MSc thesis

# Cost assessment of cryptosporidiosis on a typical Dutch dairy farm

through stochastic modelling, partial budgeting and data analysis

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## Preface

In front of you lays the master thesis that is part of my Master Food Safety. Conducting a study at a size I did not do before might have been a little daunting in the beginning, but is all the more rewarding in the end. The research was initiated by MSD, who after a lot of years finally developed a vaccination against bovine cryptosporidiosis. To give insights in what this could mean for farmers, this research is conducted.

Although my name is the only one appearing on the front page, I did not do it all by myself. Firstly, I would like to express my gratitude to Henk for supervising me and giving me great guidance through his own expertise. Furthermore, I would like to thank Geert for giving me the opportunity to travel to Athens to attend the conference on Cryptosporidiosis. The visit and conversations gave me valuable perspectives that helped me along the way. Also, I would like to thank Vivienne for her extensive dataset and help with creating a good basis for my data analysis. Lastly, I am very appreciative of all my friends that along the way listened to my struggles about my thesis, especially my girlfriend Lieke who always gave her (unsolicited) advice.

**Abstract**

Cryptosporidium is a parasite that affects the intestines. An infection with cryptosporidium results in cryptosporidiosis which is a zoonotic disease characterized by different symptoms, predominantly diarrhoea. Human cryptosporidiosis can be foodborne as well as waterborne. The majority of zoonotic cryptosporidiosis originates from livestock. When newborn calves are affected, the disease does not only have immediate implications such as treatment and extra labor, but there are also long term consequences of the disease such as growth retardation.

The aim of this research was to estimate the total costs associated with a cryptosporidium outbreak on a typical Dutch dairy farm. First, an overview of the factors that can incur costs was made. These factors were either included in a partial budget or in the stochastic model. The model was used in previous research estimating the costs of rearing heifers, for this study the model was slightly adapted to fit the situation at hand. A Monte Carlo simulation was run 10,000 times during each simulation in @RISK. The one partial budget estimated the costs and revenues that are caused by mortality due to cryptosporidium in the first two weeks after calving. The second partial budget estimates the costs that are associated with reduced first lactation after an early life cryptosporidium infection.

From the model it appeared that it was €141 mor expensive to rear a heifer successfully in a situation with default settings (with cryptosporidium prevalence as found in literature) as opposed to a situation without any cryptosporidium prevalence. The first partial budget estimated the costs of mortality on an average farm to be €7 per successfully raised heifer. The second partial budget estimated the costs of reduced milk production to be €47 per heifer. In total costs of cryptosporidiosis in early life add up to €195 per successfully raised heifer. Tough, due to uncertainty of existence and or extent of certain effects of cryptosporidiosis the total costs should be interpreted with caution. Nevertheless, these costs can have implications on management practices and/or might help to make decision in preventive treatments.

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## 1. Introduction

### *1.1 Background*

Cryptosporidium is a parasite that affects the intestines of calves, cryptosporidium causes the disease cryptosporidiosis (Shirley et al., 2012). Cryptosporidiosis in newborn dairy calves causes diarrhoea which results in important economic losses (Garro et al., 2021). The majority of zoonotic cryptosporidiosis originates from livestock, with cattle being considered as one of the key sources. In cattle, C. parvum, C. bovis, C. ryanae and C. andersoni are the main species causing infections, the first being the most common. When calves are infected with C. parvum, they can either be asymptomatic or develop severe diarrhoea (Cho & Yoon, 2014). In the most severe cases, mortality can occur (Naciri et al., 1999).

An infection by cryptosporidium can arise through various means; by vertebrates that shed oocysts via the fecal route or from contaminated food or water (Xiao, 2010). Human cryptosporidiosis is characterized by vomiting, diarrhoea, nausea, fever and abdominal pain. Symptoms last from several days up to five weeks. Besides, immunocompromised patients can be hospitalized or even die (Enbom et al., 2023).

Cryptosporidium frequently causes cryptosporidiosis through foodborne transmission. The World Health Organization (WHO) reported that in 2010, 8.6 million people became ill and 3,759 died due to foodborne cryptosporidium. Additionally, 296,156 disability-adjusted life years (DALYs) were attributed to this disease (WHO, 2015). Additionally, in a combined report with the Food and Agriculture Organisation (FAO), the WHO ranked cryptosporidium as fifth out of 24 foodborne parasites regarding its importance as a foodborne pathogen (FAO/WHO, 2014). There are many routes of transmission for cryptosporidium oocysts to contaminate food. Routes of transmission from cattle to food can happen during slaughter, direct on farm contact or food crops getting fertilized with contaminated manure. Contamination of surface water through manure containing oocysts is also a common problem.

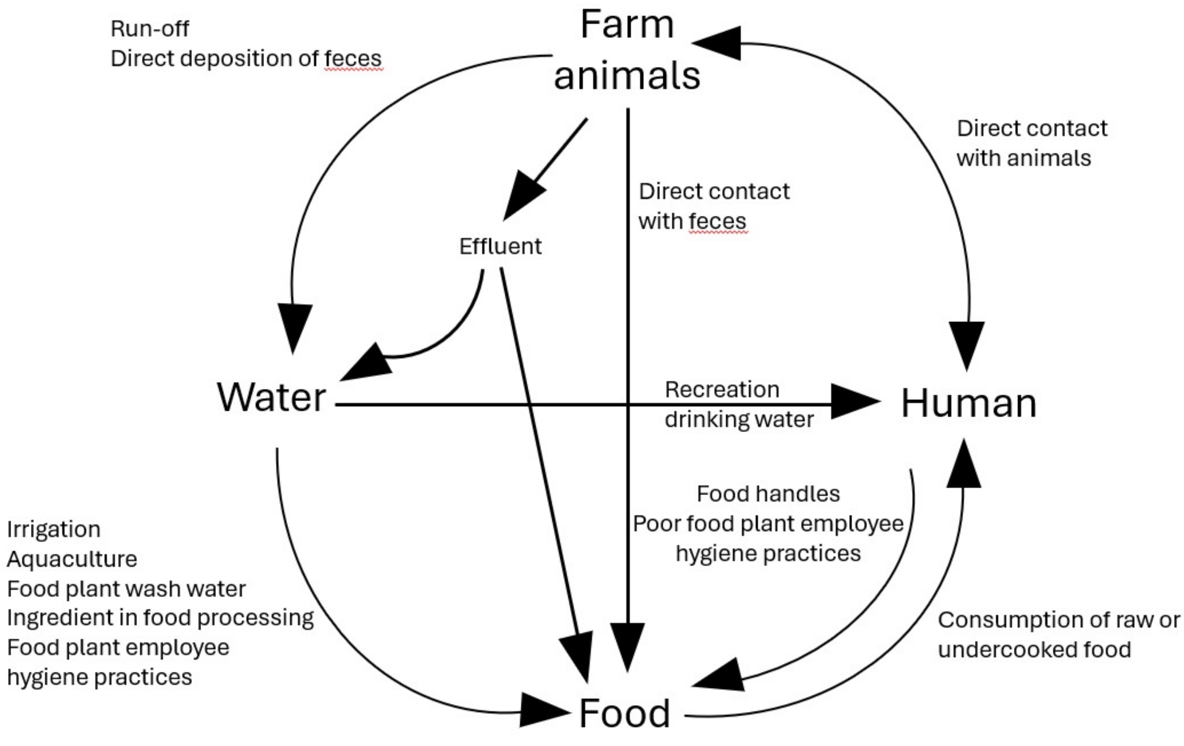


Figure 1: Transmission routes of cryptosporidium (Budu-Amoako et al., 2011) shows a full overview of transmission routes. additionally, in various studies on different management practices, researchers consistently find higher levels of cryptosporidium oocysts contamination downstream of farms compared to upstream (Budu-Amoako et al., 2011).

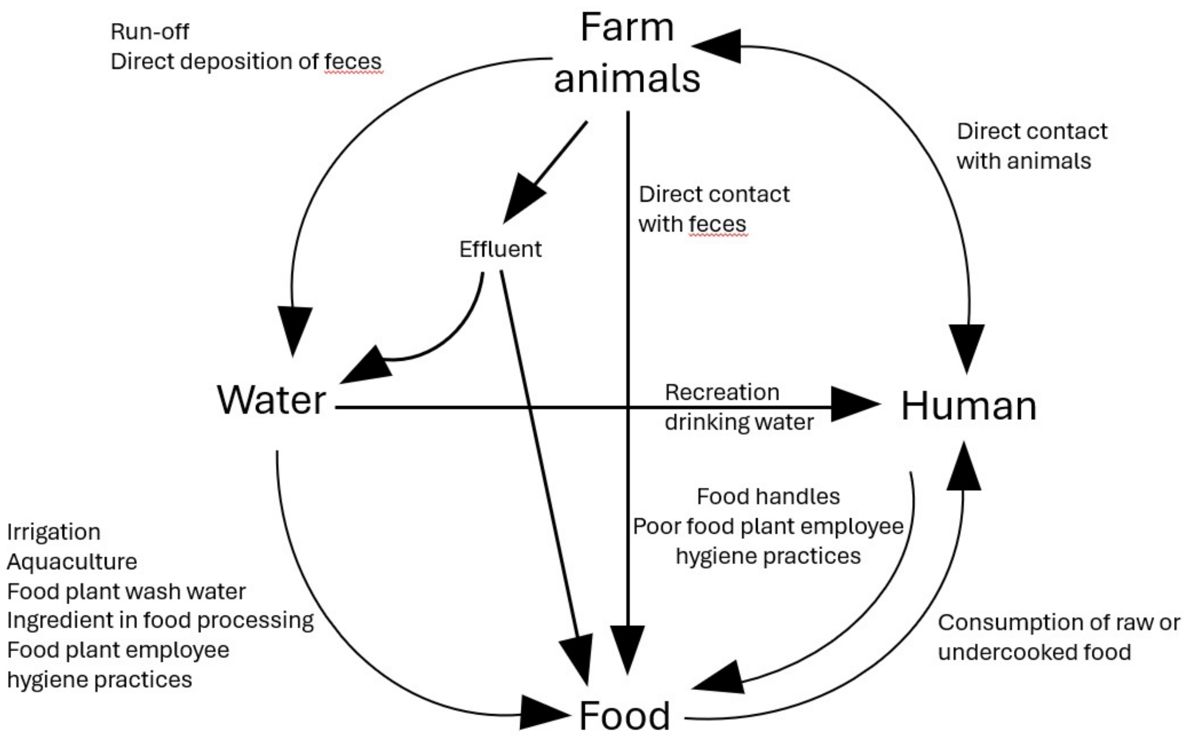


*Figure 1: Transmission routes of cryptosporidium (Budu-Amoako et al., 2011)*

Moreover, cryptosporidiosis is a common occupational disease. Cattle contact can be linked to contracting cryptosporidiosis by either directly working with calves or by visiting farms. The biggest risk factors associated with work on the farm are: contact with young cattle (either calves with diarrhoea or calves without symptoms), consuming water or food that is contaminated with feces, inadequate handwashing and protective gear stained with excrement (Enbom et al., 2023).

### *1.2 Research problem*

Cryptosporidium is not only a public health problem and an occupational disease, it also affects a farm's economic performance in many ways. Both directly through mortality of the affected animals but also less quantifiable, for example through reduced growth during the rearing of calves (Nydam & Mohammed, 2005; Shaw et al., 2020). Farmers play a crucial role in reducing the threat of the parasite persisting in their farm through treatment or by the implementation of for example disease management practices. Before implementing any changes, farmers need to ensure that they will have a positive effect on the operation. Primarily since some costs are indirect, the farmer might not be aware of the severity of costs that an outbreak brings.

A study by Roblin et al. (2023) conducted across the Netherlands, Belgium and France, assessed the costs of a cryptosporidium outbreak in the first three weeks after birth as well as the effect of better management practices on these costs. The considered costs were (limited to) losses due to mortality, health expenditures, and extra labor costs. In the baseline situation, the average costs per diarrheic calve with cryptosporidium in their stool ranged from 43,83, 58,24 and 60,62 in respectively France, Netherlands and Belgium. This study acknowledges that only considering three types of costs provides a limited overview of the economic impact of a cryptosporidium outbreak. Predominantly for the following three reasons; other direct costs could be taken into account such as cleaning costs for the pens and costs of replacing bedding (both in materials and labor) (Klein et al., 2008). Additionally, economic effects of growth retardation can be quantified and included e.g. extra feed costs (De Graaf et al., 1999; Shaw et al., 2020). Moreover, young dairy cattle with a history of diarrhoea showed less milk production during their first lactation (Svensson & Hultgren, 2008). The study by Roblin et al. (2023 )is the only one that quantifies the costs of a cryptosporidium outbreak for North-western European dairy farms, but it is too limited.

*1.3Objective of the study*

This study aims to assess the costs of a cryptosporidium outbreak for a typical dairy farm in the Netherlands. This objective will be answered by fulfilling the following sub-objectives;

(1) To give an overview of the biological as well as economic factors related to a cryptosporidium outbreak
(2) To create a model including the biological and economic factors to make a full assessment of costs related to a cryptosporidium outbreak
(3) To parameterize the factors included in the model related to a cryptosporidium outbreak
(4) To identify the key drivers in the model

The main research question is;
What are the costs of cryptosporidiosis for a replacement heifer on a typical Dutch dairy farm?

## 2. Literature review

During the introduction, cryptosporidium and farm economics were briefly explained. The upcoming section will provide a more detailed description of various aspects, relevant to cryptosporidiosis. Firstly, zoonoses in general will be explained. After which, cryptosporidiosis and the short- and long-term consequences will be elaborated. To assess what the costs of a cryptosporidium outbreak are, the economics of a farm will be explained. Lastly, the cost estimation methods of other diseases are laid out after the conceptual framework is presented.

*2.1 Cryptosporidiosis*

Zoonoses are diseases and infections that are passed along between people and vertebrates. Estimates suggest that zoonoses cause around one billion cases of illness and millions of deaths annually. About 60% of emerging infectious diseases globally are zoonoses (Chomel, 2009). Zoonotic diseases can be spread in many ways, both by direct or indirect contact with animals or humans. Also, foodborne transmission is a possibility. Zoonotic diseases are the cause of one-third of all foodborne diseases (Leahy et al., 2022). There are at least 60 major zoonotic diseases (Rahman et al., 2020; Contini et al., 2020).

The majority of zoonotic cryptosporidiosis originates from livestock, with cattle being considered as one of the key sources. Human cryptosporidiosis is characterized by vomiting, diarrhoea, nausea, fever and abdominal pain. Symptoms last from several days up to five weeks. Besides, immunocompromised patients can be hospitalized or even die (Enbom et al., 2023). The infectious dose of cryptosporidium is very low. Some studies suggest that ingestion of 10-100 oocysts is enough to be infected (Vanathy et al., 2017). Whereas cattle sheds between $1 \times 10^3$, and $1 \times 10^6$ when infected with C. parvum (Zambriski et al., 2013a).

The infection of a host can be divided into three phases. Firstly the ingestion of oocysts, then the development within the host of the oocysts, and lastly the extraction of new oocysts. The transmission of oocysts can happen in many ways, but one example could be a pen which is still contaminated by oocysts shed by the previous calve. Figure 2 shows the life cycle of cryptosporidium in cattle (Thomson et al., 2017).

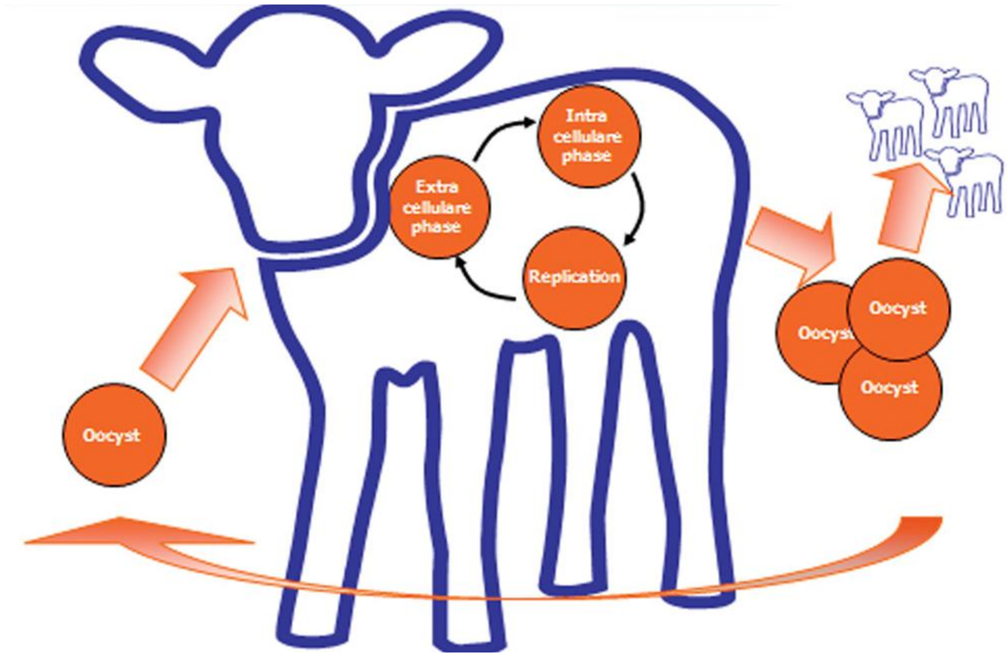


*Figure 2: Life-cycle of Cryptosporidium in a calve (Thomson et al., 2017)*

Two studies from the United States concluded that cryptosporidium is a problem for laborers on farms. A population-based study from Minnesota showed that over 5-year period, the incidence of enteric zoonotic diseases in agricultural workers is significantly higher than in members of the general public. Of the enteric diseases in this study, 60% were C. parvum cases (Klumb et al., 2020). A study from Nebraska over a 10-year period showed that cryptosporidiosis was caused by animal (specifically cattle) contact in 8.7% of the cases, making it an occupational disease (Klumb et al., 2020).

In 96.5% of the foodborne cryptosporidiosis outbreaks, C. parvum was the species responsible. On the other hand, C. hominis was the responsible species in 72.2% of the waterborne outbreaks (Zahedi & Ryan, 2020). Waterborne outbreaks most often occur through infected recreational water sources such as swimming pools, due to the capacity of cryptosporidium to resist chlorine and the challenge to filter the oocysts out (Zambriski et al., 2013b).

### *2.2 Effect of cryptosporidiosis on heifer performance*

Cryptosporidiosis has short-term effects in cattle such as diarrhoea and consequently dehydration. There are also long-term effects of cryptosporidium infection in the first weeks after birth of the calve. Table 1 demonstrates a list of different effects of cryptosporidiosis. Since there is only a limited number of studies conducted on the long-term effects of cryptosporidiosis, also diarrhoea of which the underlying disease is not identified, is taken up in this list.

*Table 1: Long-term effects on of different early life calve diseases on performance later in the rearing process*

| Cryptosporidium and related conditions | Factor | Degree | Source |
|---|---|---|---|
| C. muris | Decreased milk production | 3.2kg/d | Esteban & Anderson, 1995 |
| Neonatal diarrhoea | Mortality | | De La Fuente et al., 1998 |
| C. Andersoni | Reduced Average Daily gain | 0.44 kg/d | Ralston et al., 2010 |

| | | | |
|---|---|---|---|
| Cryptosporidiosis | Weight gain | 34 kg less over six months | Shaw et al., 2020 |
| Diarrhoea in first month | # days from birth to conception | 8 days later / calf | … |
| | # days from birth to first calving | 10 days later / calf | Aghakeshmiri et al., 2017 |
| C. Parvum | Bodyweight (difference between healthy and infected cows) | 49 days old (-3.81kg)<br>56 days old (-4.20kg)<br>77 days old (-6.03kg) | Renaud et al., 2021 |
| Scours | Weaning weight (difference between scouring calves and non-scouring calves) | -9kg | (Anderson et al., 2003) |
| Scours in the first 90 days | Calving <900 days | 48.9% for affected cows, 53.6% for health cows. Difference 4.7% | (Waltner-Toews et al., 1986) |
| Mild diarrhoea during first 3 months of life | Decreased milk production | -344 kg per 305d | Svensson & Hultgren, 2008 |
| Diarrhoea during preweaning | Decreased milk production | -325kg per 305d | Abuelo et al. (2021) |

The different short- and long-term effects of an infection are undesired, thus farmers try to combat the disease. Both by prevention and treatment. Cryptosporidium oocysts are very difficult to eradicate from the environment since they are resistant to common disinfectants. Different management practices such as changing the type of flooring and cleaning of feeding utensils are taken up. When infection occurs treatment is also needed, but none of the drugs that are commonly used are completely effective (Shahiduzzaman & Daugschies, 2012; Trotz-Williams et al., 2008).

### *2.3 Farm economics*

In the same way as other companies, the economic performance of a farm is based on a combination of revenues and costs. The net result is the total revenue minus the total costs. Within the costs, a distinction can be made between variable costs and fixed costs. Variable costs change based on the amount of output produced while fixed costs remain the same with different amounts of output.

Specifically for dairy farmers, Liba (2019) made a document explaining the specific revenues and costs for a dairy farm. This document is especially helpful to identify the particular revenues and costs relevant to dairy farms as well as the specific terminology used. The tables 'financial results' supplemented with information from the table on 'milk margin' in the document from Liba (2019) provides an adequate overview of the dairy farm economics (Table 2). This overview of all revenues and costs is necessary to properly assess the impact of cryptosporidiosis on the economics of a dairy farm.

*Table 2: Revenues and costs of dairy farms (Liba, 2019)*

| **Revenues** | **Costs** |
|---|---|
| Milk revenues | **Fixed costs** |
| Revenue and rearing of cattle | Labor by workers |
| *Selling of cattle* | Contract work |
| *Rearing of cattle* | Machines |
| Other revenues* | Milk installations |
| | Land and buildings |
| | Production rights |
| | Lease |
| | Interest |

| | |
|---|---|
| | General costs |
| | Depreciation |
| | **Variable costs** |
| | Feed costs |
| | *Concentrate* |
| | *Milk products* |
| | *Roughage* |
| | *Wet by products* |
| | *Stock change feed* |
| | Cattle costs |
| | *Rearing* |
| | *Milk control* |
| | *Animal health expenditures, drugs, diagnostics, veterinary costs* |
| | *Litter* |
| | Cultivation costs |
| | *Seed* |
| | *Manure* |
| | *Pesticides* |

*other revenues than already mentioned; e.g. subsidies, company allowances, management fees, contract work, packaging of products, contract fees (veal), sheep farming, stock changes of own roughage, revenues of sold energy, recreation, renting out of assets, interest, arable farming

### *2.4 Estimation methods disease*

The costs of disease in dairy cattle can be calculated in different ways. Methods include simple loss additions, partial budgets and (stochastic) modelling. The calculations of losses are performed by several methods for example; by estimations with data from surveys (Jemberu et al., 2014) or with data that was gathered on the farm (Kaneene & Scott Hurd, 1990). Partial budgeting is also used as an estimation method (Govindaraj et al., 2020). In some cases, partial budgeting is combined with finding a breakeven point (Damaso & Rushton, 2017). Most studies that were found on cost estimations used economic simulation models. Examples of the types of models include a multivariable regression model (Ott et al., 1999) and stochastic models (Lassen & Østergaard, 2012)(Raboisson et al., 2015).

When specifically focusing on cost estimations of disease in youngstock, a very limited amount of studies were found. One of the studies by Mohd Nor et al. (2012), used the software @RISK, which is an extension of Microsoft Excel to develop a stochastic model. The inputs were parameterized by either literature or veterinary expertise. Another study by Raboisson et al. (2016) on youngstock uses a stochastic model to estimate costs as well, but data is gathered through a meta-analysis on relevant articles. A combination of these methods will be used during this study.

### *2.5 Conceptual framework*

Partial budgeting
Rushton et al. (1999) describes different methods to assess the cost of disease. One of the methods that is suggested is the partial budget. In this case, the partial budgeting will not be a calculation to estimate the change in a system, but merely an estimation of which revenues and costs will be classified into which category. The numbers related to each burden will not be elaborated on since the estimation will be made by a simulation model at a later stage. The partial budgeting will be made by categorizing the identified burdens from table 2. The burdens that are susceptible to change will be categorized into the corresponding categories. Also the long-term effects from Table 1 will be categorized. The partial budget is based is the difference between a farm without cryptosporidium and a farm after a cryptosporidium outbreak.

*Table 3: Partial budget of a farm affected by Cryptosporidium*

| New costs | Cost saved |
|---|---|
| Labor work | Less feed |
| Feed costs; milk products | Less labor |
| Rearing | |
| Animal health expenditures, drugs, diagnostics and veterinary costs | |
| Litter | |
| Culling | |
| Mortality (incl. rendering) | |
| **Revenue foregone** | **New revenue** |
| Milk revenues | Culling |

Conceptual model

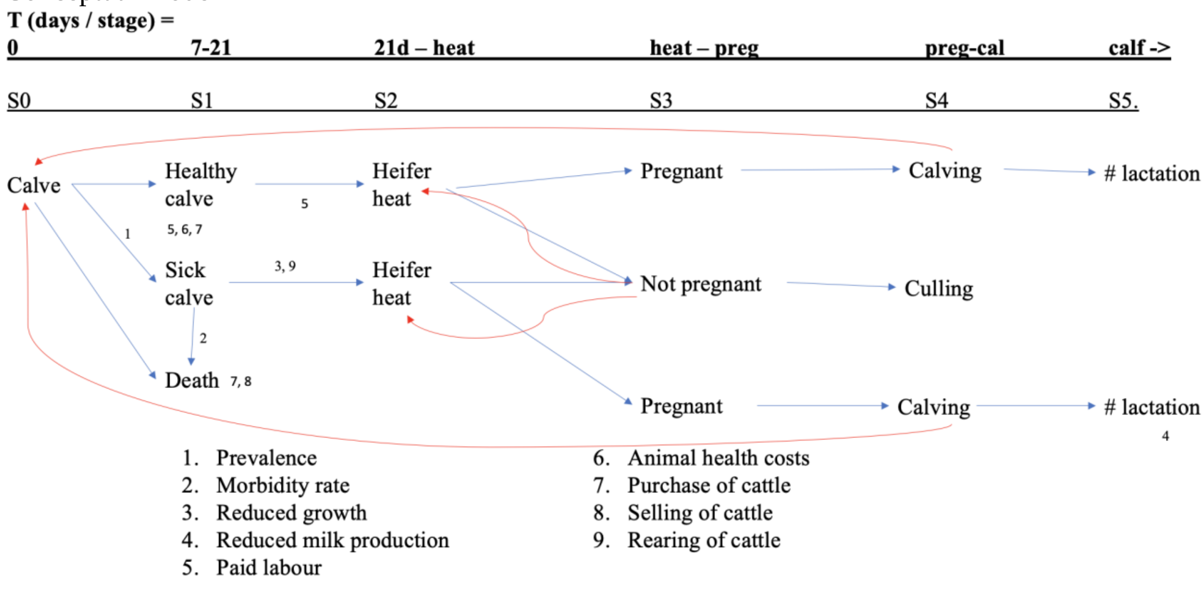


*Figure 3: Conceptual framework which shows a simplified version of a calves life with the risk of falling ill. The list shows factors related to cryptosporidium inducing extra costs.*

Figure 3 shows the rearing of a calve and the effects of a possible cryptosporidium infection. The different stages (St) indicate the phase of the calf's rearing process. In the top of the figure the timeline can be seen, which is based on days. From the third stage onwards the stages are defined by moments in the calves rearing process since these moments take place at more variable moments. Part of the factors identified in the previous paragraphs are included in the conceptual model since they are related to the states of the calve. The conceptual model will be the basis of the next model in @RISK.
The model in the study of Mohd Nor et al. (2012) will be used. It will be adapted to fit the situation described in Figure 3.

Most of the factors that are listed below the figure describe a relatively straightforward relationship with the economics of the farm. 'Reduced growth' is somewhat more ambiguous. Reduced growth indicates that an infected cow has a lower growth rate and is thus ready at a later stage to get pregnant. The different factors are estimated through among others, a data analysis on farm data. Afterwards, these quantified relationships are used as inputs for the previously mentioned stochastic model.

## 3. Materials & methods

In this chapter, the available materials (data and model), analyses and parameterization will be described. This research was built around an existing model on cow performance and a stochastic model that estimates the costs of heifer rearing under uncertainty of disease. Since the available model starts at week 3 in the life of a heifer, the effects of cryptosporidium on a young calves (bull and heifer calves that will be solved as well as the heifer calves that will be kept) were left out of the estimation. To incorporate this in the total estimation, an additional partial budget analysis was performed to quantify this relationship. Furthermore, the effects of a cryptosporidium infection on first lactation are not part of the existing simulation model. To estimate those a second partial budget analysis was performed. Figure 4 illustrates how the material and methods is put together. The sensitivity analysis, which is not part of the figure, will be described in paragraph 3.8.

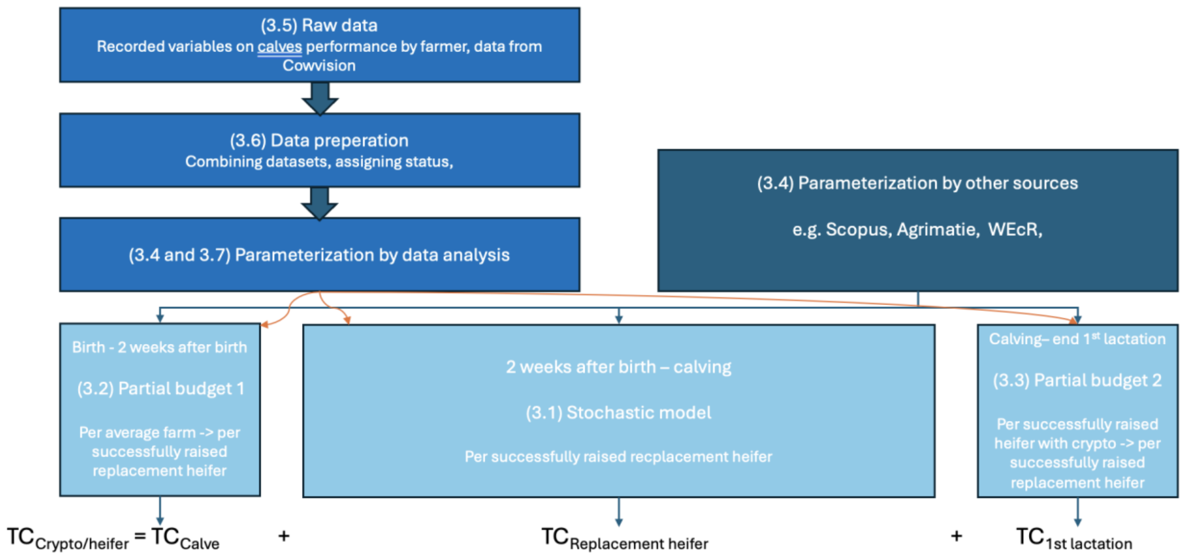


*Figure 4: Visualization of the different parts of the materials and methods section. The figure shows through which manners costs are estimated and how parameterization takes place.*

### 3.1 Model description

The model that is used is a Monte Carlo simulation made at calf level by Mohd Nor et al. (2012). It is a young stock rearing model, starting from the moment it is clear a calf stays at the farm to be reared as replacement heifer. During each iteration the life of one calve is simulated. The life is modeled from the third week of life until the first lactation, divided in stages of 1 week (until the calve is 4 months of age) and 3 weeks (from 4 months of age until calving). The calve can be in different states (healthy, sick or dead). The probabilities of getting in each state are different for each stage, fitting to the risk of becoming sick. These probabilities are combined in a transition matrix. Every 2 weeks a variety of costs are accumulated. Costs that are always present include feed costs (dependent on growth), barn costs and labor. The reproduction phase of the heifer is also part of the model. The reproduction phase only starts when the heifer reaches a weight of 360 kilograms. Thus when growth retardation occurs due to disease, the costs for feed, labor and others will be incurred for a longer period. Specific costs for disease are treatment costs, extra labor costs and (possible) veterinary costs which are incurred when the calf transitions into a state of disease. Heifers that are not successfully inseminated after 6 inseminations are culled. The costs of heifers that died or were culled were added to those that were successfully raised, the full calculation for the cost of a replacement heifer is shown in equation 1. Overall the model remains roughly the same as described in the paper by Mohd nor et al. (2012). The following changes were made to fit the model a cryptosporidium outbreak. Firstly, for simplicity the only disease in the model is cryptosporidium. The transition matrix was simplified by making the chance of failing ill due to e.g. respiratory disease zero. Next to that, the growth curve was extended to account for growth losses due to cryptosporidium. Lastly, a variety of inputs were adjusted. The changed inputs are mentioned in the parameterization paragraph.

*Equation 1: Calculation of total costs for a successfully raised replacement heifer Mohd nor et al. (2012)*

$$Total\ costs\ of\ a\ replacement\ heifer = TC_{succes} + \frac{(TC_{Dead} * n_{Dead}) + (TC_{Culled} * n_{culled})}{n_{succes}}$$

### 3.2 Partial budget 1

The phases that are not included in the model but are still affected by cryptosporidium are the first 2 weeks of a calves life after birth and the first lactation. To make sure that cost-inducing parts are not excluded in the total calculation, two partial budget analyses were conducted. The structure of the partial budget was the same as it is presented in the study by Rushton et al. (1999).

The first partial budget was focused on the costs of mortality due of bulls due to cryptosporidium in the first 2 weeks. Table 4 shows the components that are estimated regarding mortality caused by a cryptosporidium outbreak in the first two weeks. The estimates are on farm level. After the estimates are performed the farm level results will be calculated to be on calve level.

*Table 4: Partial budget regarding the effects of mortality of bulls due to cryptosporidium during the first two weeks after calving*

| Increase revenues | Calculation | Decrease revenues | Calculation |
|---|---|---|---|
| | | Sales of bulls | Yearly # calves born * Ratio bulls/heifers * prevalence crypto * mortality rate of calves with crypto * price of bull |
| Decrease expenses | | Increase expenses | |
| Labor on dead animals | Yearly # calves born * prevalence crypto * mortality rate of calves with crypto * labor feeding | Carcass removal costs | Yearly # calves born * prevalence crypto * mortality rate of calves with crypto * price of carcass removal |

*3.3 Partial budget 2*

The components estimated in the second partial budget were due to the long-term effects of cryptosporidium on lactation. This simple partial budget is shown in table 5. The estimations for each specific component will be explained in the parameterization paragraph.

*Table 5: Partial budget on the effects of reduced milk production due to cryptosporidium during the first lactation. The*

| Increase revenues | | Decrease revenues | |
|---|---|---|---|
| | | Milk production | effect of crypto on lactation * milk price |
| Decrease expenses | | Increase expenses | |
| Feed costs | effect of crypto on lactation * price of feed * kg of feed needed per kg of milk | | |

*3.4 Parameterization*

To correctly estimate what the effect is of the previously named factors, the parameterization was done on these factors. The first way to do the estimation is by using the collected and analyzed data, which will be explained later. If that method didn't provide an answer, literature was used. In the last case, expert knowledge was used. The factors that will be parameterized are the following;

*Table 6: An overview of all factors that will be parameterized. The table also shows in which part of the model the factors are used.*

| Factor | PB 1 | Model | PB 2 |
|---|---|---|---|
| Prevalence | X | X | |
| Mortality rate | X | X | |
| Reduced growth | | X | |
| Effect crypto on lactation | | | X |
| Animal health costs | | X | |
| Calf price at 2 weeks | X | X | |
| Price of feed | | X | |
| Carcass removal costs | X | X | |
| Labor costs | X | X | |
| Milk price | | | X |
| Kg of feed per kg of milk | | | X |
| Yearly # of calves born | X | | |
| Ratio bulls/heifers | X | | |

*3.5 Raw data*

The dataset that was used to conduct the data analysis consists of 2 main parts. The first part was made up of data gathered and recorded by the farmer herself, the second part is data extracted from Cowvision, a farm management program used by the farmer for herd management (Agrovision Agricultural Software, 1996). The farm where the data was collected is located in the east of the Netherlands and holds about 250 lactating cows. The majority of the cows are Holstein Frisian. Replacement heifers are raised on the farm itself.

The farmer collected data on variables that describe the performance of a newborn calf within the first two weeks of its life. This data was recorded for each calve separately on a form (Appendix A). The recorded data was then entered manually from the forms into Excel files by the farmer. This data was merged into one Excel sheet by the farmer. Data on newborn calves was not collected continuously but during several periods between 2018 and 2023. During the preparation of the dataset, five separate documents were available that each spanned a period in which calves were born. In some periods additional data was collected. There is a number of calves born every year. In the years that are recorded only the performance data concerning the heifers is relevant. For a variety of reasons, heifers can be removed from the farm before they are of the age to get inseminated themselves. Table 9 shows the number of calves on which data was collected yearly.

*Table 7: number of heifers and bulls born in the recorded years*

| Year | # of heifers | # of bulls |
|---|---|---|
| 2018 | 29 | 30 |
| 2019 | 87 | 103 |
| 2020 | 0 | 0 |
| 2021 | 47 | 58 |
| 2022 | 111 | 138 |
| 2023 | 51 | 65 |
| Total | 325 | 396 |

To make the data analysis as complete as possible, the same variables were taken from each period. The variables that were not recorded each period were disregarded for the analysis. The fecal score is assessed twice daily, during the feeding moments of young calves, from the third day of life until the third week of life when they are placed in the 'next group' on the farm. The feces of the calves were scored with 0, 1, 2 and 3, with 0 being complete solid feces ranging to 3 which would be fluid feces. Such scoring systems are common in other studies (Jaureguiberry et al., 2023; Renaud et al., 2020)

Secondly, data was taken from Cowvision. This program records large amounts of data for the management of cow herds. Recorded data ranges from milk production performance per cow to treatments received. A list of all variables available from Cowvision can be found in Appendix B. From this large database, only few variables were selected that were necessary for the analysis.

*Table 8: List of variables that were taken from the data that was collected by the farmer and variables that were extracted from Cowvision*

| Variables from farmer | Variables from Cowvision |
|---|---|
| Cow number | Date of first calving |
| Stalnummer | Disposal date |
| Sex | Insemination attempts |
| Liters of 1st colostrum | Date of first insemination |
| Total colostrum intake | Date of successful insemination |
| Milk intake | Calving interval |
| Fecal scores | Milk production 305d |
| Date of birth | Milk production 1st lactation |

### *3.6 Data preparation*

The data was manually extracted from Cowvision due to the inconsistent usage of cow numbers from the cows in the first datafiles. To link the calves from both datasets correctly to each other, there were steps taken. In most cases the 'levensnummer' of the calve was used. In other cases the 'stalnummer' of the mother cow was used in the first datafile. If the mother cow was still present in the farm this could identify the calve together with the birth date. In the case that only the 'stalnummer' was written down and the mother cow was not present, the calve data was linked by birth date which was available in both the dataset and the Cowvision database.

After the intensive process of merging this data, some new variables were created that could be used as indicators.

- Birthdate combined with date of first insemination was used to create the variable ‘interval birth to insemination’.
- Birthdate combined with date of first calving was used to create the variable ‘interval birth to calving’.
- The separate fecal scores were combined in two sums; the first variable was the ‘total sum of fecal score’, the second variable was the ‘sum of fecal scores after day 6’.

To ensure the integrity of the data analysis, data points deemed implausible were excluded from the dataset.

To test for a relationship between a cryptosporidium infection and the recorded variables, it is needed to know if a calve had cryptosporidiosis. In this dataset not all calves were tested consistently for cryptosporidium with a test kit, though there is data on daily fecal performance per calve. This is an indicator since diarrhoea is one of the main symptoms of Cryptosporidiosis (Thomson et al. 2017). Besides, the calves in this dataset are all vaccinated against rotavirus and coronavirus. Hence, a definition needs to be established with which fecal scores a calve is labeled as being ‘infected’ with cryptosporidium.

The symptoms of an infection start showing in the second week of life. The disease usually appears in calves that are at least 7 days old calves (Thomson et al. 2017). Therefore, the grouping was done based on fecal scores before and after day 6 higher than 1. Fitting to the symptoms, a calve was only considered sick when it has a fecal score higher than 1 for 2 moments (1 day) or more. The days where a calve has a fecal score of 1 are not used while making the distinction. The calves with diarrhoea for 2 moments (1 day) before or on day 6 are taken up in another group, as well as calves with diarrhoea for 2 moments (1 day) before and after day 6. Calves with less than 2 moments of diarrhoea or no diarrhoea at all were considered healthy and grouped together. These status numbers were added as an extra column in the dataset, based on a cell formula in Excel. After assigning the status to all bulls and heifers, the following numbers per year can be found in table 9 for both sexes.
In summary, the following groups are made:

- Status 0, no fecal score for 2 moments or more higher than 1
- Status 1, fecal score for 2 moments or more higher than 1 after day 6
- Status 2, fecal score for 2 moments or more higher than 1 before day 6
- Status 3, fecal score for 2 moments or more higher than 1 before day 6 and after day 6

*3.7 Data analysis*

The data analysis aimed to identify the magnitude of the effects that were found in the table 1 in the described dataset. The following steps were undertaken to achieve the aim;

- First an overview of the variables included in the dataset will be provided by using descriptive statistics. These descriptive statistics will be supported by several figures illustrating trends in the dataset..
- Secondly, on the previously established groups statistical tests were be performed to test if there is a difference on the variables* of these groups. For example, a Wilcoxon rank sum test was performed to tests if the mean insemination attempts for the group of status 0 is significantly different to that of the group with status 1.
- Thirdly, a multivariate regression analysis was performed to control for confounding variables*.
- Lastly, a a regression analysis was conducted on the sum of fecal score after day 6 as independent variable and different variables* as dependent variables.

*the variables that are subject to test are; interval between birth and first insemination, interval between birth and first calving, insemination attempts, milk production 1$^{st}$ lactation, milk production 305d, calving interval.

The descriptive statistics were all computed in Excel. The statistical test were performed in R.

*3.8 Sensitivity analysis*

To identify the key drivers in the model and to validate the model, a sensitivity analysis was carried out. During the sensitivity analysis, the effect of changing some selected parameters was evaluated for different economic and non-economic outputs. In the study by Mohd nor et al. (2012), all elements of the model were tested on sensitivity. In this case the parameters that were tested are those that were changed during the adaptation of the model. Table 6 shows which input parameters were changed. Besides, the table also shows which (non-)economic outputs were studied.

*Table 9: Inputs and outputs studied in the sensitivity analysis*

| Input | Economic outputs | Non economic outputs |
|---|---|---|
| Incidence | Total costs | Crypto cases (%) |
| | Feed costs | |
| Mortality | Labor costs | Heifers culled (% |
| Growthreduction cryptosporidiosis | Barn costs | Heifers dead (%) |
| | | Age esterus detected |
| Labor costs (eu/hr farmer) | | Pregnancy age |
| Vet call | | |
| Costs of treatment by farmer | | |
| Costs of treatment by veterinarian | | |

## 4. Results

*4.1 Descriptive statistics*

The variables that are included in the data analysis together with the number of heifers is stated in table 8 . Together with some descriptive statistics. Because the data is recently collected, there is more data for some variables than others. For example, the heifers monitored in 2022 have not reached their first full lactation.

*Table 10: descriptive statistics on the studied variables*

| Variable | Period | # of heifers | Average | SD | Min | Max | Median |
|---|---|---|---|---|---|---|---|
| Fecal score | | 325 | 3,6 | 5,0 | 0 | 26 | 1 |
| Interval birth - 1st insemination | Until 2023 | 148 | 472 | 71 | 193 | 863 | 461 |
| Interval birth – 1st calving | Until 2022 | 100 | 775 | 78 | 500 | 1143 | 772 |
| Insemination attempts | Until 2022 | 106 | 2,03 | 1,57 | 1 | 9 | 1 |
| Milk production 1st lactation | Until 2021 | 50 | 7490 | 2243 | 1178 | 15817 | 7238 |
| Milk production 305 days | Until 2021 | 50 | 6691 | 1415 | 1178 | 9259 | 6727 |
| Calving interval | 2018 and 2019 | 41 | 385 | 36 | 334 | 462 | 379 |

In figure 5, the frequency of fecal score higher than 0 across the moments is shown. The figure fits a farm that suffers from cryptosporidium outbreaks, since the symptoms of the disease start showing from day 7 onwards. Interesting observations from the data on fecal performance are that; It can be seen that fecal score of 2 is used relatively less than 1 and 3. Figure 6 shows average cumulative fecal score per cow across different years. Average fecal score is highest in 2018, with some stable years in 2019, 2021 and 2022 with a slight decrease in 2023. Moreover, the average fecal score is higher in bulls, which is shown in figure 7.  The figures are based on the both bulls as heifers since both stay on the farm for at least 2 weeks according to legislation, therefore there is data on performance of both sexes.

After the figures, two tables show descriptive statistics regarding the previously assigned status. Table 11 contains the number of calves that belong to a certain group during each year. Then, the averages for all statuses on different variables are shown in table 12.

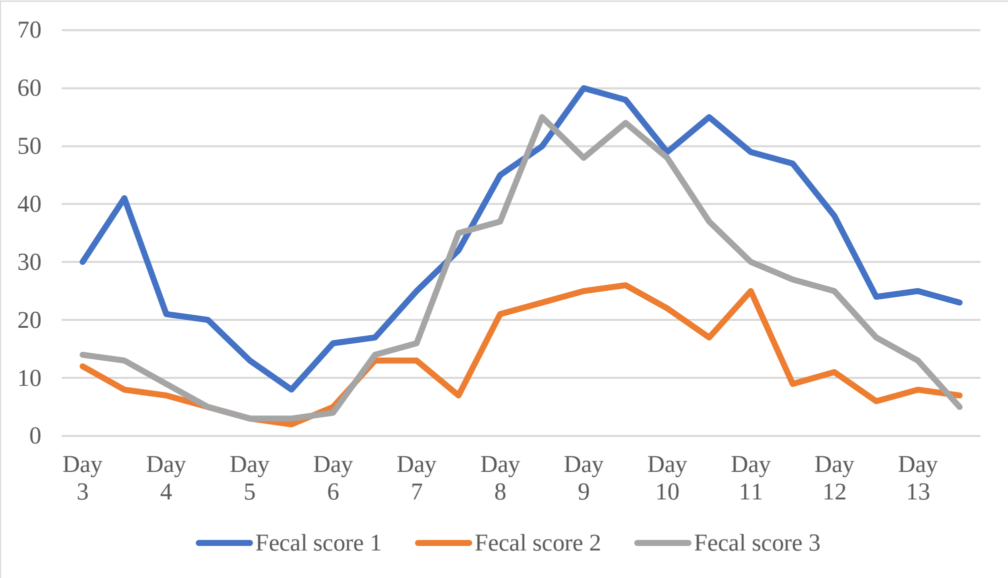


*Figure 5: Frequency of fecal across different days in the beginning  of a calves life*

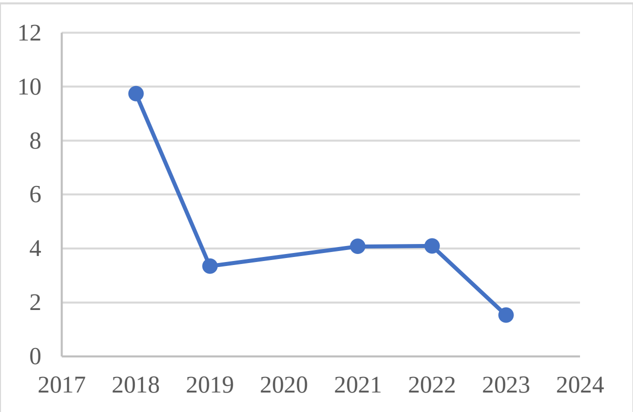


*Figure 6: Average cumulative fecal score per year of all new born calves on the farm*

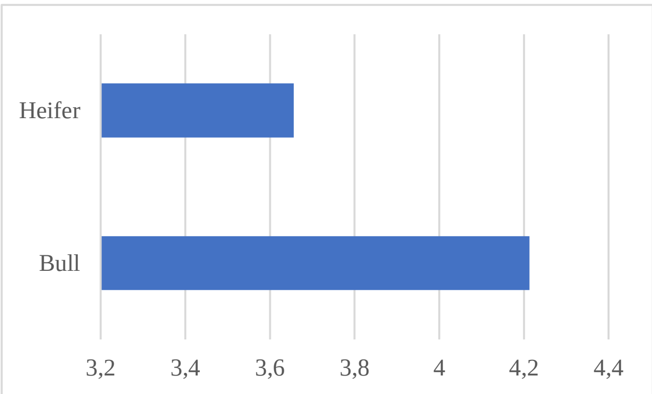


*Figure 7: Average cumulative fecal score for different sexes of calves*

*Table 11: # of bulls and heifers with a certain  status per year*

| **Year status** | **Bull** | **Heifer** | **Total** |
|---|---|---|---|
| **2018** | **30** | **29** | **59** |
| 0 | 8 | 10 | 18 |
| 1 | 15 | 14 | 29 |
| 2 | 2 | 3 | 5 |
| 3 | 5 | 2 | 7 |
| **2019** | **104** | **87** | **191** |
| 0 | 78 | 68 | 146 |
| 1 | 22 | 13 | 35 |
| 2 | 2 | 6 | 8 |
| 3 | 2 | | 2 |
| **2021** | **58** | **47** | **105** |
| 0 | 44 | 32 | 76 |
| 1 | 13 | 13 | 26 |
| 2 | | 1 | 1 |
| 3 | 1 | 1 | 2 |
| **2022** | **139** | **111** | **250** |
| 0 | 88 | 87 | 175 |
| 1 | 48 | 24 | 72 |
| 2 | 2 | | 2 |
| 3 | 1 | | 1 |
| **2023** | **65** | **51** | **116** |
| 0 | 59 | 47 | 106 |
| 1 | 6 | 3 | 9 |
| 2 | | 1 | 1 |
| **Total** | **396** | **325** | **721** |

*Table 12: Descriptive statistics for different groups on the measured variables*

| | Total | Status 0 | | Status 1 | | Status 2 | | Status 3 | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | N | Value | N | Value | N | Value | N | Value | N |
| Cummulative fecal score | 325 | 1,3 | 242 | 9,9 | 52 | 7,9 | 14 | 13,9 | 17 |
| Interval birth - 1st insemination (days) | 136 | 477 | 94 | 466 | 25 | 446 | 6 | 463 | 11 |
| Interval birth – 1st calving (days) | 100 | 774 | 68 | 784 | 18 | 717 | 5 | 797 | 9 |
| Insemination attempts | 106 | 1,8 | 71 | 2,6 | 19 | 2 | 6 | 2,4 | 10 |
| TKT (days) | 41 | 386 | 24 | 383 | 7 | 391 | 4 | 381 | 6 |
| Milk production 1st lactation (kg) | 49 | 7663 | 30 | 7558 | 9 | 7329 | 4 | 6886 | 6 |
| Milk production 305d (kg) | 49 | 6598 | 30 | 7023 | 9 | 7070 | 4 | 6525 | 6 |

*4.2 Statistical tests*

The variables that were being tested were first checked for normality by visual inspection. None of the variables were normally distributed. Besides, the groups did not comprise of the same number of calves. Therefore a Wilcoxon rank sum test was selected as an appropriate test. The aim was to test whether a difference exists between the groups. The group of healthy calves (status 0) was tested against the group with a cryptosporidium infection (status 1). None of the test showed a signficant outcome.

A multivariate regression analysis was conducted to check the influence of the sum of fecal score as independent variable on the dependent variables that are previously shown. By conducting this analysis, the combination of the dependent variables is used to make a prediction for the independent variable. This regression analysis showed no significant results.

In appendix C several scatter plots are shown. The scatter plots depict the sum of fecal score after day 6 plotted against the previously tested variables for only the period 2018-2019. These suggest there is a trend between the severity of sickness and the performance on certain variables. Due to the limited number of observations the significance of the performed test might be constrained.

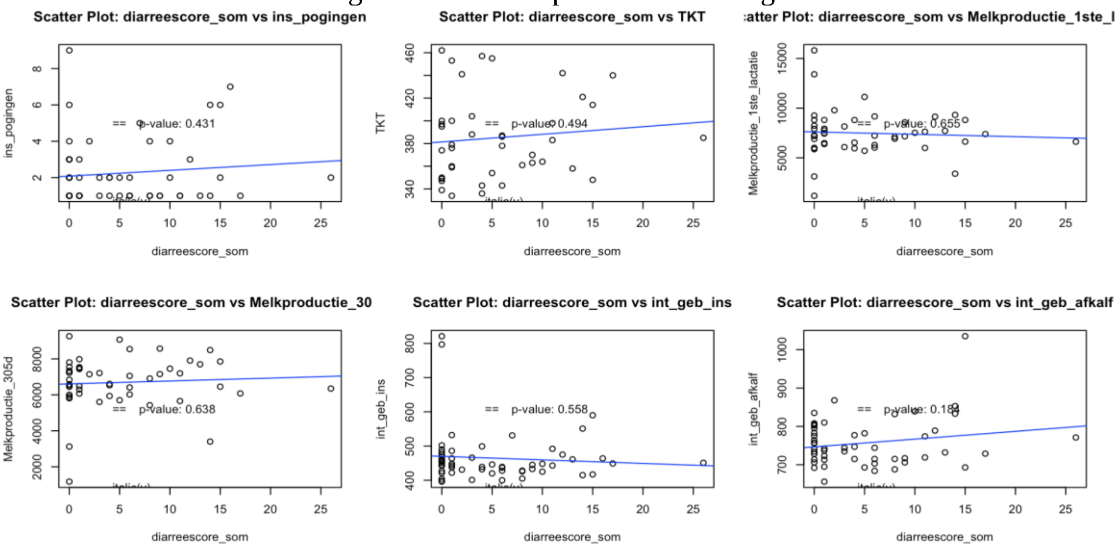


*Figure 8: Regression analysis for sum of fecal score after day 6 plotted against the independent variable fecal score sum*

*4.3 Parameterization of the simulation model*

Prevalence

The morbidity rate of cryptosporidium is a widely studied subject. Across different countries, regions and farms different outcomes are found when studying this subject. Pinto et al. (2021) conducted a study specifically on the prevalence across dairy farms in the Netherlands and found that 32,5% of calves suffered an infection. This is higher than the global prevelance found by Chen et al. (2023). Part of this difference can be explained by the relatively high stocking density in the Netherlands which is suggested as a risk factor.

Mortality rate

In the worst case, an infection with cryptosporidium can lead to mortality. Mortality rates as high as 35.2% are found (Singh et al., 2006). The only study on the mortality rate in the Dutch dairy industry is conducted by Roblin et al. (2023). The study shows that in the Netherlands mortality rates of 23.3% and 14.3% are found in 2018 and 2021 for diarrhoeic calves.

Reduced growth

Retarded growth due to diarrheic disease is frequently mentioned as a possible cost burden (De Graaf et al., 1999; Ghazy et al., 2015; Thomson et al., 2017) Quantification of this reduction is estimated by

Shaw et al. (2020) who found a 34 kg decrease in weight gain during the first 6 months for calves suffering severe cryptosporidiosis.

Reduced milk production
Whether milk production is affected by cryptosporidiosis has been studied before. On the one side there is research by Moerman et al. (1994), Esteban & Anderson (1995), Svensson & Hulltgren (2008), Abuelo (2021) which suggest there is a significant relationships with either a cryptosporidium infection or early life calf diarrhoea and first lactation milk production. On the other side there is research by Aghakeshmiri et al. (2017) which suggest no such relation. 3 studies suggest a relationship and also provide an estimate for the degree of the relationship; -3.2kg daily, -976kg per 305d (Esteban & Anderson, 1995), -344kg per 305d (Svensson & Hultgren, 2008) and -325kg per 305d (Abuelo et al., 2021).

Treatment costs
Both cost of treatment performed by the farmer themselves and for treatment by the vetenarian are estimated. The cost for an 'average' treatment will be considered. In the case of the farmers treatment this will be eloctrolytes, which will cost 18 euros for the total duration of the treatment. When the vetenarian will visit another treatment will be performed, being an intravenous drip. This will cost 100 euro for treatment only/ Both treatments exclude the labor costs. The odds of a veterinarian visiting are also taken up in the model. There was no data on the chance that a visit from the vet occurs in practice. Farmers expertise was used and resulted in a 5% chance of a vetenarian getting called when a scours cases occurs.

Purchase of cattle & Selling of cattle
In most cases the dairy farm and heifer rearing facility are the same farm, but on paper they exist as separate identities. Therefor a price needs to be paid from one enterprise to the other. Cost of a 2 week old heifer also vastly different from those of 2 week old bulls. To estimate these cost the 3 year average between 2021 and 2023 of Agrimatie will be used. For bulls this comes down to € 94,17, for heifers this is € 31,66 (Agrimatie, 2024)

Concentrate
A lactating cow needs to be fed concentrate to produce milk. When lactation is lower due to disease, concentrate consumption is also reduced. A rule of thumb is 0.5kg of concentrate per kg of milk (H. Hoogeveen, Personal communication, April 12, 2024). Price of standard dairy cow concentrate is € 0,33 per kg (Agrimatie, 2024)

Labor costs & carcass removal costs
These costs that are also mentioned in the model will the same in the patial budget. Carcass removal costs are 31,70 (Rendac, 2024). The cost of labor of the farmer in the first 2 weeks are estimated at 13,42, consisting of the time needed for feeding the calve per week.

### *4.4 Economic effects of crypto: model*

When the model was run with 10,000 iterations with the default input parameters, the following results were found: it was found that 90.72% of the heifers were raised successfully, 6.38% died as a result of disease and 2.9% were culled because of reproductive failure. 35.64% of the heifers suffered a cryptosporidium infection. Total costs for a successfully raised heifer were € 2508. Feed costs were the biggest part of the total, at € 1141 (45,5%), the second biggest cost was the labor € 554 (22,10%), barn costs were the third biggest expense at € 445 (17,75%). Insemination costs (2,5%), lost sales (1,8%), preventive treatment (1,44%) and treatment costs (0.5%) make up most of the other costs. The age at which the average pregnancy started was after 14.7 months at an average bodyweight of 368 kg.

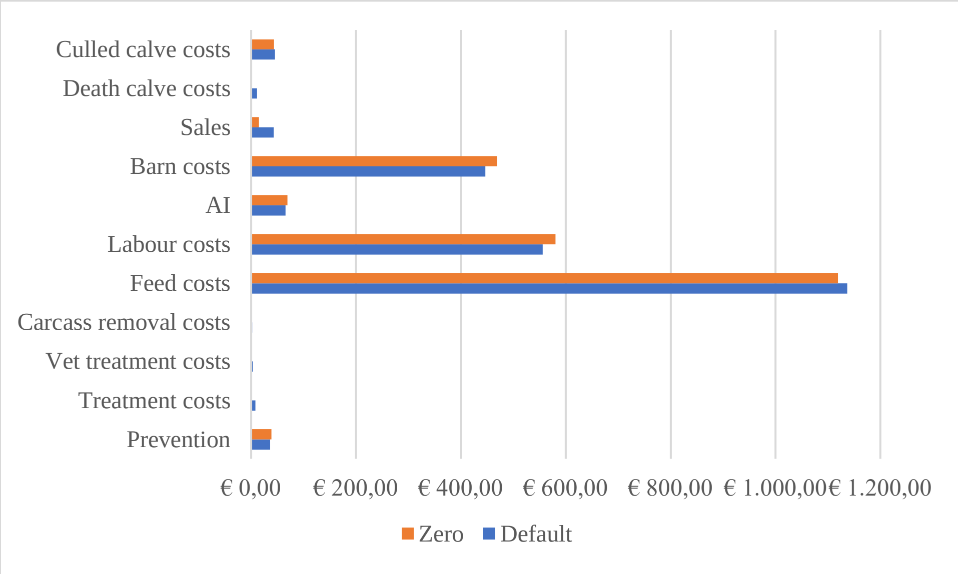


*Figure 9: Comparison of the components of the total costs in two different simulation. The simulation with default crypto incidence (32.5%) and zero crypto incidence.*

When the incidence of crypto is set to zero, the total costs drop by 5.6%, to € 2367. This is mostly due to the costs of dead heifers which decrease dramatically. Other parts of the rearing, such as feed and barn costs increase in costs. Figure 9 shows the difference between the default inputs and the zero cryptosporidium incidence simulation. A clear difference can be seen between the two, not only in the total but also in the combination of the costs. In terms of non-economic parameters, the age of estrus and calving is all lower (-2,01% and -1,63%), first calving weight is slightly higher at +0,59%.

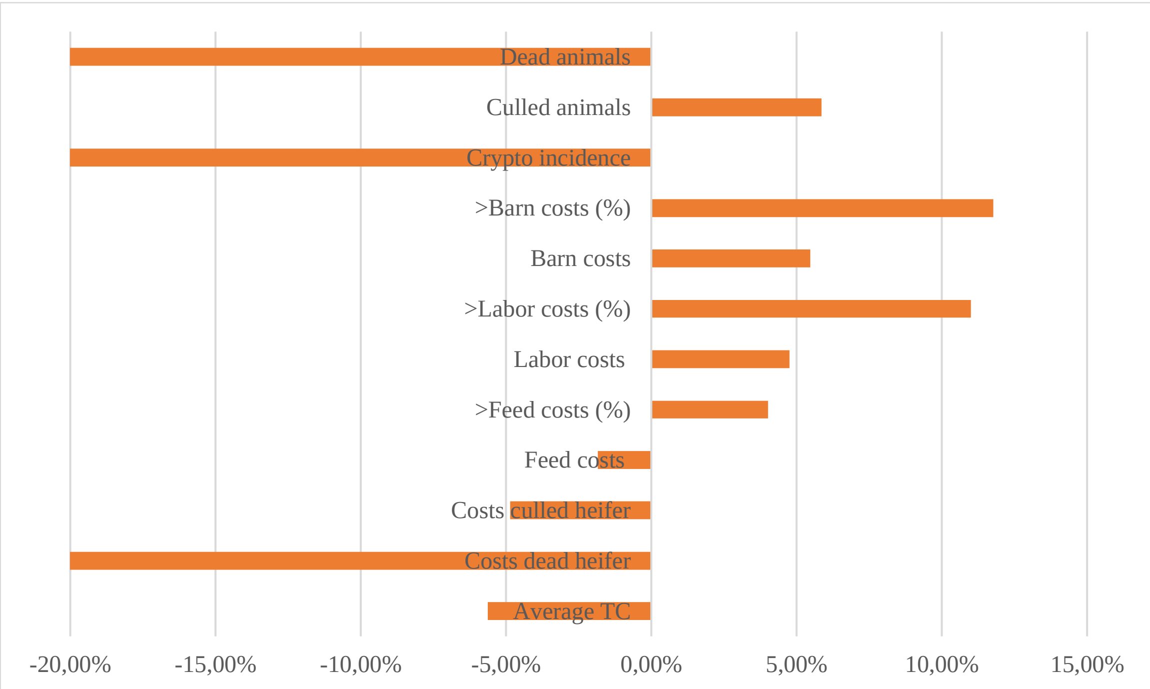


*Figure 10: Percentage change in economic output parameters comparing the default situation versus the situation with no cryptosporidium*

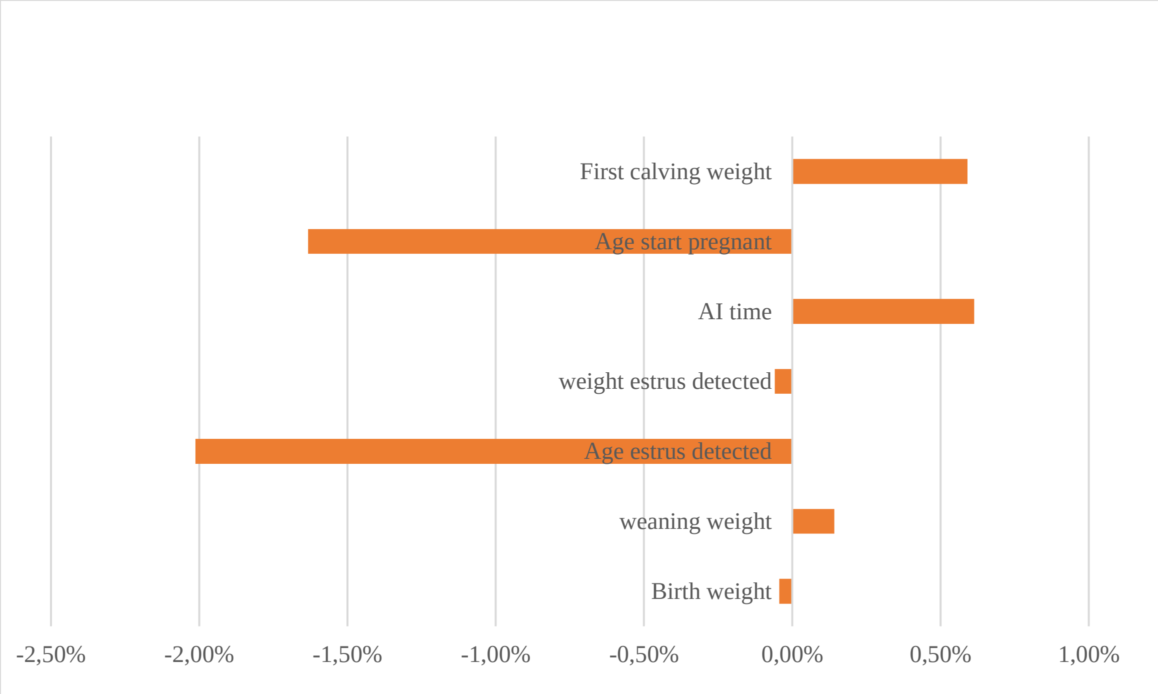


*Figure 11: Percentage change in economic output parameters comparing the default situation versus the situation with no cryptosporidium*

### *4.5 Economic effects of crypto: partial budgets*

The first partial budget is on the scale of a farm instead of calf level. For the first partial budget on the mortality during the first two weeks the average number of calves born per farm is needed. Together with the Dutch replacement rate (28%), the TKT (410d), and the average farm size (107 cows), an estimation can be made. Approximately 68 cows are born yearly (107*(1-0.28)*(365/410) = 68). Of which roughly half are bulls, which have the same chance of falling ill and dying from cryptosporidium. An overview of the revenues and costs can be found in table 12. The total costs incurred in the first partial budget are in total -€ 242, divided over 34 heifers born is -€ 7. The full calculation can be found in appendix C. Mortality costs of heifers are left out of the calculation since their death is also included in the model.

*Table 13: Results of the partial budget on mortality in the first two weeks after calving*

| Increase revenues | | Decrease revenues | |
|---|---|---|---|
| | | Sales of bulls and surplus heifers | -€ 203,43 |
| Decrease expenses | | Increase expenses | |
| Labor on dead animals | € 28,99 | Carcass removal costs | -€ 68,48 |

The second partial budget on the costs of milk losses due to cryptosporidium is provided in table 13. The average milk losses per 305d lactation were estimated at -537 kg ((-944+-344+-325)/3). With a milk price of € 0.46 this would incur a cost of -€ 247. With a ratio of 0.5 for kg of concentrate / kg milk yield, the reduced costs are € 90,48. The total costs for the second partial budget are thus € 161,76. These costs is incurred for successfully raised heifer which did suffer from a cryptosporidium infection in early life. On a farm, approximately 29% of the heifers fit that description (0.353*(1-0.18)=0.28946). Therefore the losses per successfully raised heifer are -€ 46. Also the full calculation for this partial budget can be found in appendix D.

*Table 14:: Results of the partial budget on reduced milk production during the first lactation*

| Increase revenues | | Decrease revenues | |
|---|---|---|---|
| | | Milk production | -252,23 |
| Decrease expenses | | Increase expenses | |
| Feed costs | 90,48 | | |

*4.6 Sensitivity analysis*

| Input | Default | Source | Change | Economic outputs | Non economic outputs |
|---|---|---|---|---|---|
| Incidence | 32.5% | Pinto et al. (2021) | -10% and +10% | Total costs<br>Feed costs | Crypto cases (%) |
| Mortality | 18% | Roblin et al. (2023) | -10% and +10% | Labor costs | Heifers culled (% |
| Growth reduction cryptosporidiosis | -13.6% | Shaw et al. (2020) | -5% and +5% | Barn costs | Heifers dead (%)<br>Age esterus detected |
| Labor costs (eu/hr farmer) | € 20/hr | Expert knowledge | -3 eu and +3 eu | | Pregnancy age |
| Vet call | 5% | Expert knowledge | -5% and +5% | | |
| Costs of treatment by farmer | €18 | Expert knowledge | -€10 and +€ 10 | | |
| Costs of treatment by veterinarian | €100 | | -€ 50 and +€ 50 | | |

The sensitivity analysis shows that an increase and decrease of hourly labor costs has the highest impact on the total costs of 3% and -3.3% respectively. The incidence of crypto also impacts the total costs, but to a lesser degree. The other changes of input parameters don't show such a tremendous effect on the total costs. Where sometimes a change in input parameters doesn't affect the total costs, it might only affect the relative costs. For example; increasing the odds of a veterinarian getting called by 5% does not affect the total costs, but it makes the costs of each dead heifer 6% higher. When the mortality rate increase by 10%, the feed costs change by -4.5%, the labor costs by -3.7% and the barn costs by -3.8%.

The changes in non-economic outputs that result from the sensitivity analysis are only found in the age of the heifers (Age estrus detected, age start pregnancy, first calving age). This is because the stage of the model depend on bodyweight. Relative change in estrus detected is highest in the situation with high mortality rate (-1,82%). The change in growth reduction saw a smaller reaction in the low growth reduction (-0,71%) and high growth reduction (+0,52%) case. In all cases the change of age start pregnancy is observable the same, but smaller. The number of artificial inseminations is the same in all situations.

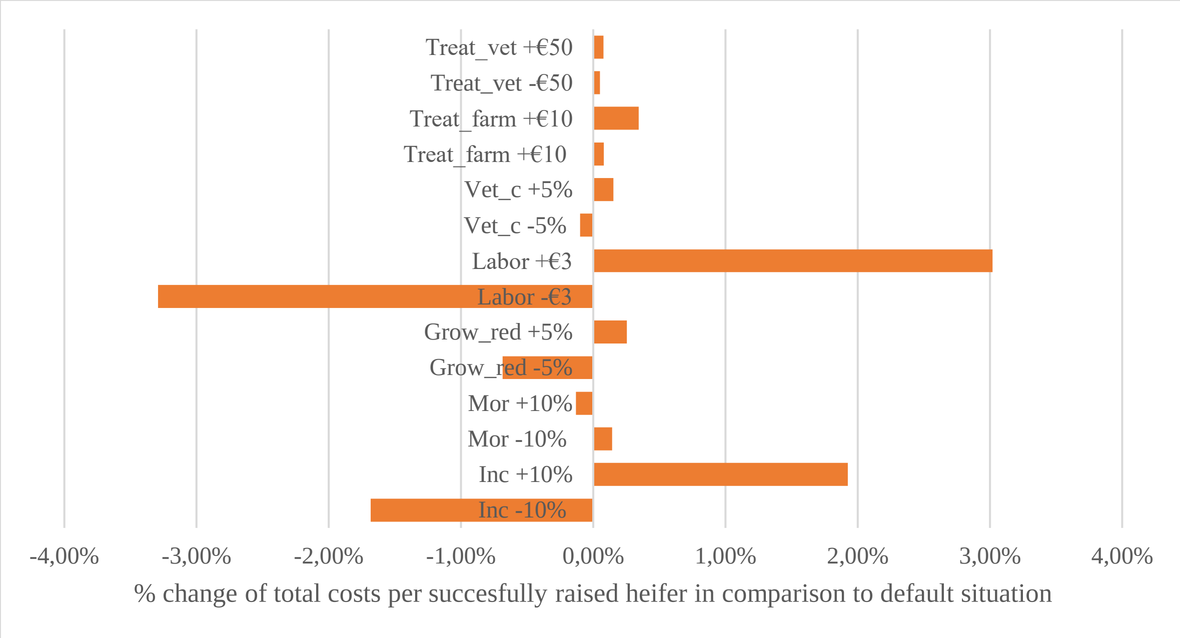


*Figure 12: Sensitivity analysis of different input parameters with their percentual effect on total costs. Treat_vet = treatment costs of veterinarian, treat_farmer = costs of treatment by farmer, Vet_c = % of cases in which veterinarian is called, Labor = Hourly wage of farmer, Grow_red = percentual growth reduction across the first 6 months of life, Mor = mortality rate due to cryptosporidiosis, Inc = Incidence of cryptosporidiosis.*

### *4.7 Total results*

To estimate the costs an outbreak of cryptosporidium, the situation with default settings is compared to the one with zero incidence. The first partial budget on the first 2 weeks had a total result of -€ 242, divided over 34 heifers leaves -€ 7. The model for heifer rearing had a result of -€ 141. The partial budget on the first lactation showed losses of -€ 112 per heifer, combined with the prevelance of cryptosporidium leaves -€ 47 For the three parts together, the combined costs add up to € 195 in total (-€ 7+-€ 141+-€47).

## 5. Discussion

For a long time it was suggested that an early infection with cryptosporidium also incurred costs due long term effects (De Graaf et al., 1999; Ghazy et al. 2015). However, only one calculation on these effects could be found (Roblin et al. 2023), but this research was limited to the direct costs. The objective of my research was to give a total estimation of these costs involved by also estimating the long-term costs. In order to quantify these long term effects, farm data was available from a Dutch dairy farm of above average size. The collected data included among others fecal performance of the first weeks of the calves life as well as performance indicators of performance at later stage of the rearing process. During the literature review the biological and economic effects of cryptosporidium (and diarrhoeal) disease were listed. The goal of the subsequent analysis of the collected data was to quantify these effects. At this point several limitations were presented.

Firstly, due to inconsistent and limited testing of calves for cryptosporidium the diagnosis of disease was done by assessing the fecal performance. The grouping of animals based on fecal performance on certain days of an early calf's life does indicate whether the animal was sick. Tough, the dams on the farm were vaccinated against rotavirus, this doesn't exclude the possibility of getting infected by the virus (Pinheiro et al., 2022). It is therefore essential to acknowledge this assumption and the implications this could have had on the subsequent results.

Secondly, the several analyses done on the own data yielded no significant results. Although there was data on a considerable amount of heifers, the effects of disease that were found earlier could not be verified and quantified in this research. A larger dataset from the same farm or data from additional farms could solve this issue. The quantification of the long-term effects is now done by reviewing literature.

Assumption of the model that was used are also discussed in the paper by Mohd Nor et al. (2012). The changes that were made to the model were either to fit the model to the current situation or for simplification. For that reason, only one disease was included. In practice, a lot more diseases are conceivable.. More important is the difference between the outcome of the default situation in comparison to the outcome without any cryptosporidium. The result of that comparison is that the total cost increases with € 141 with the incidence rate that is found by Pinto et al. (2020). At the same time, labor costs and barn costs are higher when there is no disease. This can be attributed to the fact that a dead animal is much cheaper in itself than a heifer that is raised successfully.

The sensitivity analysis shows that changing the price of labor has the biggest impact on costs. This could be expected since these costs are incurred daily. Also when changing the incidence rate of cryptosporidium these costs are very much affected. Costs of the vet are only a very small part of total costs; this is confirmed by the farmer. When considering the non-economic outputs, growth retardation caused the age at which estrus was detected to be later as well as the age at which pregnancy started. This is in contradiction with management practices previously studied by Mourits et al. (2000), which suggests that breeding moment is not determined by weight but by age in the Netherlands.

Interestingly, 10% higher mortality rate in the model makes the total costs decrease. Even though in regards to costs mortality is not a big issue, calf mortality in the popular media is perceived very negatively (RTL Nieuws, 2019; NOS, 2019 ).

A limitation to the model is that it does not account for variability in retardation of growth. When an animal is diseased the growth is retarded by a 13% which is found by Shaw et al. (2020), but the same research also suggest that the severity of disease can impact the degree of retardation. This is not included in the model.

One of the effects quantified by literature is the reduced milk production in the first lactation by cows that were previously infected by cryptosporidium. There are at least 4 studies supporting this finding (Moerman et al., 1994; Esteban & Anderson, 1995; Svensson & Hulltgren, 2008; Abuelo, 2021)) On the other hand, some studies on large datasets do not find this difference (e.g. Aghakeshmiri et al. 2017). Therefore, claiming that this large cost burden exists is not without hesitation. Further research on first lactation milk production after early life disease can be insightful. The combination of these limitations indicates that the absolute total costs should be perceived carefully. Consequently, it is advisable to interpret the total estimation as an indication that costs could run up to that extent.

The total costs of cryptosporidium could reach up to € 195 per successfully reared heifer, of which only a small part is incurred directly during the ill period of the calve at the start of life. The study by Roblin et al. (2023) estimated the costs at € 58.24 (and € 39.48 after changing management practices). This substantial difference can be explained because my study takes into account a lot more economic and biological factors that incur costs, while the study by Roblin et al. only considers direct costs. This study contributes to better understanding the economic impacts that cryptosporidiosis has on the long term for dairy farms. With the recent introduction of a vaccination against cryptosporidium (MSD Animal Health, 2023) this research could contribute to understanding the cost-effectiveness of a vaccination. This study cannot solve the decision on whether to vaccinate pregnant dams or not, but in combination with the effectiveness of a vaccination the economics of such preventive treatment can be estimated.

## 6. Conclusion

The aim of the research was to estimate the total costs of a cryptosporidium outbreak on a typical Dutch dairy farm. To make a complete estimation, literature was studied to find the short term and long term economic and biological effects. Effects that were found included direct costs such as treatment costs, extra labor costs and mortality. Furthermore, long term effects such as growth retardation and reduced milk production were found. An existing stochastic model from Mohd Nor et al. (2012) was slightly adapted to estimate the cost of cryptosporidium in a Dutch setting. Since this model did not cover all cost incurring factors of a sick calve, two simple partial budgets were performed. The first partial budget estimates the cost that mortality has in the first 2 weeks after birth. The second partial budget quantifies the results of reduced milk production in the first lactation. Successfully rearing a heifer from 2 weeks of age until first lactation costs € 141 when the farm suffers from cryptosporidium. In the first 2 weeks mortality will cost a dairy farm € 7 euros per heifer. Reduced first lactation is estimated to cost € 47 per heifer. The total costs of cryptosporidiosis for rearing a replacement heifer on a typical Dutch dairy farm are up to € 195 per successfully raised heifer.

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## Appendices

Appendix A: Registration form newborn calves

## Registrationform Halve Welle Trial Sangrovit® WS

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Liveno cow/no calf | Calf | Date of birth | Time of birth | birth weight | | | | Date of removing calf | | |
| | Bull/Heifer | | | | | | | | place of birth | |
| Birth | | | | | | | | | | |
| | | | Colostrum quality | Probe | | Colostrum of | | Manure score | Sangrovit® WS | |
| Colostrum | Time | Intake (L) | Brix | Yes | No | Yes | No | 0-1-2-3 | yes | No |
| 1 | | | | | | | | | | |
| 2 | | | | | | | | | | |
| 3 | | | | | | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| Remarks | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| Milk replacer | Intake | Start concentrate | Manure score | Probe | | | | | Sangrovit® WS | |
| | in liters | | 0-1-2-3 | Yes | No | Medication | | reason | yes | no |
| 1 | | | | | | | | | | |
| 2 | | | | | | | | | | |
| 3 | | | | | | | | | | |
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| 28 | | | | | | | | | | |
| 29 | | | | | | | | | | |
| Weight day 14 | Heifer | Bull | Remarks | | | | | | | |
| Breast | | | | | | | | | | |
| Weight/date | | | | | | | | | | |

Appendix B: A list of all variables available from Cowvision

| Basisgegevens | Diergezondheid | Vruchtbaarheid | Melkcontrrole |
|---|---|---|---|
| Dier aanwezig | Aantal dagen lact | Uitvoerder drachttest | Kg melk totaal (lact) |
| Diercategorie | Behandeling | Uitvoerder inseminatie | Melkcontroledatum / MPR |
| Diernr | Behandeldatum | Uitvoerder tochtigheids controle | Celgetal -1 (vorige) |
| Kalfdatum | Behandelingen | Melkmee datum (na behandeling) | Celgetal -2 (voorlaatste) |
| Lactatienr | Diagnose datum | Melkmee datum (na kalven) | Celgetal 0 (laatste / huidige) |
| Levensnummer | Diagnosecategorie | Opmerking(vruchtb.) | Celgetal 1 |
| Werknr | Droogzetdatum | Aantal inseminaties | Celgetal 2 |
| Aanw op ltste MPR datum | Droogzetter gebr | Bevruchtingsdatum | Celgetal 3 |
| DryOnMPRdate | Locatie | Chargenr insem | Celgetal drempelwaardes |
| Geboorte datum | Medicijn | Dekdatum / ins.datum | Celgetal |
| Geslacht | Opmerking (ziekte) | Dekinfo / type inseminatie | Eiwit % (dag) |
| Haarkleur | Regnl | Dosis | Eiwit% (305) |
| Koe productie type | Soort medicijn | Drachtonderzoek | Eiwit% (lact) |
| Laatste / huidige lactatie | Toedieningswijze | Interval na kalven | ISK |
| Leeftijd | Wachttijd melk | Lactatiedagen actueel | Ketose (dag) |
| Leeftijd maanden | Wachttijd vlees | Leeftijd afkalven | Kg melk (dag) |
| Naam | Ziekte / stoornis | Nat dek | Kg melk /dag (lact) |
| Responder 1 | Bact onderzoek | Stiernaam | Lactatiedagen |
| Aan- afvoer datum | Batchnr | Tocht datum | Lactatiewaarde |
| Aanhouden | Behandelplan actief | Toestand / status | Lactose % (dag) |
| Aankoopdatum | Behandelplan afkorting | Verwachte afkalfdatum | Leeftijd op moment van MPR |
| Aankoopprijs | Behandelplan omschr | Actief stieren | Levenstotaal Kg melk |
| Aanvoerdatum | Behandeltype | Dagen dracht realisatie | Netto opbrengst EJR (305 dgn) |
| Afk. naam vader | Dagen droog | Dagen drachtig actueel | Ureum (dag) |
| Afmesten | Document nr | Datum drachtonderzoek | V+E gr (dag) |
| Afvoer leeftijd | Eenheid | Datum ltst drachtonderzoek | Verwachte kg melk |
| Afvoerdatum | Eigen voorraad | Dracht uitslag / resultaat | Vet + Eiwit (dag) |
| Bestemd voor verkoop | Med actief | Eigen voorraad | Vet% (305) |
| Datum notitie | Medicijn afk | Einde samenweiden | Vet% (dag) |
| Donorkoe | Stoornis lactnr | Gesext | Vet% (lact) |
| Donormoeder | Toegediend door | Proc kalfdatum | Droogzetdatum lact prod koe |
| Externe tak | UDD | Proefstier | Kg eiwit (305) |
| Geboorte gewicht | Locatie behandeling | Statusdagen actuele status | Kg eiwit (lact) |
| Geboren op bedrijf | Staalnemer | Stier actief | Kg melk totaal (305) |
| KI-Code vader | Staaltype | Stier insem levnr | Kg vet (305) |
| Levensnummer moeder | Testdatum | TKT | Kg vet (lact) |
| Levensnummer vader | Uitslag | Toestands-/statusdatum | Vet / Eiwit (lact) |
| Locatie overgang | Hoeveelheid totaal behandelingen | Type kalving | |
| Moeders vader | Behandeling temperatuur | Verwachte TKT | |
| Moeders vader regid | Hoeveelheid / behandeling | Verwachte droogzetdatum | |
| Naam moeder | | Vleesstier | |
| Naam vader | | | |
| Notitie / opmerking dier | | | |
| Overleving geboorte | | | |

| | | | |
|---|---|---|---|
| Productiedoel | | | |
| Responder 2 | | | |
| Toestand kalf | | | |
| Type aan- afvoer | | | |
| Type diernummer | | | |
| Vaders vader | | | |
| Vaders vader regid | | | |
| Verkocht aan | | | |
| Verkoopprijs | | | |
| Verkoopreden | | | |

Appendix C: Full partial budget calculations for the effect of mortality due to cryptosporidium in the first two weeks after calving

| Effect of mortality in first 2 weeks due to cryptosporidiosis | | | |
|---|---|---|---|
| **Additional income** | | **Lost income** | |
| | | Sales of bulls | -€ 205,18 |
| | | | |
| **Cost saved** | | **Additional costs** | |
| Labor spent on animals | € 29,24 | Carcass removal costs | -€ 69,07 |
| | | | |
| **Total losses per farm** | -€ 245,01 | | |
| **Per succesfully raised heifer** | -€ 7,14 | | |
| | | | |
| Size of farm | 107 | Dutch average | |
| Replacement rate | 28,00% | Dutch average | |
| TKT | 410 | Dutch average | |
| jaar/tkt | 0,8902439 | Depending on farm | |
| Aantal koeien die niet vervangen worden, v | 77,04 | Depending on farm | |
| # of calves born yearly | 68,58 | Depending on farm | |
| Mortality rate due to crypto | 6,35% | Roblin et al. (2023) | |
| Ratio bulls / heifers | 0,5 | Henk | |
| Price of bull at 2 weeks | € 94,17 | Agrimatie (2024) | |
| Price of carcass removal | € 31,70 | Rendac (2024) | |
| Labor feed | € 13,42 | from model | |

Same calculation, but with formulas shown

| | | | |
|---|---|---|---|
| Effect of mortality in first 2 weeks due to cryptosporidiosis | | | |
| **Additional income** | | **Lost income** | |
| | | Sales of bulls | =-(B16*B18*B17*B19) |
| | | | |
| **Cost saved** | | **Additional costs** | |
| Labor spent on animals | =(B21*B16*B17)*B18 | Carcass removal costs | =-B20*(B16*B17)*B18 |
| | | | |
| **Total losses per farm** | =B6+D6+D3 | | |
| **Per succesfully raised heifer** | =B8/(B16*B18) | | |
| | | | |
| Size of farm | 107 | Dutch average | |
| Replacement rate | 0,28 | Dutch average | |
| TKT | 410 | Dutch average | |
| jaar/tkt | =365/B13 | Depending on farm | |
| Aantal koeien die niet vervangen worden, wel kalven | =B11*(1-B12) | Depending on farm | |
| # of calves born yearly | =B14*B15 | Depending on farm | |
| Mortality rate due to crypto | =0,353*0,18 | Roblin et al. (2023) | |
| Ratio bulls / heifers | 0,5 | Henk | |
| Price of bull at 2 weeks | =(107,5+97,5+77,5)/3 | Agrimatie (2024) | |
| Price of carcass removal | 31,7 | Rendac (2024) | |
| Labor feed | 13,42 | from model | |

Appendix D: Full partial budget calculations for reduced lactation due to cryptosporidium

| | | |
|---|---|---|
| **Additional income** | **Lost income** | |
| | Milk production | -€ 252,23 |
| **Cost saved** | **Additional costs** | |
| Feed costs | | |
| € 135,16 | | |
| | | |
| **Per affected heifer** | -€ 117,07 | |
| **Per succesfully raised heifer** | -€ 33,89 | |
| | | |
| Effect crypto on lactation | -548,3333333 | Esteban & Anderson (1995), Svensson & Hultgren (2008), Abuelo et al. (2021) |
| Milk price | 0,46 | WECR, 2024 |
| Price of feed | 0,493 | Agruniek Rijnvallei (2024 |
| Kg of feed needed per kg of milk | 0,5 | Hoogeveen (2024) |
| Crypto incidence | 0,353 | Roblin et al. (2023) |
| Calves that reach 1st lacation while I | 0,28946 | |

Same calculation, but with formulas shown

| | | |
|---|---|---|
| **Additional income** | **Lost income** | |
| | Milk production | =(B10)*B11 |
| **Cost saved** | **Additional costs** | |
| Feed costs | | |
| =-(B10)*B13*B12 | | |
| | | |
| **Per affected heifer** | =C2+A5 | |
| **Per succesfully raised heifer** | =B15*B7 | |
| | | |
| Effect crypto on lactation | =((-3,2*305)+(-344)+(-325))/3 | Esteban & Anderson (1995), Svensson & Hultgren (2008), Abuelo et al. (2021) |
| Milk price | 0,46 | WECR, 2024 |
| Price of feed | =9,86/20 | Agruniek Rijnvallei (2024) |
| Kg of feed needed per kg of milk | 0,5 | Hoogeveen (2024) |
| Crypto incidence | 0,353 | Roblin et al. (2023) |
| Calves that reach 1st lacation while having had crypto | =B14*(1-0,18) | |