and calf immunity, calf housing, calf nutrition, sick calves, dry cows, and cow vaccination (H4DC, 2023). Some of these measures may already have been in place on some farms prior to the project, and depending on the context of each producer, additional actions to be implemented during the project have been proposed (Supplementary file S1). The aim was not to carry out as many preventive actions as possible, but to target those that are most relevant to the farmer in terms of his health and financial situation, and his ability to initiate change (willingness, skills, available manpower, time, etc.). Three years later, another round of surveys and samplings were carried out to assess the evolution of losses linked to diarrhoeas caused by *Cryptosporidium* spp. after implementing best practices for the management of cryptosporidiosis. The panel of farms having been modified between the beginning and the end of the study, the results of the second round will be presented on a limited sample of farms.

3. Results

3.1. Panel description

All data given in Table 1 are taken from the individual data provided by the farms and collected in the questionnaires. Only the milk revenue has been calculated, by multiplying the price per litre of milk paid to the farmer by the volume he produces per year.

In France, the average size of a dairy herd in 2021 was 67 dairy cows (IDELE, 2022). In Belgian Flanders, this figure was 86 head (Etat de l'agriculture Wallonne, 2022), while in the Netherlands, it reached 106 dairy cows per farm (CBS, 2023). According to these figures, the study panel showed a varied sample with farms of different sizes and production systems with a minority of very small farms and a majority of medium-sized to very large structures. In fact, 4% of the farms in the sample had fewer than 60 cows and they were all in Belgium; 64% of the farms had between 60 and 160 cows; and 32% of the farmers involved had more than 160 cows, and more than half of them were Dutch.

The prevalence of *Cryptosporidium* spp. in calves reached around 40% for the whole panel; these results are comparable to the observations of Meganck et al. (2015).

3.2. Economic impact in 2018

The differences in calf losses observed between the three countries were reflected in the live calf sale price for 2018, which reached €154.33 in Netherlands, €156.4 in Belgium, and €84 in France (Table 2). These animals would have never produced added value, so the valuation gave

Table 1
Economic key figures and sanitary situation in 2018 per farm.

	Milk production (l)	Milk revenue (€)	No. of dairy cows	No. of calves born	No. of diarrhoeic calves	No. of dead calves	Prevalence of *Cryptosporidium* spp. (%)[a]
Belgium (*n*/*N*)	17/17	16/17	17/17	17/17	17/17[b]	17/17	17/17
Minimum	156,143	€46,982	20	13	3	0	0
Maximum	2,500,000	€754,416	260	221	5	17	70
Mean	1,162,847	€400,327	118	104	26	4–5	40
Median	1,050,000	€362,535	105	85	21	3–4	40
France (*n*/*N*)	20/20	13/20	20/20	19/20	17/20	17/20	20/20
Minimum	440,000	€170,000	65	40	1	0	0
Maximum	1,900,000	€718,590	196	180	99	20	100
Mean	969,250	€371,619	106	105	24	5–6	43
Median	971,500	€330,000	106	109	20	5	41
Netherlands (*n*/*N*)	18/20	19/20	19/20	19/20	10/10	16/20	20/20
Minimum	744,757	€266,771	74	76	2	0	0
Maximum	5,831,477	€2,220,000	625	404	150	19	80
Mean	1,981,013	€795,193	212	200	47	5–6	35.5
Median	1,690,178	€679,123	176	192	26	4	35

Abbreviations: *n*, number of farms that provided the data; *N*, total number of farms surveyed.

[a] Data provided by Pinto et al. (2021).

[b] Figures provided by the veterinarian as the number of diarrhoeic calves was not recorded on the farms before 2019.

Table 2
Between country comparison of the economic impact of dairy calves' diarrhoea in 2018.

	All	Belgium	France	Netherlands
Losses due to mortality (*n/N*)	46/57	13/17	17/20	16/20
Minimim (€)	0	0	0	0
Maximum (€)	2717.00	2210.00	1400.00	2717.00
Mean (€)	691.57	716.92	481.41	865.31
Median (€)	508.53	582	400.00	678.00
Health expenditures (*n/N*)	49/57	16/17	16/20	17/20
Minimum (€)	25.00	55.66	79.00	25.00
Maximum (€)	5622.19	5622.19	5312.70	1990.00
Mean (€)	1008.95	1263.31	1306.68	489.32
Median (€)	€635.50	900.60	815.00	450.00
Extra labour cost (*n/N*)	37/57	17/17	20/20	10/20
Minimum (€)	0	68.06	0	336.28
Maximum (€)	10,190.83	3392.55	10,190.83	4791.99
Mean (€)	1718.50	1477.62	1345.70	2873.59
Median (€)	1222.90	1727.69	433.11	3116.60
Total economic impact (*n/N*)	37/57	13/17	14/20	10/20
Minimum (€)	528.35	1018.55	528.35	625.50
Maximum (€)	8510.28	8510.28	5597.67	6259.50
Mean (€)	2974.09	3377.58	2150.91	3601.99
Median (€)	2447.92	2497.66	2049.78	3996.18

Abbreviations: *n*, number of farms that provided the data; *N*, total number of farms surveyed.

a value to the net loss of gross product.

Health costs in Belgium and France were of the same order of magnitude (€50 difference) contrary to costs in the Netherlands (more than €500 less) (Table 2).

In the additional labour cost evaluation, differences between countries were noticed, with an average cost that can double (€1477 in Belgium to €2873 per year in the Netherlands). There were two main reasons for these differences. First, the cost of labour in each country is different. Within the European Dairy Farms Network, a labour cost was applied for each country according to the standard of living, remuneration, possible social security charges, etc. For 2019 an hourly wage was evaluated at €17.95 for Belgium, €17.47 for France and €24.02 for the Netherlands. Secondly, the length of visiting time also played a great role. Depending on the size of the herd, this could represent very significant costs. On the other hand, some farms were relatively unaffected by diarrhoea and the care of the few diarrhoeic calves did not require more than 20 min per day. Out of the 57 farms of the panel, there were some farms for which the sanitary situation did not require any extra labour hours, whereas for one farm in France, the additional labour cost reached more than €10,000.

Table 3
Between country comparison of the changes in the health impact of dairy calves' diarrhoea between 2018 and 2021.

	Belgium	France	Netherlands
n/N	11/15	10/16	7/17
Sum of born calves			
2018	1196	1079	892
2021	1618	1142	968
Sum of diarrhoeic calves			
2018	299	227	176
2021	325	119	160
Sum of dead calves			
2018	61	62	41
2021	23	20	23
Diarrhoeic/Born calves (%)			
2018	25	21	19.7
2021	20.1	10.4	16.5
Dead/Diarrhoeic calves (%)			
2018	20.4	27.3	23.3
2021	7.1	16.8	14.3
Dead/Born calves (%)			
2018	5.1	5.7	4.6
2021	1.4	1.9	2.4

Abbreviations: *n*, number of farms that provided the data; *N*, total number of farms surveyed.

The economic extra cost due to diarrhoeic diseases could be divided into 3 expenditure items. The major components of economic losses were the additional labour cost (42%) followed by the health costs (35.6%) and the losses from mortality (22.4%).

This study revealed that in 2018, the 57 selected dairy farms from France, Belgium and the Netherlands had an annual loss of €3000 due to diarrhoea among calves (Table 2), i.e. €94 per diarrhoeic calf. Now focusing on cryptosporidiosis, with an overall prevalence of 41.3%, the overall cost could come down to €1239 per farm and on average €38.82 per calf considering the proportion of *Cryptosporidium*-infected calves among the cohort of calves born.

3.3. Risk factors outcomes and management practices effectiveness

Among the specific measures proposed during the study, the most widely supported in Belgium were "Improving the time spent with dam after birth" chosen additionally by 4 farms, "The use of vaccines against *E. coli* or other vaccines" also by 4 farms and "Measure colostrum quality and only give good quality colostrum" tested by 5 farms. In the Netherlands, "Measure colostrum quality and only give good quality colostrum" has been chosen by 4 farms and "Improving the cleaning and disinfection" by 5 farms (Supplementary file S1). Data were not recorded for France.

Original data collected about dairy farms and their cryptosporidiosis-related negative outcomes were looked for evidence about possible risk factors or protective practices (Supplementary file S2). This work highlighted a number of avenues to be explored which appear to have an impact on cryptosporidiosis.

- Disinfection protocols (order well/unwell calves; for equipment; hands, boots or both).
- Ventilation and individual *versus* group housing status of young calves.
- Oocyst introduction risks that may relate to frequency and/or duration of calf care visits.
- Differences in husbandry practices dependent on formal education status of calving staff.
- How much colostrum calves receive after birth.
- Quality control practices for colostrum.
- Litres of milk received by calf by 2nd day of life.
- Acidified milk feeds at room/cold temperatures *vs* warmed milk feeds (not acidified).
- Vaccine regimes for dams (against calf enteritis).

Table 4
Between country comparison of the changes in the economic impact of dairy calves' diarrhoea per farm between 2018 and 2021.

	Belgium ($n = 11$)	France ($n = 10$)	Netherlands ($n = 7$)
Losses due to mortality (€)			
Mean 2018	740.11	437.55	705.13
Mean 2021	237.72	143.21	440.86
Health expenditures (€)			
Mean 2018	1401.59	1126.88	401.32
Mean 2021	414.27	783.83	253.07
Extra labour cost (€)			
Mean 2018	988.27	677.69	1727.15
Mean 2021	906.76	367.17	811.36
Total economic impact (€)			
Mean 2018	3141.22	2129.43	2833.60
Mean 2021	1558.75	1323.01	1505.28
Total economic impact per diarrhoeic calf (€)			
Mean 2018	148.07	113.63	156.81
Mean 2021	108.78	130.12	78.95
Total economic impact per calf born (€)			
Mean 2018	37.02	26.27	19.80
Mean 2021	13.86	21.77	10.64
Cryptosporidium spp. prevalence among infected calves (%)			
Mean 2018	40.94	38.57	37.14
Mean 2021	42.20	24.70	50.00

3.4. Evolution of the sanitary situation and the economic impact in 2021

Three years after the first economic survey and after the farmers had implemented preventive measures with the help of their veterinarian or livestock advisor, a second survey was conducted. Due to the cessation of activity of several farmers, and the lack of data collected on some farms, the results on the evolution of diarrhoea and the associated economic impact were presented for 11 Belgian, 10 French and 7 Dutch farms.

Indicators of morbidity and mortality of this farm panel between 2018 and 2021 have improved overall in the three countries. Fewer calves presented diarrhoea symptoms and fewer of the diarrhoeic calves died (Table 3). This was reflected in the economic impact as all items of expenditure related to calf diarrhoea management improved in all three countries (Table 4).

Despite an increase in the prevalence of *Cryptosporidium* spp. in Belgium, the economic impact per diarrhoeic calf decreased by almost €40. The situation was the same in the Netherlands with a reduction of €78. Conversely, the lower prevalence of *Cryptosporidium* spp. in French farms did not translate into lower costs linked to diarrhoea, which have increased by €16.50. Nonetheless, if we reduce this cost to the total number of calves born, in France, the farms involved from the beginning have seen an average saving of €4.5 in the cost of diarrhoea, in Belgium, the saving reached €23.16 and in the Netherlands, it reached €9.16.

Applying the prevalence of *Cryptosporidium* spp. shown in Table 4, the cost of cryptosporidiosis per Belgian farm decreased from €1286 to €657.80. This cost decreased from €821.32 to €326.80 per French farm and from €1052.40 to €752.64 per Dutch farm. Similarly, the cost of cryptosporidiosis per infected calf decreased from €60.62 to €45.91 in Belgium, from €43.83 to €32.14 in France and from €58.24 to 39.48 in the Netherlands. Finally, the cost of cryptosporidiosis per born calf decreased from €15.16 to €5.85 in Belgium, from €10.13 to €5.38 in France and from €7.35 to €5.32 in the Netherlands. This represented an average of €15 saved per infected calf and €5.40 saved per calf born between the beginning and the end of the study.

4. Discussion

As mentioned, before this research, no studies had tried to assess the cost of cryptosporidiosis among calves, and it was therefore difficult to find recent comparable data. However, some studies about the costs of diarrhoea had been carried out. A Scottish survey conducted by Gunn and Stott (1997) in beef herds estimated this loss to be around £33, i.e. €50. The cost may have been lower 20 years ago, but the distribution of expenditure items corresponds to what our study observed, i.e. a major contribution due to the cost of labour, then health expenditure and finally the cost of mortality. A more recent study by Rocha Valdez et al. (2019) carried out in Mexico with a population of 510 dairy calves found higher costs. These authors have estimated $341, i.e. €290 per diarrhoeic calf, but this calculation considered the costs caused by diarrhoea from birth to six weeks, i.e. twice as long. At €94, the cost of diarrhoea highlighted in the present study before implementing specific measures should be in the middle of the range established by the studies by Gunn and Stott (1997) and Rocha Valdez et al. (2019). However, because of a lack of data for many farms in 2018, especially the number of veterinary visits related to diarrhoea symptoms, and a lack of precision on the medicine administered, we could expect an increase in costs related to diarrhoea.

After sharing and implementing good husbandry practices with farmers to control *Cryptosporidium* spp., the study reported an overall improvement in mortality and morbidity indicators related to diarrhoea and its economic impact on farms (Tables 3 and 4). The results showed that the economic impact is directly linked to calf morbidity and mortality. Improvement of health indicators resulted in lower losses for farmers. Nonetheless, the two-step approach developed in this study did not allow us to conclude on the causal link between the implementation of these practices and the improvement of the sanitary situation and economic impact of the farms. In fact, some data were missing, few were independently observed, and some practices only partly implemented. Also, it was not feasible to ask about all aspects of every practice without risking respondent fatigue. Plus, the dataset was small with only 10 calves tested per farm. The lack of data about experiences of individual calves, such as how much colostrum that individual calf had or its individual birth experience, etc., prevented the practices dataset from being consistent or large enough to support an independent and robust epidemiological analysis to confidently link specific practices with individual outcomes. Thus, it is assumed that the results achieved are the result of several factors.

Regarding improving the mortality results, two hypotheses could be formulated given what was observed during the study. First, the implementation of new *Cryptosporidium* spp. management practices may have played a large role in improving the situation on the farms (Harp and Goff, 1998; Barrington et al., 2002; Mee, 2008), especially the colostrum management (Carter et al., 2022). It was one of the avenues explored by the study in Supplementary file S2. Secondly, the panel has changed over the two years, and the farms with the most difficulties have stopped. It is therefore presumed that the farms that remained in the study are globally those with the best performances and husbandry practices. The study showed differences between countries and between farms that could be explained from a cultural point of view, and the ease and cost of implementing measures. In fact, some measures are easier and less costly to implement colostrum management (giving a refractometer to farmers), changing disinfectant to a product active against cryptosporidiosis, etc. On the other hand, some obstacles are more difficult to overcome on certain farms, for reasons of cost or desire: creating a calving pen, isolating sick animals, etc. The implementation of new practices was well accepted and carried out on certain farms depending on the involvement of the farmers in the study, depending on their affinity with their veterinarian, their livestock advisor, or the dynamics of the group with the other farmers. On a human level, integration into a professional network and support from peers are an important factor in the success of a change in practice (Compagnone, 2019). On the farm level, it is recognised that constants can vary from one outbreak to another and from one calf to another calf three years later (Gunn and Stott, 1997). So, a third factor that cannot be controlled but needs to be considered is the environment: weather, strain variation, environmental conditions (Barrington et al., 2002).

The present study targeted the direct costs generated by the symptoms during the diarrhoeal episode in dairy calves. To be more accurate in assessing the economic impact of cryptosporidiosis, it would have been necessary to improve the sampling method. Only 10 calf stool samples were analysed per farm to determine *Cryptosporidium* spp. prevalence, extrapolated to the whole herd of calves. This very empirical method, linked to the difficulties in the field, had its limitations. In fact, the number of calves suffering from diarrhoea could sometimes be high (37/83), and the prevalence of *Cryptosporidium* spp. very low or even null, on farms that were nevertheless vaccinating against rotavirus and coronavirus. Besides, several samples were taken from non-diarrhoeic calves. It also highlighted the presence of cryptosporidiosis without any apparent symptoms at the time of sampling.

A second improvement would be to supplement these data with other direct costs like the cost of cleaning and disinfecting calving pens, as well as the cost of replacing bedding (including the cost of products and labour time) and the indirect costs, as longer-term effects persist beyond 3 weeks (Klein et al., 2008). A study by De Graaf et al. (1999) suggested that the economic losses associated with this disease are also linked to the retarded growth of the previously infected animals. This has been confirmed by Shaw et al. (2020). In case of severe infection, calves showed a growth retardation. It can be assumed that it will induce an extra feed consumption to reach the same weight as their peers and thus extra costs. Shaw et al. (2020) estimated this significantly reduced weight gain over a 6-month period, at £130, i.e. around €150. Furthermore, as a result, heifers with a history of diarrhoea showed poorer production performance such as substantially reduced milk production during the first lactation period (Svensson and Hultgren, 2008) and other indirect losses due to the associated weight reduction, which is not compensated after recovery (Millemann, 2009).

To ascertain the economic impact of cryptosporidiosis in the long term, it would require following previously detected infected calves all along their lives, and evaluating the losses linked with the deterioration in these zootechnical performances. One study by Bennett and Ijpelaar (2005) has attempted to assess the cost of enteric diseases in Great Britain, considering longer-term effects such as milk loss and fertility problems. Their work revealed an average cost of €67.20 per adult animal. Another option to assess the economic impact of calf cryptosporidiosis in more detail, would be to compare the current situation on each farm with an ideal health situation, and to evaluate the variation in income and costs between the two situations, at the overall farm level thanks to a partial budgeting method (Fourrichon et al., 2001), considering the evolution of the economic price context.

It is therefore alleged that significant losses occur during the first few weeks of the calf's life during the diarrhoea episode, but that the costs associated with the impact of *Cryptosporidium* spp. continue for at least 6 months or even longer, and the costs highlighted by this study should therefore be revised upwards.

5. Conclusions

The present study updated data on the costs associated with neonatal diarrhoea in calves and highlighted the significant losses due to cryptosporidiosis on dairy farms. Following the introduction of preventive measures, breeders have seen an improvement in the health situation at the end of the 3-year course, leading to a reduction in the cost of the disease. In addition to creating new economic references, this article emphasised that even if the amount saved per farm did not seem enormous, out of the 11 million calves reared in the Interreg 2 Seas area, this represented €55 million, which is not insignificant for a sector under pressure. The findings provide valuable insights for farmers and stakeholders in the dairy industry, enabling them to better exchange, to better understand and address the economic consequences of *Cryptosporidium* spp. and diarrhoea, but also to the scientific community in the framework of a one-health approach.

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Ethical approval

The study was carried out with the permission of the farmers who provided written informed consent prior to enrolment in the project. All positive animals were experiencing a natural infection with *Cryptosporidium* and the samples were taken by authorised personnel, in compliance with the regulations of each of the countries involved.

CRediT authorship contribution statement

Maud Roblin: Conceptualization, Methodology, Validation, Formal analysis, Writing - original draft, Writing - review & editing. **Evi Canniere:** Investigation, Resources, Writing - review & editing. **Anne Barbier:** Investigation, Resources, Writing - review & editing. **Yvonne Daandels:** Investigation, Resources, Writing - review & editing. **Martine Dellevoet-Groenewegen:** Investigation, Resources, Writing - review & editing. **Pedro Pinto:** Investigation, Resources, Writing - review & editing. **Anastasios Tsaousis:** Investigation, Resources, Writing - review & editing. **Hélène Leruste:** Conceptualization, Methodology, Writing - review & editing. **Julii Brainard:** Formal analysis, Writing - review & editing. **Paul R. Hunter:** Formal analysis, Writing - review & editing. **Jérôme Follet:** Investigation, Writing - review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data generated or analysed during this study are included in this article and its supplementary files. Datasets are available from the corresponding author upon reasonable request.

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Appendix A. Supplementary data

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