AARHUS UNIVERSITY
DEPARTMENT OF ANIMAL SCIENCE

Occurrence and effects of calfhood diarrhea and respiratory diseases in dairy herds

Forekomst og effekter af kalvediarré og luftvejslidelser i malkekvægbesætninger

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Preface

This 30 ECTS Master's thesis is submitted in partial fulfilment of the requirements for the Master's degree in Agrobiology, Animal health and welfare at the faculty of Science and Technology at Aarhus University.

The thesis was written based on interest for dairy calves and great support from my advisors and the Cattle department at the Knowledge Centre for Agriculture.

I would like to thank my advisors, Anne Braad Kudahl, Henrik Læssøe Martin and Jakob Sehested for their input and help with this thesis. I would also like to thank Marlene Trinderup (AgroTech), Jørgen Nielsen (Knowledge Centre for Agriculture) and Jehan Ettema (SimHerd) for support with data extraction and analysis.

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Last but not least, I would like to thank my family, friends and Bryce Fisher for supporting me through this Master's thesis and my years as a student at Aarhus University, the University of Manitoba and Lincoln University.

Skejby, May 2014

Elba Lorenzen

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Summary

Calf mortality is of concern to the public and farmer, and reduces the profit of a dairy farm. Danish 1 to 180 day calf mortality was at 7.8% in 2012 which is above the strategic goal of 5.5% for Danish dairy herds. Campaigns have been run, with the objective to reduce calf mortality through improved calf management. However, mortality levels are only slowly decreasing. Diarrhea and respiratory disease are two major causes of death. However, current incidences of the diseases and the associations between these diseases and death in Denmark are not known. An answer to this knowledge gap would give an indication of how large of a problem these diseases are amongst Danish dairy herds and which disease should be most in focus in order to lower the 1 to 180 day calf mortality. A comparison to other countries with similar production systems would give an estimate of how well the Danish dairy sector is doing compared to other countries. Further, finding knowledge of the effect of diarrhea and respiratory disease on production and the economic effect of diarrhea may give an incentive to farmers and the dairy sector to increase the focus on calf management.

In order to estimate the incidence of diarrhea and respiratory disease amongst Danish dairy herds, the 0 to 180 day calf treatment records originating from 605 yield controlled 'Module 2 plus' herds were extracted from the Danish Cattle database. Herds with the 'Module 2 plus' Herd Health Contract type were used because they are the only herds obligated to record all treatments on calves. Further, the extracted treatment records and recordings for 1 to 180 day calf mortality were used to assess the association between treatment for diarrhea and/or respiratory disease and death. Results found in the Danish Cattle database were compared with literature results from countries with similar production systems. Further, a literature review on the effect of diarrhea and respiratory disease on production was made. The literature review and results from the Danish Cattle database were the basis for SimHerd simulations of the economic effect of diarrhea in an average Danish dairy herd and a Danish dairy herd with poor reproduction.

Results indicate that the *incidence* of diarrhea and respiratory disease is within the range of disease incidences found in countries with similar dairy production systems. The treatment incidence for intestinal problems (diarrhea, coccidiosis and cryptosporidiosis) is estimated to be at 16%, the estimated treatment incidence of diarrhea is at 9.3% and the treatment incidence of respiratory disease is estimated to be 9.5% in the 'Module 2 plus' herds. The 1 to 180 day dairy calf *mortality* (4.7%) in 'Module 2 plus' herds is also within the range of mortalities found in other countries. It was found that both the treatment risk and mortality risk varies between 'Module 2 plus' herds. The found treatment incidences are assessed to underestimate the actual disease incidence in 'Module 2 plus' herds. Further, it is assessed that the average disease incidence and mortality amongst Danish dairy herds is higher compared with the incidences found in the 'Module 2 plus' herds.

Associations between diarrhea, respiratory disease and death varied depending on sex of the calf. The results from the heifer calf group indicated that heifers are at a significantly higher risk of dying following treatment and at a significantly higher risk of contracting respiratory disease following an intestinal problem. The risk of dying was highest (21.8%) among heifers treated for

respiratory diseases and the second highest risk of dying (18.5%) was among heifers treated for both diseases. In total 4.1% of all heifer calves died following no treatment, 1.1% died following treatment for respiratory disease, 1.2% died following treatment for an intestinal problem and 0.4% of all heifers died following treatment for both diseases. Association results from the heifer calves were in agreement with the found literature. The association-results for the bull calves were either opposite from the heifer calves or non-significant. Compared to the heifer calves, a large percentage of bull calves were treated for respiratory disease or an intestinal problem (13.7% vs. 34.4%). Bull calves treated for an intestinal problem had a risk of dying of 41.6% followed by a 39.6% risk of dying after no treatment. Out of all bull calves 26% died following no treatment, 5% died following treatment for respiratory disease, 6.6% of all bull calves died following treatment for an intestinal problem and 1.2% died following treatment for both diseases. For the association analysis it is noted that calves might have died due to other reasons than what they were treated for and non-treated calves might also have died from respiratory disease or diarrhea. It is assumed that the group of bull calves has an overrepresentation of dead and diseased calves in its group, due to sale of healthy calves for fattening.

The found literature on *effects* of diarrhea and respiratory disease on *production* is limited and generally opposing results were found.

Diarrhea has a significant *negative effect on the economy* of both the average herd and the herd with poor reproduction. The poor reproduction herd is more affected by diarrhea incidence than the average herd, making it more profitable to lower the diarrhea incidence in this type of herd. An average herd with a diarrhea incidence of 18% would on average lose 84 DKK in gross margin per cow-year due to the effects of diarrhea. A herd with poor reproduction and a diarrhea incidence of 18% would an average have a 261 DKK lower gross margin per cow-year due the effects of diarrhea.

Based on found production effects of respiratory disease, it is assessed that respiratory disease also has an impact on the dairy herd economy. Considering that the effects of respiratory disease on production are similar to the effects of diarrhea, it is assessed that the economic effect of respiratory disease would have approximately the same extent as diarrhea.

In *conclusion*, the incidence of respiratory disease and diarrhea amongst calves in Danish dairy herds is assessed to be higher than disease incidences in other Scandinavian countries but within range of other countries with similar dairy production systems. Diarrhea and respiratory disease are associated with a higher risk of death. It is assessed that a reduction of the 1 to 180 day incidence of diarrhea and respiratory disease will improve farm economy and lead to reduced calf mortality levels amongst Danish dairy herds.

Chapter 1 Introduction

Calf mortality is an international animal welfare issue (Mee 2013) which also concerns the Danish public (Dyrenes Beskyttelse 2014) and contributes to a bad image of the dairy industry. From the farmers perspective, high calf mortality is unethical, and reduces the 'happiness at work' (*arbejdsglæde*) (Mogensen 2014). Moreover, calf mortality has an economic impact on the dairy farm (Defra 2003; Østerås *et al*. 2007).

In 2005, it was formulated that calf mortality needed to be reduced (Enemark 2005), and a reduction in the 1 to 180 day calf mortality to 5.5% was included in the strategic goal of 2013 (Dansk Kvæg 2009). Campaigns aiming to reduce calf mortality were run in 2001/02 ('*stærke kalve*'; Fisker *et al*. (2001)) and in 2008 ('*levende kalve';* Vaarst & Enemark (2008)). Despite much knowledge dissemination to farmers about calf management and a widespread farm-advisory system in Denmark (Vaarst & Sørensen 2009), the calf mortality was not decreased to the goal of 5.5% by 2013. Thus, a reduction of the 1 to 180 day dairy calf mortality to 5.5% is again included as a goal in the current 2014-2018 strategy of the Danish Agriculture and Food Council (Landbrug & Fødevarer 2014). The mortality amongst Danish dairy calves has in the last decade been at around 8%, with a 1 to 180 day calf mortality of 7.8% in 2012 (Figure 1.1; Enemark *et al*. (2014)).

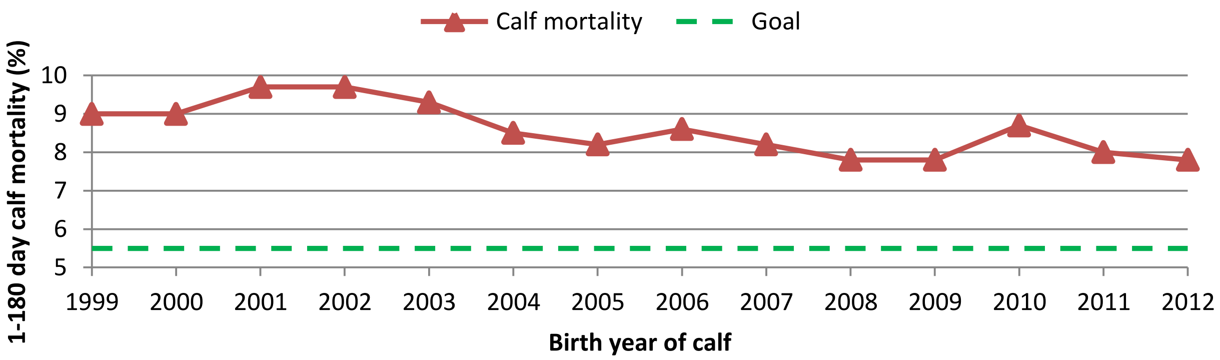

Figure 1.1 The Danish 1 to 180 day calf mortality amongst all dairy breeds (Enemark *et al*. 2014) and the strategic goal set by the Danish Agriculture and Food council (Landbrug & Fødevarer 2014).

It is known that diarrhea and respiratory disease are two major causes of calf mortality in the first 180 days of life (Virtala *et al*. 1996a; Svensson *et al*. 2006b; Gulliksen *et al*. 2009a). Thus, lowering the incidence of diarrhea and respiratory disease should aid in lowering overall calf mortality.

Current estimates of incidences of diarrhea and respiratory disease amongst calves in Danish dairy herds are not known because registration of morbidity information is optional. Thereby it is also now known how Danish dairy herds compare with other countries with similar production systems. Further, the association between diarrhea, respiratory disease and death are not known for Danish dairy herds. Depending on the outcome, knowledge of the Danish incidences of the two diseases, comparison with other countries and the association between the diseases and death on national level may give an incentive to increase focus on either one or both diseases on national level. The knowledge would also be helpful in finding out if focus needs to be directed towards a specific disease. Further, estimates of the economic effect of respiratory disease and diarrhea are lacking. An estimate of economic effects on the dairy herd might give an incentive to increase the national focus towards these two diseases. Based on the information available to farmers, it is assessed that Danish farmers know how to take proper care of dairy calves. Thus, a reason for the (too) slowly decreasing calf mortality may be that implementation of knowledge is lacking. It is the hope that knowledge about economic effects of diarrhea will motivate the farmer to increase focus towards dairy calf management and such that extended recommendations on calf management are implemented.

Based on the above introduction and problem statement, the ***objectives*** of this thesis are to obtain an estimate of the incidence of calf diarrhea and respiratory disease in Denmark and to compare the incidence with other countries with similar production systems. Further it is an objective to investigate the association between diarrhea, respiratory disease and death and to obtain an estimate of the economic effect of diarrhea. The economic effect of respiratory disease will not be investigated at this time.

The following ***research questions*** are set up in order to answer the above objectives:

- What is the incidence of calf mortality and morbidity in countries with dairy production systems similar to Denmark?
- What is the 1 to 180 day calf mortality risk and incidence of diarrhea and respiratory disease in Danish dairy herds?
- What are the associations between diarrhea, respiratory disease and death?
- What are the effects of calf diarrhea and respiratory disease on production?
- How does diarrhea affect the economy of an average Danish herd and a Danish herd with poor reproduction?

In order to answer the research questions, a literature review will sum up what is already known about levels of calf mortality, disease incidences and the link between them in countries with similar dairy production systems. The focus in the literature review will, where possible, be on diarrhea and respiratory disease in dairy calves between 1 to 180 days of age and calf mortality between 1 to 180 days of age. Data material on calf mortality and treatment incidences of diarrhea and respiratory disease will be extracted from the Danish Cattle database in order to estimate the Danish levels of morbidity and mortality. The findings of the literature review will be compared with the results from the data material from the Danish Cattle database. Data will be extracted from the Danish Cattle database to investigate the association between treatment for diarrhea, respiratory disease and death. The second part of the literature review will investigate the effects of diarrhea and respiratory disease on production. In this review, focus will be on the effects that respiratory disease and diarrhea contracted within the first six months of life have on production. The found effects of diarrhea on production, findings from the first part of the literature review and data from the Danish Cattle database will be used to estimate the economic impact of diarrhea in Danish dairy herds.

Chapter 2 Literature review

It is the aim of this chapter to investigate the mortality amongst dairy calves and the incidence of diarrhea and respiratory disease in dairy calves based on studies from countries with similar dairy production systems as Denmark. Further, the case-fatality of diarrhea and respiratory disease and cause of death will be investigated. These literature studies are performed to compare the results from the Danish Cattle database (Chapter 3) with findings from other comparable countries. Further, it is the aim of the literature review to investigate the effect of diarrhea and respiratory disease contracted within the first 6 months of life on production. The results on effects of diarrhea on production and from the first part of the literature review are later applied in the SimHerd simulation (Chapter 4) to estimate the economic effect of diarrhea.

This chapter will include a short background on diarrhea and respiratory disease followed by materials and methods for the literature review. The literature review is split into two topics; the first review (Section 2.3) will be on calf mortality, cause of mortality, case-fatality and disease incidence amongst dairy calves with focus on diarrhea and respiratory disease. The *second* review (Section 2.4) will be on effects of calfhood diarrhea and respiratory disease on production. The end of the literature review (Section 2.5) will include a discussion of factors which may reason differences between found results the literature review.

2.1 Background

This section will give a brief background on the major causes of diarrhea and respiratory disease amongst calves and describe the clinical signs of diarrhea and respiratory disease.

2.1.1 Diarrhea

According to Roy (1990b) a calf is defined to suffer from diarrhea if its feces has less than 120 gram dry matter per kg. Diarrhea is one of several terms used for a calf having watery feces. Other common terms used are scours, enteritis and gastrointestinal disease.

Diarrhea in calves is a multifactorial disease most commonly involving an interaction between microorganisms with the calf's immunity, nutrition and environment (Roy 1990b; Lorenz *et al*. 2011). In most cases, more than one microorganism is involved in the development of diarrhea (Roy 1990b). The most significant infectious causes of calf diarrhea are enterotoxigenic *Escherichia coli*, rotavirus, coronavirus, and *Cryptosporidium pavum* (Roy 1990b; van Metre *et al*. 2008; Foster & Smith 2009). Further, *Eimeria bovis* and *Eimeria zuernii*, which cause coccidiosis and *Salmonella* spp. are common causes of diarrhea (Roy 1990b; van Metre *et al*. 2008). Clinical signs for the different causes of diarrhea are similar and may include mild to severe diarrhea, dehydration, weakness, reduced suckle response, reduced appetite, depression and/or fever (van Metre *et al*. 2008). Diagnostics of diarrhea in studies is most often based on clinical signs, rather than finding the causative microorganism(s) for diarrhea through feces samples (Johnson *et al*. 2011). Diagnosis through fecal samples may be difficult, as both sick and healthy calves can shed the pathogens, as they may be present normally in the calf's intestinal tract or environment (Roy 1990b; Lorenz *et al*. 2011). Diarrhea is usually transmitted via feces (McGuirk & Ruegg 2011).

Therefore, a high level of hygiene in the calving pen and where the calf is housed plays an important role in prevention of diarrhea (van Metre *et al*. 2008). Timely feeding of colostrum of sufficient quality and quantity aids in prevention of diarrhea (van Metre *et al*. 2008). Diarrhea is typically treated with electrolytes in order to rehydrate the calf (van Metre *et al*. 2008).

2.1.2 Respiratory disease

According to van der Fels-Klerx *et al*. (2002a) bovine respiratory disease (**respiratory disease**) is a general term that covers a range of clinical signs that can be caused by a variety of infectious agents.

Respiratory disease is a multifactorial disease and develops as a result of interactions between predisposing factors (e.g. high air humidity, dust, draught, high infectious pressure, poor colostrum management or inadequate ventilation) and pathogens (Radostits & Blood 1985; Roy 1990a). The most common pathogens involved in development of respiratory disease are Bovine Respiratory Syncytial Virus (BRSV), Parainfluenza-3 Virus, *Mycoplasma dispar* and *Mycoplasma bovis*, *Pasteurella haemolytica* and *Pasteurella multocida* (Roy 1990a; Divers 2008; McGuirk & Ruegg 2011).Clinical signs of respiratory disease may include increased respiration rate, fever, nasal discharge, coughing, tilted head or ears, mild depression or reduced feed intake (Roy 1990a; Divers 2008). Diagnosis of respiratory disease is often made based on clinical signs rather than identifying the causative viruses or bacteria, leaving the diagnosis as undifferentiated respiratory disease (van der Fels-Klerx *et al*. 2002a). Usually the source of infection for respiratory disease is aerosol (McGuirk & Ruegg 2011). Thus, good air quality is recommended in order to lower the amount of dust and thereby pathogens in the air (Radostits & Blood 1985). Air quality can be improved through ventilation and hygiene. Further, timely feeding of colostrum of sufficient quality and quantity aids in prevention of respiratory disease (Roy 1990a). Respiratory disease is treated with antibiotics.

2.2 Materials and methods

As previously stated, this chapter includes two literature reviews (Section 2.3 and 2.4). This section will describe the considerations and methods for selection of literature used for the two literature reviews.

The literature search for Section 2.3 and 2.4 made use of the databases CAB Abstracts and Web of Science. Both sections focus on diarrhea and respiratory disease in dairy calves. Mainly peer-reviewed publications in English, Danish or German were included in the two literature reviews. Apart from peer-reviewed articles, Section 2.3 also included information on Danish calf mortality risks based on data material from the Danish Cattle database (Nielsen *et al*. 2002; Enemark *et al*. 2014). These two publications were assessed to be relevant and reliable sources of information, as all deaths occurring on a dairy herd have to be recorded in the Animal Register, which transfers information into the Danish Cattle database. The publications needed to fulfill the following two criteria in order to be included: firstly, animals in the study must have been of dairy breed and housed in dairy herds or ranches that only raise heifers for dairy purpose. Secondly, the study needed to be done in Canada, the USA, Northern Europe or Western Europe as these areas overall have a production system comparable to Danish conditions. Section 2.3 includes articles that were published between January 1994 and February 2014. Only articles from the last 20 years were included in an attempt to represent the most current information available. Apart from the before listed criteria, the included studies also needed to fulfill the following two criteria for Section 2.3: (i) studies needed to include quantitative information on mortality, morbidity and/or cause of mortality on calves in the age between 1-180 days and finally, (ii) the objectives of the included studies must have been to find the mortality rate or risk, case-fatality, cause of mortality and/or incidence of diarrhea and respiratory disease. In total, 14 studies met these criteria. Section 2.4 includes articles that were published between January 1980 and February 2014. Articles were included from a larger time period compared with Section 2.3 because the amount of literature present in this field is limited. Setting time limits to 1980 was an attempt to find more studies on this topic. It is assumed that the effects of the diarrhea and respiratory disease on production are similar throughout the included years. Other criteria that the studies needed to fulfill were: (i) studies needed to include quantitative information on production effects of calf diarrhea or respiratory disease which was contracted between 1-180 days of age and finally, (ii) the objective of the experiment must have been to investigate the effect of diarrhea and/or respiratory disease on production, or to find out if there is an association between diarrhea and/or respiratory disease on one or more production parameters in heifer calves, or dairy cows. In total, 12 studies met these criteria.

The effect of diarrhea and respiratory disease on height growth was not included in the literature review, as this parameter cannot be simulated in SimHerd. Throughout the literature review, ‘diarrhea’ and ‘respiratory disease’ will be used as general terms which cover definitions such as scours, enteritis, gastrointestinal disease, pneumonia, respiratory problems and bovine respiratory disease (BRD).

2.3 Mortality and disease incidence

It is the aim of this section to present found results on dairy calf mortality, cause of mortality, case-fatality and disease incidence amongst dairy calves. A review on calf mortality is found in Section 2.3.1 and predominant causes of mortality and case-fatality for diarrhea and respiratory disease are reviewed in Section 2.3.2 and in Section 2.3.3 the incidence of diarrhea and respiratory disease is reviewed. These results will later be compared with found results from the Danish Cattle database (Chapter 3) and aid in parameter value estimation for the simulation in Chapter 4. An overview of background information on the studies cited in Section 2.3 is given in Table 2.1. All of the included Northern American studies are from the USA (Table 2.1). When looking at studies from Northern Europe, relevant studies from Denmark, Sweden and Norway were found. However, no recent Danish studies regarding cause of mortality, case-fatality and disease incidence were found. Furthermore, only relevant Western European studies from France were found (Table 2.1).

Table 2.1 Overview of studies included in the literature review on calf mortality, cause of mortality and disease incidence in dairy calves (Section 2.3).

Study	Region, Country	Birth-period of calves in the study (month/year)	Number of herds	Number of animals	Section 2.3.1	Section 2.3.2	Section 2.3.3
Donovan *et al*. (1998b)	Florida, USA	1/1991 to 1/1992	2 D	3253 Hi	X	X	
Enemark *et al*. (2014)	Denmark	1999 to 2014 Danish Cattle database	n/a	n/a, Hi, Bu	X		
Fourichon *et al*. (1997)	Pays de la Loire, France	In 1995 and 1996, each herd participated for 3 months	236 D	n/a	X		X
Gulliksen *et al*. (2009a)[a]	Norway	In 2005 Norwegian Dairy Herd Recording System	i: 14,474 D ii: 125 D	i: 289,038, ii: 5382, Hi & Bu	X	X	
Gulliksen *et al*. (2009b)	Norway	Between 9/2004 to 1/2007, each herd participated for 1 year, Norwegian Dairy Herd Recording System	135 D	6668 Hi & Bu			X
Nielsen *et al*. (2002)	Denmark	1998 to 1999 Danish Cattle database	9333 D	687,470 Hi 678,905 Bu	X		
Raboisson *et al*. (2013)	France	2005 and 2006 National Bovine Identification Database	Differs[b]	Differs[c], Hi	X		
Sivula *et al*. (1996)	Minnesota, USA	In 1991	30 D	845 Hi	X	X	X
Svensson *et al*. (2003)	Skaraborg, Sweden	In 1998	122 D	3081 Hi			X
Svensson *et al*. (2006a)	Skaraborg, Sweden	In 1998	122 D	2947 Hi			X
Svensson *et al*. (2006b)	Skaraborg, Sweden	1998 to 2000	122 D	8964 Hi	X	X	
Virtala *et al*. (1996a)	New York, USA	In 1990	18 D	410 Hi	X	X	X
Virtala *et al*. (1996b)	New York, USA	In 1990	18 D	410 Hi		X	X
Wells *et al*. (1996)	28 states, USA	1991 to 1992	906 D & R	NA, Hi	X		X

[a] Two dataset; (i) Norwegian dairy herd recording system herds and (ii) Survey herds.

[b] 3 day to 1 month old heifers; 2005: 71,846 farms, 2006: 69,231 farms, 1-6 months old heifers; 2005: 72,096 farms, 2006: 69,725 farms.

[c] 3 day to 1 month old heifers; 2005:1,158,838 heifer-months, 2006: 1,148,323 heifer-months, 1-6 months old heifers; 2005:1,125,546 heifer-5 months, 2006: 1,121,002 heifer-5 months.

D = dairy herd, R = Heifer ranch, Hi = heifer, Bu = bull, n/a = not available

2.3.1 Calf mortality

It is the aim of this section to give an overview of found dairy calf mortalities from countries with similar dairy production systems. The results from the found studies that looked at calf mortality amongst dairy calves are summarized in Table 2.2.

The method of calculation differed between studies: The studies by Fourichon *et al*. (1997), Gulliksen *et al*. (2009a) and Raboisson *et al*. (2013) calculated the mortality rate whereas the remaining studies calculated the mortality risk. Further, different age ranges of calves were investigated, where the included ranges varied from 1 to 15 days (Fourichon *et al*. 1997) and from 1 to 810 days (Svensson *et al*. 2006b). It also differed whether the first 24 hours after birth were included in the study-period or not (Table 2.2). The implications of differing calculation methods and age of the calves included will be discussed in Section 2.5.

Highlighting some of the results from Table 2.2, the heifer calf mortality in the first month of life varied between 4.0% and 4.9% (Raboisson *et al*. 2013; Enemark *et al*. 2014). Further, the found mortality in the first 6 to 7 months of life varied between 3.6% to 12.6% for heifer calves (Donovan *et al*. 1998a; Nielsen *et al*. 2002; Svensson *et al*. 2006b; Enemark *et al*. 2014).

Based on data material from the Danish Cattle database, Nielsen *et al*. (2002) and Enemark *et al*. (2014) reported mortality risks for both heifer and bull calves (Table 2.2; Figure 2.1). Both studies reported lower heifer calf mortality risks (e.g. 6.3% and 7.7%) compared to bull calf mortality risks (e.g. 7.7% and 10.2%). Despite utilizing the same database, mortality risks found by Nielsen *et al*. (2002) were lower compared with risks found by Enemark *et al*. (2014). A reason for this could be differences in the inclusion criteria of dairy calves, which will be discussed in Section 2.5.

When comparing within age ranges of the calves, the 1 to 180 or 210 day mortalities found in both Sweden (Svensson *et al*. 2006b) and Norway (Gulliksen *et al*. 2009a) were lower compared with Danish mortality risks found in both Enemark *et al*. (2014) and Nielsen *et al*. (2002). Further the mortality risks found in the USA were higher than the mortalities found in Europe (Table 2.2).

Gulliksen *et al*. (2009a) estimated mortality rates based on two groups of dairy herds, which were registered the Norwegian Dairy Herd Recording System (**NDHRS**). As shown in Table 2.2, the average mortality rates in the survey herds were higher than the mortality rates found amongst all the herds registered in the NDHRS.

Table 2.2 Overview of found calf mortalities and the age range of calves included in the studies.

Study	Age range of calves	Mortality rate (%)	Mortality risk (%)
Donovan *et al*. (1998b)	2 d - 6 mo Birth - 6 mo	-	11.7 12.6
Enemark *et al*. (2014)	1 - 30 d; 1 - 180 d	-	See Figure 2.1
Fourichon *et al*. (1997)	1 - 15 d	3.1	-
Gulliksen *et al*. (2009a)*	1 d - 1 year	i: 1-30 d: 1.5 ii:1-30 d: 1.8 1-180 d: 3.3 1-180 d: 4.0 1-365 d: 3.7 1-365 d: 4.7	-
Nielsen *et al*. (2002)	1 - 180 d	-	Heifer calves: 6.3 Bull calves: 7.7
Raboisson *et al*. (2013)	3 d - 1 mo	2005: 4.6 2006: 4.4	-
Raboisson *et al*. (2013)	1 - 6 mo	2005: 3.2 2006: 3.1	-
Sivula *et al*. (1996)	Birth - 16 weeks	-	7.6
Svensson *et al*. (2006b)	1 d - 1st calving/27 mo	-	1-90 d: 3.1 1-210 d: 3.6 1d - 27 mo: 4.7
Virtala *et al*. (1996a)	Birth - 90 d	-	5.6
Wells *et al*. (1996)	Birth - 8 weeks	-	6.3

* Two dataset; (i) all herds registered in the Norwegian dairy herd recording system and (ii) Survey herds, which were also registered in the Norwegian dairy herd recording system.

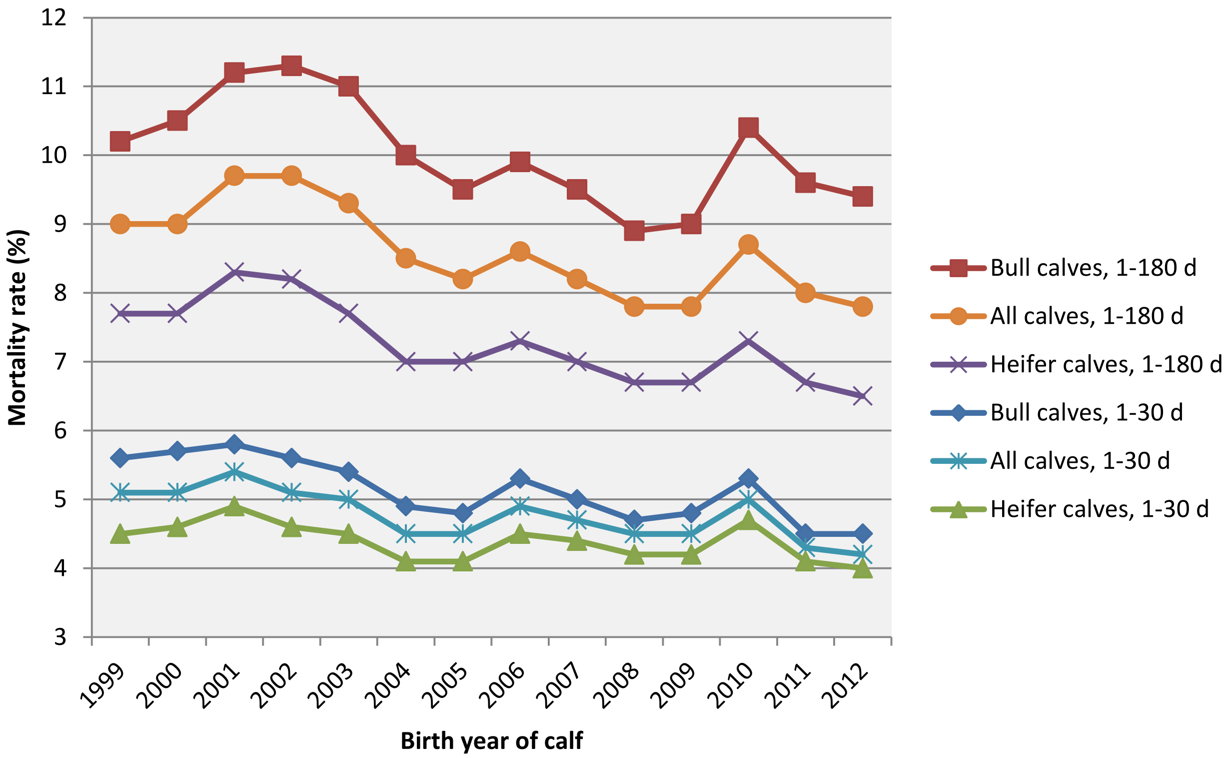

Figure 2.1 The 1-30 and 1-180 day calf mortality risk (%) of Danish dairy calves born alive in 1999 to 2012 (Enemark *et al*. 2014).

2.3.2 Cause of mortality and case-fatality

This section presents the primary causes of mortality in countries with similar production systems as Denmark. Further, the case-fatality was investigated in order to find out how deadly diarrhea and respiratory disease are. An overview of the found results on cause of death and case-fatality amongst dairy calves is found in Table 2.3.

Cause of death

The primary cause of death varies between the found studies, as can also be seen in Table 2.3. However, diarrhea and respiratory disease were always found amongst the top three causes of death. Which cause of death was the primary one may be dependent on the age range of calves studied: Both Virtala *et al*. (1996a), Virtala *et al*. (1996b) and Sivula *et al*. (1996) found that in the first 3 to 4 months of the calf´s life, diarrhea was the major cause of death followed by respiratory disease (Table 2.3). Furthermore, Svensson *et al*. (2006b) found that diarrhea was the most common cause of death amongst calves dying in the first month of life (29.9%), whereafter respiratory disease was the most common cause of death in calves between 31 to 90 days of age (39.4%) and in calves between 91 to 210 days of age (46.9%) (data not shown). When looking at longer time spans (to 6, 7 or 12 months of age), two studies (Svensson *et al*. 2006b; Gulliksen *et al*. 2009a) found that respiratory disease was the major cause of death, followed by diarrhea, and the study by Donovan *et al*. (1998a) found that septicemia was the major cause of death followed by respiratory disease and diarrhea.

Case-fatality

The case-fatality describes the risk of dying from a specific disease. Results of case-fatalities for diarrhea and respiratory disease varied between studies (Table 2.3). When looking at calves which have diarrhea, Sivula *et al*. (1996) found that 17.9% of the diseased calves ended up dying from diarrhea, whereas Virtala *et al*. (1996a) and Donovan *et al*. (1998a) found that only 7.6% and 7.7% of diseased calves ended up dying from diarrhea, respectively. When considering calves suffering from respiratory disease, Virtala *et al*. (1996b), Sivula *et al*. (1996) and Donovan *et al*. (1998a) found case-fatalities of 4.2%, 9.4% and 13.8%, respectively.

Table 2.3 Overview of found cause of mortality and case-fatality and the method for determination of death cause..

Study	Age range of calves	Determination method	Cause of death (%)		Case-fatality (%)	
			Diarrhea	Respiratory disease	Diarrhea	Respiratory disease
Donovan *et al*. (1998b)	48 h - 6 mo	By farmer	10	21.9[a]	7.7	13.8[b]
Gulliksen *et al*. (2009a)[c]	1 d - 12 mo	Postmortem	15.4	27.7	-	-
Sivula *et al*. (1996)	Birth - 4 mo	n/a[d]	43.8	29.7	17.9	9.4
Svensson *et al*. (2006b)	1 d - 7 mo	Postmortem	21.1	30.3	-	-
Virtala *et al*. (1996a)	Birth - 3 mo	Postmortem	43	24	7.6	-
Virtala *et al*. (1996b)	Birth - 3 mo	Postmortem	-	24	-	4.2[e]

[a] the primary cause of death was septicemia (55.4%)
[b] septicemia had a case-fatality of 27.6%
[c] results from the survey herds
[d] it is not clear if the reported cause of death and case-fatality are based on farmer or postmortem diagnosis
[e] treated, verified respiratory disease

2.3.3 Total morbidity, cause of morbidity and incidence of morbidity

This section presents the found total dairy calf morbidity, the major causes of morbidity and incidence of diarrhea and respiratory disease. Results on these topics are shown in Table 2.4.

Total morbidity

The total morbidity varied from 14.1% to 58% in the included studies (Table 2.4). The results by Svensson *et al*. (2003) and Svensson *et al*. (2006a) show that the total morbidity risk is higher in the first 90 days of life compared with the morbidity risk between 91 to 210 days. Further, Virtala *et al*. (1996a) found that the total morbidity risk was 5.1 percentage points higher if based on clinician diagnosed respiratory disease treatments and other diseases compared with verified respiratory disease treatments by the farmer and other diseases. All studies except from Fourichon *et al*. (1997) calculated the incidence risk of disease. Fourichon *et al*. (1997) calculated the incidence rate. Thus, the study by Fourichon *et al*. (1997) should have a lower incidence of morbidity if it was converted from morbidity rate to morbidity risk.

Cause of morbidity

All of the investigated studies, except from Svensson *et al*. (2006a), found that diarrhea was the major reason for morbidity amongst calves (Table 2.4). Svensson *et al*. (2006a) found that respiratory disease was the most common cause of morbidity. In contrast to the other studies, Svensson *et al*. (2006a) looked at the calf morbidity between 91 and 210 days of age, whereas the other studies investigated a period starting from day 0 or 1 of age, and 2 weeks to 6 months ahead. Four studies found that the second largest reason for morbidity was respiratory disease (Table 2.4; (Sivula *et al*. 1996; Virtala *et al*. 1996b; Svensson *et al*. 2003; Gulliksen *et al*. 2009b)). However, Wells *et al*. (1996) found that listlessness was the second most common recorded 'morbidity', followed by respiratory disease and Svensson *et al*. (2006a) reported that ringworm was the second largest reason for morbidity followed by diarrhea.

Incidence of diarrhea and respiratory disease

The incidence risk of diarrhea varied from 3.9% to 28.8% and the incidence risk of respiratory disease varied between 2.9% to 25.6% (Table 2.4). Virtala *et al*. (1996b) found that farmers recorded less calves with respiratory disease compared with the veterinarian, as the caretaker had found 11% of calves to be affected with respiratory disease and the clinician diagnosed 25.6% of calves with clinical or treatable respiratory disease. Gulliksen *et al*. (2009b), who investigated three methods to validate calf health data in the NDHRS, found that calf health records were underestimated by about 40% in the NDHRS.

Both Virtala *et al*. (1996a) and Wells *et al*. (1996) found that the peak occurrence of diarrhea was during the second week of life. Wells *et al*. (1996) also found that respiratory disease had its highest incidence risk in the second week of life, whereas Virtala *et al*. (1996b) found that the peak occurrence respiratory disease was during the fifth week of life.

Table 2.4 Overview of found incidence of diarrhea and respiratory disease and total morbidity.

Study	Age range of calves	Basis of diagnosis of diarrhea and respiratory disease	Incidence risk (%)		Total morbidity (%)
			Diarrhea	*Respiratory disease*	
Fourichon *et al*. (1997)	1 - 15 d	n/a[1], by farmer	-	-	17.4%
Gulliksen *et al*. (2009b)	1-180 d	n/a[1], by farmer	3.9%[2] 5.5%[3]	2.9%[2] 4.1%[3]	-
Sivula *et al*. (1996)	Birth - 16 weeks	Treatment, by farmer	15.2%	7.6%	24%
Svensson *et al*. (2003)*	Birth – 3 mo	Clinical signs and treatment, by farmer, veterinary bimonthly	9.8%	7.0%	23%
Svensson *et al*. (2006a)*	4 - 7 mo	Clinical signs and treatment, by farmer, veterinary bimonthly	2.7%	5.7%[4]	14.1%
Virtala *et al*. (1996a)**	Birth - 90 d	Clinical signs and treatment, by farmer, veterinary weekly	28.8%	-	52.9%[a] 58%[b]
Virtala *et al*. (1996b)**	Birth - 90 d	Clinical signs and treatment, by farmer, veterinary weekly	-	17.3%[a] 25.6%[c] 11.0%[d]	-
Wells *et al*. (1996)	Birth - 8 weeks	n/a[6], by farmer	24.6%[5]	8.4%	-

[1] study did not make it clear, whether the reported morbidity rates are based on only treatment registrations or if clinical signs of disease also counted as morbidity-incidence.
[2] before data validation
[3] after data validation
[4] ringworm was the second most common morbidity (5.6% of calves)
[5] listlessness was the second most common morbidity (10% cumulative incidence risk)
[6] study did not inform, whether the reported morbidity was based on only treatment registrations or if clinical signs of disease also counted as morbidity-incidence
[a] includes treated, verified respiratory disease (cases treated with antibiotics)
[b] includes clinician diagnosed respiratory disease (cases treated with antibiotics)
[c] of clinician diagnosed respiratory disease,
[d] of caretaker diagnosed respiratory disease
* and ** used same cohort of calves, respectively
n/a = not available

2.4 Effects of diarrhea and respiratory disease on production

It is the aim of this section to present found results on the impact of calfhood diarrhea and respiratory disease contracted within the first 6 months of life on production in dairy heifers. The obtained information on the effect of diarrhea on production is used as a basis for a SimHerd simulation of the economic effect of diarrhea in Chapter 4. Background information on the studies cited in Section 2.4 is presented in Table 2.5. The found literature on effects on production only includes 7 different calf-cohorts (Table 2.5). The study by van der Fels-Klerx *et al*. (2002b) does not include any cohort of calves, as the results are based on expert estimates.

Table 2.5 Overview of studies included in the literature review on production effects of diarrhea and respiratory disease in dairy heifers (Section 2.4).

Study	Region, Country	Birth-period of calves in the study (month/year)	Number of herds	Number of animals	Disease registration period	Basis of diagnosis of diarrhea and RD	Effects investigated
Britney *et al*. (1984)	Ontario, Canada	1/1971 to 12/1978	2[1]	460	Birth - 4 months	C & T for RD & diarrhea, by F &/or V	Survival, Milk production, Calving age
Correa *et al*. (1988)*	New York, USA	7/1983 to 4/1985	21	948	1-90 days	C of RD & diarrhea, by F	Calving age
Curtis *et al*. (1989)*	New York, USA	7/1983 to 4/1985	24	1069	1-90 days	C of RD & diarrhea, by F	Survival
Donovan *et al*. (1998a)	Florida, USA	1/1991 to 1/1992	2	3103	Birth - 6 months; 6-14 months	T for RD & diarrhea, by F	Growth
Svensson & Hultgren (2008)	Skaraborg, Sweden	In 1998	107	2060	Birth - 7 days before calving	C & T for RD & diarrhea, by F & bimonthly by V	1st lactation milk production
van der Fels-Klerx *et al*. (2002b)	The Netherlands	—[2]	—[2]	—[2]	—[2]	—[2]	Growth, Calving age, 1st lactation milk production
Virtala *et al*. (1996c)	New York, USA	In 1990	18	410	Birth - 3 months	C of RD & diarrhea, by V; T for RD[3] & diarrhea, by F	Growth
Waltner-Toews *et al*. (1986a)	Ontario, Canada	Born before 31/12/1981	34	1968	Birth - 90 days	T for RD & diarrhea, by F	Survival, Calving age
Warnick *et al*. (1994)*	New York, USA	7/1983 to 4/1985	25	1031	1-90 days	C of RD & diarrhea, by F	Calving age, Dystocia at 1st calving
Warnick *et al*. (1995)*	New York, USA	7/1983 to 4/1985	25	728	1-90 days	C of RD & diarrhea, by F	1st lactation milk production
Warnick *et al*. (1997)*	New York, USA	7/1983 to 4/1985	25	787	1-90 days	C of RD & diarrhea, by F	Survival after calving
Windeyer *et al*. (2014)	Ontario, Canada; Minnesota, USA	1/2008 to 12/2008	19	2874	1-7 days to 3 months	T of RD & diarrhea, by F	Growth

*same cohort of calves

[1] institutional herds

[2] expert quantification of the effect of severe respiratory disease (0-3 months) and of a mild respiratory disease outbreak (3-6 months)

[3] some respiratory disease treatments were done at the advice of veterinarian, remaining respiratory disease treatments were verified by veterinarian

RD = respiratory disease, C = clinical signs of disease, T = treatment for disease, F = farmer, V = veterinarian

2.4.1 Effects of diarrhea on production

This section presents the found results regarding effects of diarrhea obtained within the first six months of life on production. Mainly significant effects of diarrhea on production are summarized in Table 2.6.

Weight gain

Heifers that had been treated for diarrhea between birth and 6 months of age had a significantly ($P<0.01$) reduced daily weight gain during this period of 13.4 g per day per treatment day (Donovan *et al*. 1998a). Using the mean number of days treated for diarrhea (3.76 days) a reduction in 180-day weight gain of 9.07 kg was predicted. Diarrhea between birth and six months or between 6 to 14 months did not significantly affect growth between 6 to 14 months (Donovan *et al*. 1998a). Accordingly, Windeyer *et al*. (2014) found a significant effect ($P<0.0001$) of being treated for diarrhea before 3 months of age, such that calves treated for diarrhea had a 1.1 kg lower body weight gain before 3 months of age than non-affected calves. On the other hand, Virtala *et al*. (1996c) found that diarrhea during the first 3 months of life had no significant effect on average daily gain nor total body weight gain during the first 3 months of life. The authors noted that this might indicate that calves are able to compensate for any loss in growth from diarrhea or that diarrhea had no long term effect on growth.

Mortality and culling up to first calving

Heifers which had been treated for diarrhea during the first 90 days of life were more likely (Odds= 2.5, 95% CL 1.42, 4.42) to be sold as dairy replacements ($P \leq 0.05$) between 90 and 900 days of life than other calves (Waltner-Toews *et al*. 1986a). The alternative would have been to stay in the dairy herd to enter the milking herd. Calves treated for diarrhea during the first 90 days of life did not have an increased risk of dying or being culled for beef between 90 and 900 days of age (Waltner-Toews *et al*. 1986a). In accordance with this, Curtis *et al*. (1989) reported that the effect of diarrhea on the likelihood of dying after 90 days was not found statistically significant. However, it was found that diarrhea before the age of 90 days had no effect on the likelihood of being sold after 90 days of age (Curtis *et al*. 1989), which is opposite the findings from Waltner-Toews *et al*. (1986a). An explanation for the different finding may be that in the study by Curtis *et al*. (1989), heifers with a diarrhea-recording were not necessarily treated for diarrhea, but the calves in Waltner-Toews *et al*. (1986a) were only recorded for diarrhea if they were treated.

Reproduction up to first calving

A Canadian study found that calves treated for diarrhea within the first 90 days of life were significantly less likely to calve before 900 days ($p \leq 0.05$) than calves not treated for diarrhea (Waltner-Toews *et al*. 1986a). The median age at first calving for diarrhea-treated calves was 1.3 months higher than non-diseased calves (29.3 vs. 28 months) (Waltner-Toews *et al*. 1986a). On the other hand, both Correa *et al*. (1988) and Britney *et al*. (1984) found no significant difference in first calving age between heifers that had suffered of diarrhea before 90 days of age (Correa *et al*.

1988) and the first 4 months of life (Britney *et al*. 1984) and heifers without diarrhea in this time period.

Performance at or after first calving

Dystocia, long term survival and reproduction

It was found that calves which had diarrhea before 90 days of age did not have a higher odds ratio for calving difficulties (Warnick *et al*. 1994). Both calving interval and the proportion of live-born calves per lactation for heifers that had diarrhea in the first 4 months of life were not different from their control group with no treatment records (Britney *et al*. 1984). Furthermore, Britney *et al*. (1984) concluded that the group of calves that contracted diarrhea during the first 4 months of life did not have a survival function significantly different from the group of non-diseased heifers. Accordingly, Warnick *et al*. (1997) found no impact of diarrhea before the age of 90 days on survival after calving.

Milk production

In the study by Britney *et al*. (1984) there was no significant difference in milk production on a lactation basis between the cohort of heifers that had been treated for gastrointestinal disease in the first 4 months and the calves with no treatments. Warnick *et al*. (1995) confirmed this finding in their study, as the occurrence of diarrhea within 90 days of birth had no significant effect on first lactation milk production compared to unaffected herd mates. However, Warnick *et al*. (1995) noted that the percentage of heifers that survived and were kept in the herd as replacements tended to be lower for heifers affected by calfhood disease. Thus, the conclusion from their study only applies to heifers that survived, were kept as replacements and had milk production measured. The lack of effect on milk production may indicate that owners successfully selected only affected heifers that would perform as well as the untreated herd mates or that there is no effect of calfhood disease on milk production (Warnick *et al*. 1995). However, Svensson & Hultgren (2008) found that cows that had contracted mild diarrhea before 91 days of age had 344 kg lower energy corrected milk production during first 305 days of lactation in the first lactation than cows without diarrhea (P=0.0036). No significant association between severe diarrhea before 91 days of age and milk production was found (P=0.26).

Summary

The effect of diarrhea on weight gain is ambiguous; a reduced weight gain during the first 180 days of up to 9 kg and a reduced weight gain of 1.1 kg body weight in the first 3 months has been found, however another study found no effect of diarrhea. Diarrhea did not affect the long term survival during the rearing period and does not seem to affect the risk of being culled during the rearing period. However, only one study investigated the risk of culling. Results on the effects of diarrhea on being sold in the rearing period and on first calving age were ambiguous. Only one study looked at diarrhea's effect on calving interval and proportion of live-born calves, and no impact was found. Only one study investigated the effect on dystocia which also showed no effect of diarrhea. Cows which had diarrhea as calves did not have a different survival after calving compared with cows that were non-diseased as calves. Results on the effect of diarrhea on first lactation milk production were ambiguous. Only one study did find an effect of mild diarrhea before 91 days of age on milk production with a decrease of 344 kg energy corrected milk during the first 305 days of lactation. The same study however also found no effect of severe diarrhea. The effect of diarrhea on later lactations was not investigated in any found studies.

Table 2.6 Statistically significant (P<0.05) effects of diarrhea on production.

Reference	Production effect	Association	Remarks
Donovan *et al*. (1998a)	Weight gain 0-6 months	-13.4 g/day/ treatment day	
Windeyer *et al*. (2014)	Weight gain before 3 months	-1.1 kg	Calves were part of vaccination trial at the same time. Vaccination had no impact on weight gain (Windeyer *et al*. 2012).
Waltner-Toews *et al*. (1986a)	Sold for dairy purpose before calving	Odds = 2.5	
Waltner-Toews *et al*. (1986a)	Median 1st calving age	+1.3 months	
Svensson & Hultgren (2008)	305-day milk production in 1st lactation	-344 kg ECM	Mild diarrhea

ECM: energy corrected milk

2.4.2 Effects of respiratory disease on production

This section presents the found results regarding effects of respiratory disease obtained within the first six months of life on production. Mainly significant effects of respiratory disease on production are summarized in Table 2.7.

Weight gain

Duration of respiratory disease in the first 3 months of life was significantly associated (P<0.01) with body weight at the end of 3 months; each week of respiratory disease reduced the total body weight gain by 0.8 kg (Virtala *et al*. 1996c). A mean duration of respiratory disease of four weeks as found by Virtala *et al*. (1996b) would result in a total weight reduction of 3.2 kg. Accordingly, Donovan *et al*. (1998a) found that treatment for respiratory disease before 6 months of age significantly (P<0.01) decreased daily weight gain between birth and 6 months of age, with 10.5 g per day per treatment day. Using the mean number of days treated for respiratory disease (5.63 days) a reduction in 180-day weight gain of 10.64 kg was predicted. Furthermore, the number of days treated for respiratory disease before 6 months of age significantly (P<0.01) decreased average weight gain during the period 6-14 months with 2.3 g per day per treatment day. It was estimated that respiratory disease in the first 6 months of life would account for a 3.11 kg reduction in growth between 6 to 14 months of age (Donovan *et al*. 1998a). Respiratory disease between 6-14 months of age did not affect growth between 6-14 months (Donovan *et al*. 1998a). In the study 39.5% of the heifers that left the herd before 6 months of age did so because of the effect of chronic respiratory disease on growth (selective follow-up). Thus, the real impact of respiratory disease on weight gain was likely to be higher (Donovan *et al*. 1998a). On the other hand, Windeyer *et al*. (2014) found that respiratory disease was not a risk factor associated with body weight gain before 3 months of age.

The study by van der Fels-Klerx *et al*. (2002b) had 13 experts that were specialized in the field of bovine respiratory disease in dairy heifers quantify the effects of respiratory disease on growth and other parameters; the median body weight after severe respiratory disease at <3 months compared with non-affected animals was estimated to be 10 kg less at 3 and 6 months of age. This estimate was similar to the estimate of a 10.64 kg reduction in body weight by 180 days made by Donovan *et al*. (1998a). Median body weight of diseased heifers at 14 months was estimated to be reduced by 29 kg after severe respiratory disease between 0-3 months of age (van der Fels-Klerx *et al*. 2002b). The estimate of a 29 kg body weight reduction by 14 months of age is higher compared with the total 13.75 kg (3.11 kg + 10.64 kg) reduction estimated by Donovan *et al*. (1998a). However, the selective follow-up that happened in the study by Donovan *et al*. (1998a) may have underestimated the effect of respiratory disease on body weight. Furthermore, the experts in the study by van der Fels-Klerx *et al*. (2002b) were instructed to give estimates based on *severe* respiratory disease. Assuming that not all treated respiratory disease-cases in Donovan *et al*. (1998a) were severe, it would by plausible if *sever*e respiratory disease has a larger impact on growth. The study by van der Fels-Klerx *et al*. (2002b) moreover reported that a mild respiratory disease outbreak between 3-6 months of age was estimated to reduce body weight at 6 months by a median of 4 kg compared to non-affected herd mates. At 14 months, the median body weight was estimated to be 24 kg less in heifers which had a mild respiratory disease outbreak between 3-6 months, compared to non-affected heifers. It was not stated whether the quantified effects were significantly different from the reference values of non-affected herd mates.

Mortality and culling up to first calving

Heifer calves which had been treated for respiratory disease during the first three months of life were 2.45 times more likely (95% CL 1.02, 5.90) to die between 90 and 900 days of age compared with non-pneumonic heifers ($p \leq 0.05$), but respiratory disease did not significantly alter the risk of being culled for beef or sold for dairy purposes between 90 and 900 days of age (Waltner-Toews *et al*. 1986a). Similarly, Curtis *et al*. (1989) reported that respiratory illness before the age of 90 days had no effect on the likelihood of being sold thereafter. Curtis *et al*. (1989) furthermore found no statistically significant effect of respiratory illness before the age of 90 days on the likelihood of dying after 90 days, which is in contrast with the finding of Waltner-Toews *et al*. (1986a). In the latter study only the treated heifers were recorded as a morbidity event, whereas in the study of Curtis *et al*. (1989) respiratory illness was recorded when there were clinical signs for it.

Reproduction up to first calving

Waltner-Toews *et al*. (1986a) found no difference in the percentage of heifers calving before the age of 900 days between heifers with and heifers without calfhood respiratory disease. However, both Correa *et al*. (1988) and Warnick *et al*. (1994) found that heifers that had respiratory disease within 90 days of age were half as likely to calve at any particular age as non-affected heifers (hazard ratio of 0.5).

The median age at first calving of heifers that had suffered from respiratory illness before the age of 90 days was delayed by three months compared with non-affected herd mates (Warnick *et al*. 1994). Correa *et al*. (1988) found that the median age at first calving for heifers with respiratory illness within 90 days of age was six months later when compared to those without respiratory illness as calves (median age of 32 vs. 38 months). Correa *et al*. (1988) and Warnick *et al*. (1994) analyzed data from the same study herds, however, as stated by Warnick *et al*. (1994), Correa *et al*. (1988) analyzed a subset of data before the end of data collection in the study herds. The experts in the study by van der Fels-Klerx *et al*. (2002b) quantified that severe respiratory disease between 0-3 months of age would delay first calving age with a median of half a month (to 24.5 months) compared to unaffected heifers. Furthermore, a mild respiratory disease outbreak in calves between 3-6 months of age was estimated to delay first calving with a median of 0.2 months (to 24.2 months). Whether the difference in calving age is significant was not quantified by Warnick *et al*. (1994), Correa *et al*. (1988) or van der Fels-Klerx *et al*. (2002b). On the other hand, two studies reported no difference in age at first calving between heifers that had respiratory disease in the first 4 months (Britney *et al*. 1984) and respiratory disease within the first 90 days of life (Waltner-Toews *et al*. 1986a) and their non-diseased herd mates.

Performance at or after first calving

Dystocia, long term survival and reproduction

Heifers that had respiratory disease before 90 days of age were 2.4 times (95% CI 1.0, 5.7) more likely to have dystocia at first calving than non-diseased heifers (Warnick *et al*. 1994). Warnick *et al*. (1994) suspected that the undesirable associations of calfhood respiratory disease with age at first calving and dystocia are due to a negative effect of early respiratory disease on growth. No difference was found in the proportion of live-born calves per lactation nor the calving interval for heifers that had calfhood respiratory disease in the first 4 months compared to the control group with no treatment records (Britney *et al*. 1984). Furthermore, Britney *et al*. (1984) found that the long term survival function from birth to over 96 months of age for animals that had suffered respiratory disease during the first 4 months of life was not significantly different from their non-affected herd mates. Accordingly, the effect of respiratory disease before the age of 90 days on survival after calving as indicated by milking herd life, was found to be statistically non-significant by Warnick *et al*. (1997).

Milk production

A study by Britney *et al*. (1984) found no significant difference in milk production on a lactation basis between the heifers that had suffered respiratory disease in the first 4 months of life and the heifers with no treatments in the first 4 months. Accordingly, heifers that had calfhood respiratory disease within 90 days of birth, survived and were selected as replacements had a first lactation milk production that was non-significant from the milk production of unaffected heifers (Warnick *et al*. 1995). However, the authors noted that it is important to consider the heifers that were lost from the study, as the percentage of heifers that survived and were kept as herd replacements tended to be lower for heifers affected by calfhood disease (Warnick *et al*. 1995). Thus, the non-significant effect of respiratory disease on milk production may indicate that owners successfully kept only affected heifers that would perform as well as the untreated herdmates or that there is no effect of calfhood disease on milk production. Respiratory disease before 91 days of age was also not significantly associated with first lactation milk production in the study by Svensson & Hultgren (2008). The experts in the study by van der Fels-Klerx *et al*. (2002b) estimated the effect of respiratory disease to be small; severe respiratory disease between 0-3 months was found to reduce 305-day milk production in first lactation by a median of 150 kg compared to cows that were unaffected of the disease as calves. A mild outbreak of bovine respiratory disease between 3-6 months was estimated to decrease 305-day milk production in first lactation by a median of 10 kg, compared to cows that were not affected with respiratory disease between 3-6 months.

Summary

The effect of respiratory disease on weight gain is ambiguous, as one out of four sourced studies did not find an effect of respiratory disease on weight gain. The other studies however found a weight gain reduction in the first 6 months of life of up to 10 kg. Results for reduced body weight at 14 months of age varied between 14 kg and 29 kg. Respiratory disease was not found to affect the risk of being sold or culled during the rearing period. The effects of respiratory disease on mortality during the rearing period and on calving age were ambiguous. Only one study looked at calving difficulties at first calving, and found that heifers with a history of respiratory disease before 90 days of age had an increased risk of dystocia. There was no difference in the proportion of live-born calves per lactation nor the calving interval for heifers that had calfhood respiratory disease, as investigated by one study. No effect of respiratory disease on survival was found. Overall, findings regarding the effect of respiratory disease on first lactation milk production were non-significant. Only one study found a small effect on milk production, however the significance level was not estimated. The effect of diarrhea on later lactations was not investigated in any found studies.

Table 2.7 Statistically significant (P<0.05) effects of respiratory disease on production.

Reference	Production effect	Association	Remarks
Virtala *et al*. (1996c)	Weight gain <3 months	-0.8 kg/treatment week	
Donovan *et al*. (1998a)	Weight gain 0-6 months	-10.5 g/day/treatment day in first 6 months	
Donovan *et al*. (1998a)	Weight gain 6-14 months	-2.3 g/day/treatment day in first 6 months	
Waltner-Toews *et al*. (1986a)	Mortality 90 – 900 days	Odds = 2.45	
Correa *et al*. (1988), Warnick *et al*. (1994)	Likelihood of 1st calving	HR = 0.5	
Warnick *et al*. (1994)	Median age at 1st calving	+3 months	
Correa *et al*. (1988)	Median age at 1st calving	+ 6 months	
Warnick *et al*. (1994)	Dystocia at 1st calving	OR = 2.4	
van der Fels-Klerx *et al*. (2002b)*	Median body weight at 3 months	-10 kg	Expert quantification
van der Fels-Klerx *et al*. (2002b)	Median body weight at 6 months	-10 kg	Severe respiratory disease
van der Fels-Klerx *et al*. (2002b)	Median body weight at 14 months	-29 kg	0-3 months
van der Fels-Klerx *et al*. (2002b)	Median age at first calving	+0.5 month	
van der Fels-Klerx *et al*. (2002b)	Median 305-day milk production in 1st lactation	-150 kg	
van der Fels-Klerx *et al*. (2002b)	Median body weight at 6 months	-4 kg	Expert quantification
van der Fels-Klerx *et al*. (2002b)	Median body weight at 14 months	-24 kg	Mild respiratory disease outbreak
van der Fels-Klerx *et al*. (2002b)	Median age at first calving	+0.2 month	3-6 months
van der Fels-Klerx *et al*. (2002b)	Median 305-day milk production in 1st lactation	-10 kg	

* Significance levels were not given in the study by van der Fels-Klerx *et al*. (2002b).
OR = odds ratio, HR: hazard ratio, RR: relative risk

2.5 Partial discussion

The following sections discuss differences in selection of data material, calculation methods, methods of data material collection and risk factors, which may influence the outcome of a study and might reason differences between found results in the literature review.

2.5.1 Data material

Differences in exclusion of calves or treatments

One reason for differing morbidity and mortality results in the literature review might be difference in choices regarding data exclusion. The difference in results on mortality risk between Nielsen *et al*. (2002) and Enemark *et al*. (2014), who utilized the same database for calculation, might be an example of this. Enemark *et al*. (2014) only excluded calves which were euthanized, slaughtered or exported from Denmark within the first 180 days of life in the dataset. However, Nielsen *et al*. (2002) amongst others excluded twins, multiples, calves with incomplete information and calves that died within the first 3 days after moving to another herd. Gulliksen *et al*. (2009a) found that calves born as twins or triplets had an increased risk of death during the first week of life, compared with singletons. Further, Nielsen *et al*. (2002) found that bull calves that were moved to another herd had a higher mortality compared with bull calves that were not moved (6.6% vs. 2.6%). Excluding calves from analysis that have a higher risk of dying would reduce the found mortality risk. In accordance with this, it was noted by Fuerst-Waltl & Sørensen (2010) that published mortality rates may be underestimated in several cases, because animals with incomplete information or twins and multiples are mostly excluded from analysis. Considerations regarding exclusion of calves may be most applicable to studies where data is extracted from a database, as was done by Nielsen *et al*. (2002), Gulliksen *et al*. (2009a), Gulliksen *et al*. (2009b), Raboisson *et al*. (2013) and Enemark *et al*. (2014).

Differences in exclusion of registrations may also impact the found result. Some studies (e.g. Virtala *et al*. (1996a); Svensson *et al*. (2006a)) only chose to include one registration per disease for each calf, whereas other studies used all registrations, provided they had a certain time span between them (e.g. Sivula *et al*. (1996)). Inclusion of more registrations would thereby give a higher incidence of disease.

Age of the calves

Difference in the age of the calves investigated may impact the found results on morbidity and mortality as the risk of morbidity and mortality changes with the age of the calf. Svensson *et al*. (2006b) for instance found that the highest probability of mortality to occur between day 1 and 810 was during the first 3 weeks of life, which is similar to the findings by Wells *et al*. (1996) and Sivula *et al*. (1996), who found that the risk of death was highest at 1 week and 2 weeks of age, respectively. The 1 to 15 day mortality rate investigated in Fourichon *et al*. (1997) would thereby not be as comparable as studies which looked at a time span longer than the first three weeks of life.

2.5.2 Calculation method –risk vs. rate

The method of calculation of total disease incidence and mortality differed between studies. As noted in the literature review, some studies calculated the rate whereas other studies calculated the risk of disease or death. The difference in calculation would impact the results, as a calculation of the mortality rate would give a higher result than if the mortality risk was calculated for the same calves, as there would be a smaller number in the denominator of the rate calculation as soon as one calf dies. The size of the difference in results would depend on when the calves died during the study, with an early death contributing to a higher difference between rate and risk results. It was however assessed that the difference in calculation would have a minor impact on the comparativeness, as numerous other factors might also affect the results of the different studies.

2.5.3 Method of data material collection

Several factors regarding data collection may impact the found results and reason differences between studies.

Postmortem analysis or farmer diagnosis of cause of death

The results on 'cause of death' and 'case-fatality' (Section 2.3.2) are dependent on correct diagnosis of the cause of death. Comparing farmer diagnosis of cause of death with postmortem diagnosis in calves that died within 4 months of life, Sivula *et al*. (1996) found a sensitivity[1] of 58.3% and a specificity[2] of 93% for farmer diagnosis of diarrhea. Farmer diagnosis for respiratory disease had a sensitivity of 56% and a specificity of 100% (Sivula *et al*. 1996). Sivula *et al*. (1996) noted that the validity of all producer supplied health information may be in question, if the found accuracy of producer diagnosis of calf mortality is an indicator of overall producer diagnostic skill. However, many producers diagnosed the reason of death with 'unknown' (Sivula *et al*. 1996). If the 'unknown' producer diagnoses would be removed then the sensitivity would increase. Based on the finding by Sivula *et al*. (1996), the results found in the study by Donovan *et al*. (1998b), which relied on farmer diagnosis, may not be as sensitive or specific in the estimation of the cause of death and case-fatality as the other studies, which conducted postmortem examinations (Table 2.3). In the study by Donovan *et al*. (1998b) the primary cause of death amongst their calves was septicemia. This result was an outlier from the results found in the other studies, however, other reasons such as differing climate increase the incidence of septicemia compared with temperate regions.

Farmer vs. veterinarian recording disease

Another aspect that could contribute to differing results of case-fatality and disease incidence is how many of the diseases amongst the calves are detected. Further, the results of studies estimating the effect of diarrhea and respiratory disease on production may also differ due to difference in disease detection.

Both Virtala *et al*. (1996b), Svensson *et al*. (2003) and Svensson *et al*. (2006a) found that farmers detect less cases of respiratory disease compared with a veterinarian. In the study by Virtala *et al*. (1996b) farmers found a respiratory incidence of 11% in calves of up to 3 months of age whereas the veterinarian found an incidence of 25.6% in the same group of calves. Only half of the respiratory disease cases diagnosed by a veterinarian in bimonthly visits were detected by farmers in 0 to 90 day old calves (Svensson *et al.* 2003). In the same group of calves, farmers only detected 14.9% of the 168 calves diagnosed to suffer from respiratory disease by the veterinarian between 91 to 210 days of age (Svensson *et al*. 2006a). Svensson *et al*. (2006a) discussed that the lower detection of respiratory disease later in the calf's life might be due to the fact that calves were kept in groups at that point, making it harder to detect diseased calves compared to earlier in life, where calves were housed individually. According to Marstal (2014) the use of a 'calf health scoring chart' could help improve the timely farmer-detection of calves with respiratory disease. Based on these findings, studies based on farmer recordings (Sivula *et al*. 1996; Wells *et al*. 1996; Fourichon *et al*. 1997; Gulliksen *et al*. 2009b) are assessed to be more likely to underestimate the true disease incidence of respiratory disease compared with studies where a veterinarian was

[1] *Sensitivity*: 'How many of the calves that died due to diarrhea found by postmortem analysis did the farmer diagnose with dying from diarrhea?'
[2] *Specificity*: 'How many of the calves that the famer diagnosed with dying from diarrhea were also diagnosed as dying from diarrhea in the postmortem analysis?'

involved. Only some studies (Virtala *et al*. (1996a); Virtala *et al*. (1996b); Svensson *et al*. 2003; Svensson *et al*. 2006a) used veterinary diagnosed respiratory disease and diarrhea to more accurately describe the risk of these diseases in calves. The likelihood of the veterinarian diagnosing respiratory disease and diarrhea increases with increasing number of visits. In the studies the calves were still only examined bimonthly (Svensson *et al*. 2003; Svensson *et al*. 2006a) or weekly (Virtala *et al*. 1996a; Virtala *et al*. 1996b). As diarrhea is more short-lived in its occurrence (less than 1 week; Virtala *et al*. (1996a)) compared to respiratory disease (mean duration 4 weeks; Virtala *et al*. (1996b)), the visits from veterinarians were more likely to have found most cases of respiratory disease compared with cases of diarrhea. A higher frequency of visits would be needed in order to detect all cases of diarrhea. Thus, the incidence of diarrhea may be more comparable between studies, as both incidences may have a comparable detection.

Underestimation of disease incidence in database material

Another reason for differing results may be that database material on disease incidence is underestimated. The study by Gulliksen *et al*. (2009b) found that the Norwegian Dairy Herd Recording system had an underestimation of disease recordings of around 40% in calf health records. It was not described whether the farmers were supposed to record both treatments and clinical signs or only treatments. Whether the Danish Cattle database has an underestimation of 40% is not known. However, as only farms with certain agreements have to record treatments and it is optional to register a disease incidence, data on different diseases in the Danish Cattle database would also underestimate the 'true' disease incidence. Estimates on mortality would not be underestimated in the Danish Cattle database, as it is mandatory to register the death of an animal.

Definition of disease incidence that should be recorded

Differing results of case-fatality and disease incidence can also be related to the definition of a disease incidence that was to be recorded in the respective study. The results of studies estimating the effect of diarrhea and respiratory disease on production may also differ due to difference in disease detection.

One study only recorded the treated incidences (Sivula *et al*. 1996) and some studies recorded untreated and treated incidences of disease (Virtala *et al*. 1996a; Virtala *et al*. 1996b; Svensson *et al*. 2003; Svensson *et al*. 2006a). Thereby would the study that records both treated and untreated incidences find a higher **disease incidence** than the study only including medically treated calves. This can be seen in the estimated respiratory disease incidences from Virtala *et al*. (1996b) where the incidence of respiratory disease is at 25.6% for the veterinary recorded cases (which were clinical and treatment cases) whereas the incidence of treated, veterinary verified cases was only at 17.3%. The case-fatality would also be impacted, as if only treated cases are in the group of diseased calves, then the risk of dying due to the disease would be higher.

Assuming that a calf that has been treated for diarrhea is more affected by diarrhea compared with a calf that has not been treated, the outcome of the studies investigating the production effect of diarrhea would also be affected. If the dataset is large enough, a study on the impact of diarrhea and for instance growth rate would be more likely to find a significant difference between the 'nondiarrheic' and treated group of calves if only calves which had a treated diarrhea are included, compared with a study that includes both treated and untreated diarrheic calves. On the other hand, only including treated calves may reduce the size of the diarrhea-group to such a low level that no statistical significance can be found due to the power of the analysis. As discussed by Svensson & Hultgren (2008) the low sample size may be the reason for the non-significant association between 'severe diarrhea' and first lactation milk production. In the study, only a significant association of 'mild diarrhea' with milk production was found. Another reason for the non-significant association could however also be that the animals which survived the severe diarrhea as calves are stronger than the other animals which were not diseased and thereby become 'winner cows', which cope well in the milking herd.

Results based on experts

If the 'data material' of a study is based on expert opinions such as in van der Fels-Klerx *et al*. (2002b), no data material is available to validate the found results. As van der Fels-Klerx *et al*. (2002b) discusses, these estimates may be subjective and the found results can never replace data from field studies. As the experts might be influenced by known results from other studies they might also be biased. Thus, caution should be taken when concluding on effects of respiratory disease on production through this study.

2.5.4 Risk factors

Several risk factors may influence the results on morbidity or mortality found in the investigated studies of the literature review. The following sections will present some of these risk factors.

Season and climate

Climatic and seasonal differences between studies might influence the found results of the different studies. A Swedish study for instance found that the risk of contracting respiratory disease was more than twice as high in the cold season (September to November) than during December to April (Svensson *et al*. 2006a). Further, the odds ratio of severe diarrhea was increased in calves born during summer (Svensson *et al*. 2003). Another study by Svensson *et al*. (2006b) found that calf mortality rates were lower during warm months compared with cold months. This finding was supported by Gulliksen *et al*. (2009a) who found that calving in spring and winter significantly increased the risk of death within the first week and month of life. However, no effect between 1 and 6 months of life was found. Findings in the study by Fourichon *et al*. (1997) might be impacted by seasonal change in weather, as each herd only participated for three months. If for instance a larger amount of herds was participating in the winter months the incidence of morbidity and mortality may be overestimated. The humid subtropical climate in Florida may affect the disease incidence in the study by Donovan *et al*. (1998b) because air humidity is a risk factor related to especially respiratory disease (Radostits & Blood 1985).

Herd size

Differing herd size may be a factor contributing to differences in found morbidity and mortality between studies. Nielsen *et al*. (2002) for instance, reported an association between high calf mortality and increasing herd size, such that the 1 to 14 day calf mortality in a 120 cow-year herd was at 4%, whereas the mortality in a 60 cow-year herd was 2.5%. Gulliksen *et al*. (2009a) speculated that the higher calf mortality rates found for their survey herds compared with the dairy herds in the Norwegian Dairy Herd Recording System (Table 2.2) may be due to the difference in herd size. In the study the survey herds had an average of 46.6 cow-years whereas the average herd size of the other herd group was at 21.6 cow-years. The review on calf housing systems by Marce *et al*. (2010) found that herd size was positively correlated with diarrhea and respiratory disease. Svensson *et al*. (2003) suggested that the lower calf disease incidence in their Swedish study may be due to lower animal density and small herds size, compared with most other countries in Western Europe and USA.

Milk yield

Two studies based on the same survey reported that a rolling herd average milk production of above 9,072 kg was associated with decreased mortality due to diarrhea and decreased mortality due to respiratory disease among pre-weaned heifer calves (Losinger & Heinrichs 1996; 1997). Similarly, Nielsen *et al*. (2002) found that the 1 to 180 day calf mortality was lower in herds with a high average milk yield. Milk yield is a risk factor that does not directly affect the calf, however milk yield is a measure of herd management. If assuming that well managed herds have higher milk yields, this would mean that well-managed herds have lower calf mortality.

Colostrum feeding

Calves are born without antibodies (hypogammaglobulinemic), so adequate passive transfer of immunoglobulin G (**IgG**) via ingestion of colostrum within the first 24 hours is the only source of antibodies until the calf's own immune system develops sufficiently (Johnson *et al*. 2011). Consequently, adequate passive transfer of IgG is important to calf health and survival, which is also supported by studies (Blom 1982; Windeyer *et al*. 2014). Danish recommendations on colostrum management state that a calf of a large breed should optimally ingest 3-4 liters of colostrum within 6 hours of birth (Thøgersen *et al*. 2013) including at least 50 mg IgG per ml (Boysen & Vesterager 2009). Differences in colostrum management between herds or regions might affect the incidence of morbidity and mortality in the studies.

Hygiene

Hygiene in the calving pen and calf pen is an important factor (Radostits & Blood 1985; Marstal 2007; van Metre *et al*. 2008; McGuirk & Ruegg 2011), as a major infectious route of diarrhea causing microorganisms is via feces. Hygiene is also recommended for prevention of respiratory disease (Radostits & Blood 1985; Marstal 2007; McGuirk & Ruegg 2011), as it would contribute to lower infectious pressure and thereby lower concentration of pathogens in the air. Thus, differences in hygiene strategy would impact the outcome of studies.

Air quality

Air quality may cause difference in the found incidence of respiratory disease between studies. The major infectious route for respiratory disease is via the aerosol (McGuirk & Ruegg 2011). Thus air quality is an important factor to prevent respiratory disease. Inadequately ventilated barns increase the risk of respiratory disease (Radostits & Blood 1985). This is because the stagnant air becomes humid, and the concentration of dust, molds and gases increases, which significantly increases the risk of developing respiratory disease (McGuirk & Ruegg 2011). Bacteria and viruses adhere to dust particles whereby they reach the respiratory system of the calf (Radostits & Blood 1985). It has been shown that calves housed outside (i.e. in fresh air) have a lower risk of contracting respiratory disease compared with calves housed in inside individual pens (Waltner-Toews *et al*. 1986b).

Housing

The housing of calves varies between farms and countries (Marce *et al*. 2010) and may influence the found results on mortality and morbidity. Group housing is a risk factor for calf morbidity (Waltner-Toews *et al*. 1986c; Perez *et al*. 1990; Olsson *et al*. 1993; Svensson *et al*. 2003). Further, the review by Marce *et al*. (2010) found that the risk of respiratory disease increased when the group size of the collective pen increased and that the risk of diarrhea and respiratory disease increased with age variability within a pen. A Danish study by Pedersen *et al*. (2009) further found that the prevalence of both diarrhea and respiratory disease was more than twice as high among calves in dynamic groups compared to calves in stable groups. The study by Gulliksen *et al*. (2009a) found that calves housed in group pens at an early age had a greater risk of death during the first month of life than calves housed in an individual pen.

Association between diseases and mortality

The found mortalities and morbidities may differ due to differing amounts of calves being diseased in the studies. Several studies have found that calfhood diarrhea and respiratory disease are associated with each other, such that calves which have had diarrhea have a higher risk of contracting respiratory disease (Curtis *et al*. 1988; Svensson *et al*. 2006a; Hultgren *et al*. 2008). It has been reasoned that the higher risk of respiratory disease may be due to a compromised immune system, because the calf is weakened from the previous disease or due to common predisposing risk factors such as inadequate feeding of colostrum (Waltner-Toews *et al*. 1986c; Svensson *et al*. 2006a). Another reason for the higher risk of respiratory disease following diarrhea might be that the farmer has more focus on the previously diseased calf and thereby is more likely to treat the calf if it contracts respiratory disease. Expectedly, it has been found that the risk of dying increases when the calf is diseased with respiratory disease or diarrhea (Waltner-Toews *et al*. 1986a; Gulliksen *et al*. 2009a; Windeyer *et al*. 2012).

Management

Differing management between herds, regions or countries may reason differences in calf morbidity and mortality between the sourced studies. Previously discussed risk factors (e.g. hygiene, colostrum feeding and milk yield) are connected with management practices. Thereby good herd management should contribute to improved calf health and survival. Feeding management is another important risk factor for diarrhea and respiratory disease. According to McGuirk & Ruegg (2011) inappropriate milk volume, concentration of fat or protein, or feeding temperature of milk or milk replacer can compromise the immunity of the calf. Further, the genetics of the calf can play a role in differences between studies, as it has been found that calf and heifer mortality is heritable (Fuerst-Waltl & Sørensen 2010). Moreover, a Swedish study found that the risk of contracting diarrhea was increased in Swedish Red and Whites and that beef cross-breeds were associated with increased risk for increased respiratory sounds (Svensson et al. 2003).

2.5.5 Production effect studies

The results from the studies on effects of diarrhea and respiratory disease on production are difficult to compare, as they are performed in varying ways. Further, it is difficult to assess whether for instance a found effect on delayed calving age is due to decreased growth rate due to diarrhea or respiratory disease, or if it is due to reduced fertility. The answer for this is based on herd management decisions: maybe the farmer decides to inseminate the heifer later due to its smaller size or the increase in calving age might be due to inferior reproduction. Some studies mentioned that an increased number of previously diseased heifers were sold. The resulting decrease in sample size would make it difficult to find out if the disease had significant effect on measurable parameters such as milk yield.

2.6 Partial conclusion

2.6.1 Disease incidence and mortality

The *incidence of dairy calf mortality* in countries with dairy production systems similar to Denmark varied between 4.0% and 4.9% in the first month of life. In the first 6 to 7 months of life the mortality varied between 3.6% and 12.6% for heifer calves. Diarrhea and respiratory disease were always found amongst the top three *causes of death* amongst the studies in the literature review. The *case-fatality* for diarrhea varied between 7.6% and 17.9% and the *case-fatality* for respiratory disease varied between 4.2% and 13.8%. The *total morbidity* was found to vary between 14.1% and 58%. The *incidence* of calf diarrhea in countries comparable to Denmark varied between 3.9% and 28.8% and the *incidence* of respiratory disease varied between 2.9% and 25.6%. Results found in the literature review are likely influenced by a number of risk factors and methods of data material collection

2.6.2 Production effects

Information on the *effect of diarrhea and respiratory disease obtained within the first six months of life on production* was limited and the found studies either gave ambiguous or non-significant results. The only exception was an increased risk of dystocia following respiratory disease. However, only one study investigated this production effect. Based on the current results, the effects of diarrhea and respiratory disease on production seem limited. No studies were found that looked at the effect of a calf being disease to both diarrhea and respiratory disease on production.

Chapter 3 Morbidity and mortality in Danish dairy herds

No recent studies were found, that investigated the calf morbidity in Danish dairy herds. Further, it is of interest to investigate the association between diarrhea, respiratory disease and death in Danish dairy calves. It is the aim of this section to estimate the 1 to 180 day calf mortality risk, and to estimate the 1 to 180 day incidence of diarrhea and respiratory disease in Danish dairy herds. Further, the association between diarrhea, respiratory disease and calf mortality in the first 180 days of a calf's life will be investigated. Information derived from the Danish Cattle database will be applied in the SimHerd analysis in Chapter 4.

The following results are based on data derived retrospectively from the Danish Cattle database. Recordings on the exact disease incidence are not available as they are not recorded. Only disease treatments are recorded and it is assumed that they somehow reflect the disease incidence in the herd. As described in Chapter 2 the farmers only find, diagnose and decide to treat a share of the diseased calves. The majority of data is from herds which are part of the Herd Health Contract 'Module 2 plus'. This section will first describe what the Danish Cattle database and the Herd Health Contract are. Secondly, materials and methods for data extraction, editing and analysis will be described. Finally, results of the analysis will be presented and discussed and a partial conclusion for this chapter will be made.

3.1 Background

3.1.1 Danish Cattle database

The '*Kvægdatabase'* (**Danish Cattle database**) is a large national database, where information regarding cattle in Denmark is stored. According to the recent rules of the executive order (Fødevarestyrelsen 2012), farmers in Denmark are obliged to report certain information around calving, death or slaughter, exit from the farm and import of cattle. Information has to be recorded electronically into the '*Dyreregistrering'* (**Animal Register**) within 7 days of the occurrence (Fødevarestyrelsen 2012). The Animal Register is a program that transfers information into the Danish Cattle database. Apart from farmers entering data, information is also entered into the database from various other parts of the cattle sector. This includes entries from veterinarians, advisors, laboratories, breeding companies, slaughter plants and dairy plants (Frandsen 2013). Thus, data stored in the database includes information ranging from reproduction and calving, results from bulk tank milk analysis and treatment information. The information in the Danish Cattle database is utilized by farmers and associated industries including veterinarians, research institutions, dairy plants, and livestock- and breeding advisors (Frandsen 2013).

3.1.2 Herd Health Contract

From July 1st 2010 the '*Sundhedsrådgivningsaftale'* (**Herd Health Contract**) was made compulsory for farmers who have a minimum of 100 cows or 200 young stock (bulls, steers and/or heifers that have not calved yet) on their CHR-number[3] by the Danish Veterinary and Food Administration. Farms who are smaller can voluntarily register for the Herd Health Contract. The recent rules of the executive order are in force since June 1st 2013 (Fødevarestyrelsen 2013).

A farm signed up for the Voluntary Herd Health Contract or Mandatory Herd Health Contract can choose between five different types of agreements (Figure 3.1). Each agreement includes varying amounts of obligatory farm visits (from 1 to 52 visits by the veterinarian and/or farm advisor) and varying allowance regarding self-treatment of animals (from no allowance to allowance to treat initially and the following times) (Fødevarestyrelsen 2013).

The agreement called '*Tilvalgsmodul 2 med 9 måneders ordinationsperiode*' (**Module 2 plus**) lets the veterinarian prescribe drugs for up to nine months. The agreement allows the farmer to treat all animal-age-classes both initially and the following times. However, the farmer can only treat for diseases that a veterinarian has given a herd-diagnosis for, otherwise he cannot treat the initial time. For example, if a herd-diagnosis is made for respiratory disease, the farmer has the prescribed drug available for treatment for nine months and he can treat an animal both the initial and following times, if needed. Only the farms, which are signed up for 'Module 2 plus' are obliged to electronically record each treatment made on any animal-age-class into the Animal Register, which then transfers data into the Danish Cattle database.

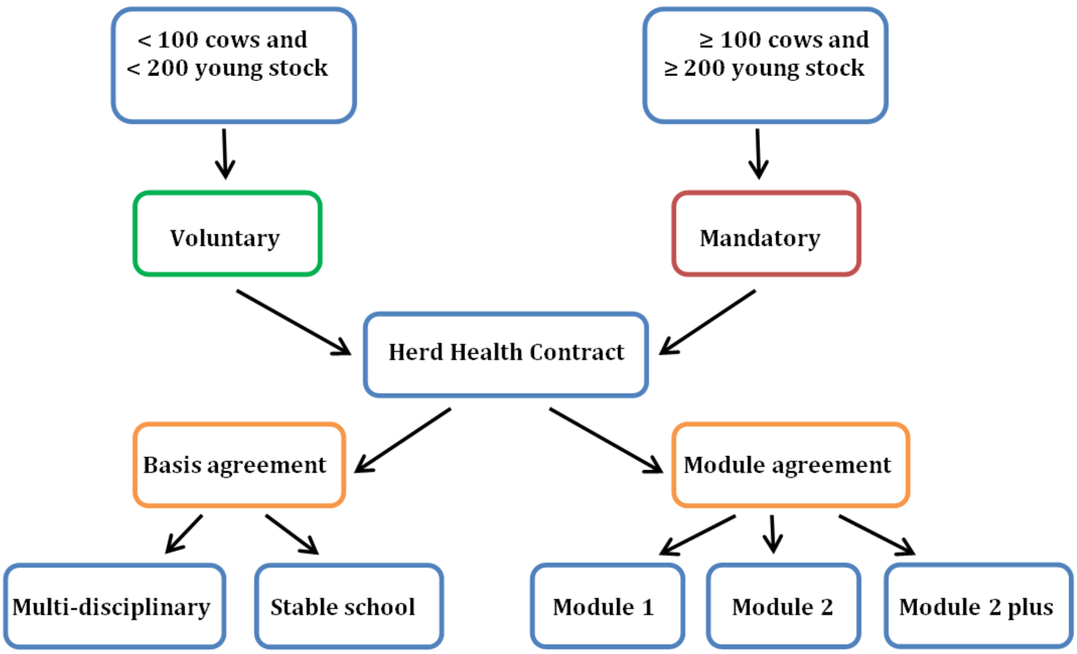

Figure 3.1. Overview of the Herd Health Contract system. As can be seen in the figure, both the voluntary and mandatory farms can choose between the Basis agreements and Module agreements. Farmers can choose between 'Multi-disciplinary', 'Stable school', 'Module 1', 'Module 2' or 'Module 2 plus'. The figure is edited from (Martin 2013).

[3] Unique number for identification of a certain geographic location.

3.2 Materials and Methods

Due to time constraints, the data material in Chapter 3 was extracted, edited and analyzed by Marlene Trinderup from AgroTech, Skejby. Data material was extracted from the Danish Cattle database, and data preparation, descriptive and inferential statistics were carried out by means of the software package SAS version 9.2. The figures in Chapter 3 and *t*-test were later made in Excel. Frequent meetings were held with Marlene Trinderup in order to discuss data extraction, editing and analysis. Results of the analysis are given through descriptive and inferential statistics.

Data from farms with the 'Module 2 plus' agreement type were used for the analysis because it was assessed that this group of farms has the most accurate treatment records regarding the amount and type of treatments done. This was assessed because farms that are signed up for the 'Module 2 plus' agreement are the only farms obliged by law to record calf treatment information into the Animal Register.

The data analysis was split into three parts, where each part was investigating a different 'overall question'. The overall questions were:

- ***Part 1:*** Are the yield controlled farms which are part of 'Module 2 plus' comparable with the remaining yield controlled farms in Denmark?
- ***Part 2:*** What is the estimated incidence of diarrhea and respiratory disease in 'Module 2 plus' herds? How high is the mortality risk in 'Module 2 plus' herds? How is the morbidity and mortality distributed amongst 'Module 2 plus' herds?
- ***Part 3:*** What is the association between intestinal problems, respiratory disease and calf mortality in 'Module 2 plus' herds?

The data material applied from the Danish Cattle database differed between each of the three parts, such that an increasing amount of herds or calves were excluded from the data material. As can be seen in Table 3.1, Part 1 included all yield controlled herds in Denmark whereas Part 2 and 3 only included 'Module 2 plus' herds. Further, Part 2 included more calves than Part 3 as the calves in Part 3 that were moved out of their first CHR-number were excluded.

The following sections will describe data extraction, editing and analysis for Part 1, Part 2 and Part 3.

Table 3.1. Overview of criteria for herds and calves included in analyses of the three 'overall questions'.

	Part 1	Part 2	Part 3
Herd criteria			
Yield controlled in 2012	x	x	x
Only 'Module 2 plus' herds*		x	x
Calf criteria			
Calves born in 2012 –followed for 180 days		x	x
- Exclude calves that die within first 24 hours of life		x	x
- Exclude beef breed calves		x	x
- Exclude calves moved out of first CHR-number within 180 days of life			x

* The herd had to be signed up both on 1. January 2012 and 30. June 2013

3.2.1 Part 1 –Comparison of two herd-groups

A *t*-test comparison of certain key-figures between 'Module 2 plus' herds and the remaining yield controlled herds was done in order to find out if 'Module 2 plus' herds were comparable with the remaining yield controlled herds in Denmark.

Dairy herds (**farm-numbers**[4]) affiliated to the Danish yield control system in all of 2012 were included in analysis for Part 1 (Table 3.1). Non-dairy herds were excluded by only including herds with registrations of energy corrected milk (**ECM**) and somatic cell count (**SCC**). By the end of 2012, 3307 out of approximately 3730 dairy herds in Denmark (89%) were signed up for yield control (Lauritsen (2014) pers. comm.). Only yield controlled dairy herds were included because we wanted to compare 'Module 2 plus' herds with other dairy herds on the parameters SCC and ECM. These parameters were only available for yield controlled herds. Information on Herd Health Contract type was extracted from the Danish Cattle database for each dairy farm in order to find the farms signed up for the 'Module 2 plus' agreement. The herd needed to be signed up for 'Module 2 plus' on both the 1st of January 2012 and 30th of June 2013 in order to be included in the 'Module 2 plus'-group. This was in order to make sure that treatment records for the calves included in the later analysis would be available. Initially, herds were grouped into 'all yield controlled herds' (n=3307) in Denmark and into a group of yield controlled farms, that were signed up for the 'Module 2 plus' agreement (n = 610). The mean, standard deviation, maximum, minimum and 25th, 50th and 75th percentile key-figure values were extracted from the key-figure database for both groups. The key-figures extracted for comparison were '*number of animal-years*', '*somatic cell count*', '*calf mortality*' (1-14, 14-60, 60-180, and 1-180 days), '*calves born dead*', '*energy corrected milk per cow-year*', '*diseases per animal-year*' and '*mastitis per cow-year*'. Instead of comparing 'Module 2 plus' with '*all* yield controlled herds' (where 'Module 2 plus' herds would be represented in both groups), it was decided to compare 'Module 2 plus' herds with the '*remaining* yield controlled herds'. Thus, a new mean for each key-figure ($\mu_{remaining}$) was calculated for the remaining herds ($n_{remaining}$) that were not in 'Module 2 plus';

$$n_{remaining} = n_{all} - n_{2plus}$$

$$\mu_{remeining} = \frac{\mu_{all} * n_{all} - \mu_{2plus} * n_{2plus}}{n_{remaining}}$$

Two-sided unpaired t-test

In order to analyze if 'Module 2 plus' herds are comparable with the remaining yield controlled herds in Denmark, it was evaluated whether there is a difference between the 'Module 2 plus' herds

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[4] Unique number given for farm identification. In the rest of this chapter, a farm or herd from the Danish Cattle database will equal 'farm-number'.

and the remaining herds in a two-sided unpaired *t*-test. The hypothesis is: '*there is no difference in the mean key-figure value between 'Module 2 plus' herds and the remaining yield controlled herds*'. A *t*-test can be used to test the difference in means between two groups (Ersbøll *et al*. 2004; Grafen & Hails 2008b). It is assumed that the applied key-figure data are normal-distributed and that the observations in the two groups have equal variance. It was not possible to test for normality (Jarque-Bera Test), because data was not available. A test for equal variance (Levene's Test of Equality of Variances) could also not be made, due to lack of data material.

The *t*-test needs information on the number of herds in the two groups (n_{2plus} and $n_{remaining}$), mean key-figure values for the two groups (μ_{2plus} and $\mu_{remaining}$) and the variances for the two groups (s^2_{2plus} and $s^2_{remaining}$) (variance = $\text{standard deviation}_x{}^2$). As described above, it was possible to calculate new mean key-figure values for the 'remaining yield controlled herds' ($\mu_{remaining}$). As data material was not available, a new standard deviation could not be calculated for the remaining herds. However, as it is assumed that the variance is equal for the two groups, the given variance for *all* of the yield controlled herds should be applicable for the *remaining* herds. Thus, $s^2_{remaining} = s^2_{all}$. The hypotheses are:

$$H_0: \mu_{2plus} = \mu_{remaining}, \quad H_1: \mu_{2plus} \neq \mu_{remaining}$$

The formula applied to calculate the test statistic value (*t*) is:

$$t = \frac{\mu_{2plus} - \mu_{remaining}}{\sqrt{s_p^2\left(\frac{1}{n_{2plus}} + \frac{1}{n_{remainung}}\right)}}$$

Where s_p^2 (estimate of the pooled variance for the two groups) is calculated using the following equation:

$$s_p^2 = \frac{(n_{2plus} - 1) * s^2_{2plus} + (n_{remaining} - 1) * s^2_{remaining}}{n_{2plus} + n_{remaining} - 2}$$

The distribution of the test statistics value (t-distribution with ($n_{2plus} + n_{remaining} - 2$) degrees of freedom) was calculated using the equation:

$$t \sim t(n_{2plus} + n_{remaining} - 2)$$

The calculated values were applied in the code 'T.FORDELING.2T*(t;n)*' in excel in order to receive the *p*-value for the test statistic value (*t*) with *n* degrees of freedom.

3.2.2 Part 2 – Mortality and treatment incidence

Data material in Part 2 was extracted in order to estimate the incidence of diarrhea and respiratory disease based on the treatment frequency amongst dairy calves and the treatment-distribution between dairy herds in Denmark. Furthermore the mortality risk and distribution of calf mortality was investigated on the basis of the data material.

As shown in Table 3.1, the two inclusion criteria for dairy herds in Part 2 were affiliation to the Danish yield control system in all of 2012 and secondly that the herd was signed up for the 'Module 2 plus' agreement both on January 1st, 2012 and June 30th, 2013. In total 610 dairy herds met these criteria.

Certain calves from the included dairy herds were used for analysis in Part 2 (Table 3.1): the **CKR-numbers**[5] of bull and heifer calves born in the included herds between the 1st of January 2012 and 31st of December 2012 were extracted. By extracting the CKR-numbers, only calves that survived the first 24 hours after birth were included in the dataset (i.e. calves with the code '*stillborn*', '*dead within 24 hours*' or '*euthanized as newborn*' and other calves that did not receive an ear-tag are not included in the dataset). Relevant treatment records and other information of each included calf was extracted from the Danish Cattle database until 180 days of age, or until death or euthanization occurred (see Table 3.2). The treatment records for enteritis, diarrhea, coccidiosis and cryptosporidiosis all give clinical signs of diarrhea and are common causes of diarrhea. As the diagnosis of diarrhea and enteritis are difficult to distinguish, enteritis and diarrhea treatments were combined to 'diarrhea'. Also, the codes for 'euthanized' and 'dead' are combined to 'dead'.

Table 3.2. Overview of information extracted from the Danish Cattle database to find the calves that should be included in Part 2 and Part 3 of the analysis.

Task	Most important information extracted
To find calves that are born in 'Module 2 plus' herds in 2012 (Part 2 & 3)	CKR-number of calf Date of birth Sex of calf
To exclude 'beef breed' calves (Part 2 & 3)	Breed of calf
To find available treatment records* (Part 2 & 3)	Date of each treatment for: '*enteritis*' (code 28), '*diarrhea*'(code 51), '*coccidiosis*' (code 52), '*cryptosporidiosis*' (code 166), '*pneumonia*' (code 41)**
To find out if/when calf died*** (Part 2 & 3)	Exit date and code for '*dead*' (code 9) or '*euthanized*' (code 19)
To find out if calves were moved out of first CHR-number within 180 days (Part 3)	Exit date from herd, and reason for exit ('*moved*', '*dead*', '*slaughter*', '*euthanized*') Each CHR-number and farm-number that calf has been in

* extracted for each calf that survived day 1 in 'Module 2 plus' herds from day 0 – 180
** 'pneumonia' will be called 'respiratory disease', as it is likely that other respiratory diseases than pneumonia were treated with this code. There is no other code for other types of respiratory disease.
*** extracted for each calf in 'Module 2 plus' herds from day 1-180

In total 126,014 calves (68,859 heifer calves and 57,155 bull calves) were born in 2012 in the 'Module 2 plus' herds. Of these calves, the ones registered as '*beef breed type*' (e.g. Galloway,

[5] Unique number given for animal identification.

Hereford or Limousine) were excluded from the dataset (n = 37 calves). The calves of the breeds Red Danish Dairy breed, Danish Holstein, Danish Jersey, Danish Red Holstein and 'other milk breeds' (e.g. Finnish Ayrshire or Brown Swiss) and crossbred calves were left in the dataset. The exclusion of '*beef breed type*' calves left 125,977 calves (68,842 heifer calves and 57,135 bull calves) for the analysis in Part 2. '*Beef breed type*' calves were excluded from the dataset in order to try and make sure that only breeds intended for milk production were included in the group of analyzed calves. Crossbred calves were still included in the dataset, as these are likely to be used for milk production. It would have been good to have a similar calf group in Part 1 as in Part 2. However, as the key-figures in Part 1 are calculated on farm-number level (and not CKR-number level), it was not possible to exclude individual calves that are of '*beef breed type'* in Part 1. A difference of 37 calves should however not make a big difference when considering that 125,977 calves are still left in Part 2.

If a calf was treated for the same disease-code several times during a period of 8 days only the first registration was included to exclude follow-up-treatments. Thereby one calf could have several different treatment recordings between 0 and 180 days of age and one calf could have the same treatment recording more than once, provided that enough days elapsed from the initial same disease-code.

The results on treatment incidence and frequency, and incidence of calf mortality and frequency are presented in descriptive statistics. The incidence risk for calves dying between 1 to 180 days was calculated by dividing the number of calves that died between 1 and 180 days of age by the total number of calves born in the herd during the study period. The incidence of the different treatments was calculated by dividing the number of treatments between day 0 and 180 of age (minus treatments within 8 days and for calves that survived day 0) for the respective disease by the total number of calves born in the herd and surviving till day 1 during the study period.

3.2.3 Part 3 – Associations between diseases and mortality

Data in Part 3 were extracted in order to investigate the relationship between intestinal problems, respiratory disease and death through a Chi-square test.

Inclusion criteria for herds in Part 3 were the same as for Part 2 (see Section 3.2.2 and Table 3.1). As shown in Table 3.1, Part 3 excluded the same calves as in Part 2, but the dataset in Part 3 additionally excluded calves that were moved from their initial CHR-number and to another CHR-number within the first 180 days of their life. Movement of calves to other farm-numbers that belonged to the same CHR-number was allowed. In total, 51.29% of calves (64,609 out of 125,977 calves), which includes 90% of the bull calves, were moved from their initial CHR-number within 180 days and were not included in the analysis in Part 3. Thus, exclusion of '*moved calves'* left 61,368 calves (55,634 heifer calves and 5,734 bull calves) for analysis. Calves that were moved out of the initial CHR-number were excluded because the next CHR-number may not have the same Herd Health Contract, and may therefore not record calf treatments as accurately as the farms that are part of 'Module 2 plus'. As it was the aim of Part 3 to look at the association between intestinal problems, respiratory disease and calf mortality, it was important to have accurate treatment records for all the calves included in the analysis in order to find the associations. If the calves that are moved out of the initial CHR-number only have registrations for the first CHR-number and no later treatment records it may bias the results, as e.g. a respiratory disease treatment in the next CHR-number would not be included in the recordings and would therefore not show an association with e.g. other treatment records or death. Furthermore, morbidity and death could also be influenced by movement to another herd, as the morbidity and mortality risk may increase due to presence of new infectious agents and a compromised immune system due to stress caused by e.g. shipping, different feeding and new grouping of calves. A Danish study by Nielsen *et al*. (2002) found that the 57-180 day mortality amongst bull calves which were moved to another herd between 1-56 days of life (17% of all bull calves) was 6.6% whereas the 57-180 day mortality amongst the bull calves which were not moved was 2.6%. Thus, mortality or morbidity may not be associated with the previous treatment but more with movement to another CHR-number.

The reason for only excluding the '*moved calves'* in the Part 3 and not in Part 2 of the analysis was that an estimate of the incidence of diarrhea, respiratory disease and mortality was wanted in Part 2. Thus it was not relevant to exclude calves from Part 2. Further, a large amount of bull calves would be lost when looking only at calves that were not moved, thus it was chosen to include these calves in Part 2.

Another option could have been to look at the **CVR-number**[6] level, which can include several CHR-numbers and several farm-numbers. An advantage of saying that only calves moved out of the initial CVR-number are excluded may be that more calves would be included in the analysis of Part 3. However, the Herd Health Contract agreement is only made on CHR-number level, which would imply that registrations of calves moved to a different CHR-number under the same CVR-number may not be as accurate because the Herd Health Contract agreement may not be the same as in the initial CHR-number.

Data extracted for calves in Part 3 is shown in Table 3.2 and coincides with information extracted for Part 2. As in Part 2, not all calf treatments recorded by the farmer were counted in the analysis in Part 3. If a calf was treated for the same disease-code several times during a period of 8 days only the first registration was included to exclude follow-up-treatments.

Chi-Square Test of two categorical variables

It was the aim of Part 3 to find out if there is an association between the categorical variables 'intestinal problem', 'respiratory disease' and 'dead' in 'Module 2 plus' herds. The Pearson Chi-square (X^2) analysis is an appropriate statistical test to apply when we look at a relationship between two categorical variables where each variable can take two, or more than two values (Ersbøll *et al*. 2004; Grafen & Hails 2008a). The X^2 test, tests the null hypothesis (H_0) that there is *no relationship between the row variable and the column variable*. The alternative hypothesis (H_1) says that there is some relationship but does not say what kind.

[6] Unique number given for company identification.

The X^2 test compares the *observed counts* of observations in the cells of the two-way table with counts that would be *expected* if H_0 were true (Ersbøll *et al*. 2004; Grafen & Hails 2008a). The *expected counts* in the two-way table are calculated as follows:

$$expected\ count = \frac{row\ total\ x\ column\ total}{table\ total}$$

The X^2 statistic is a measure of how far the observed counts in a two-way table are from the expected counts. The formula for the X^2 statistic is:

$$X^2 = \sum \frac{(observed\ count - expected\ count)^2}{expected\ count}$$

The sum is over all cells in the two-way table.

The X^2 test for a two-way table with *r* rows and *c* columns compares the values of the X^2 statistic with critical values from the X^2 distribution with **(*r*-1)(*c*-1)** degrees of freedom (Ersbøll *et al*. 2004; Grafen & Hails 2008a). The X^2 test was run in SAS. When prompting the "FREQ Procedure" and specifying the "chisq" option SAS will set up the two-way tables, calculate the expected count and the X^2 statistic and give a *p*-value.

In the X^2 analysis the categorical variable 'intestinal problem' included the treatment records for '*enteritis'*, '*diarrhea'*, '*coccidiosis'* and '*cryptosporidiosis'* and the categorical variable 'dead' included *'death'* and *'euthanization'*. In general, only the first treatment for any intestinal problem and first respiratory disease treatment of each calf counted in the analysis. Each analysis was run for bull calves and heifer calves separately. Bull and heifer calves were run separately because there may be a difference in response depending on which sex the calf is. The fact that many bull calves are moved from dairy herds at a young age might impact the outcome of the analysis. Further, a French study reasoned that the two sexes should be analyzed separately because individual management practices may differ between sexes (Raboisson *et al*. 2013). It is uncertain if this is the case for Danish dairy herds.

As can be seen in Appendix 2, eight different two-way tables were set up. Each of those tables tests a different null-hypothesis (H_0). The eight null hypotheses tested with the X^2 test were:

$H_0$1: There is no relationship between treatment for an intestinal problem and respiratory disease treatment in bull calves.

$H_0$2: There is no relationship between treatment for an intestinal problem and respiratory disease treatment in heifer calves.

$H_0$3: There is no relationship between treatment for an intestinal problem and death in bull calves.

$H_0$4: There is no relationship between treatment for an intestinal problem and death in heifer calves.

$H_0$5: There is no relationship between respiratory disease treatment and death in bull calves.

$H_0$6: There is no relationship between respiratory disease treatment and death in heifer calves.

$H_0$7: There is no relationship between treatment and death in bull calves.

$H_0$8: There is no relationship between treatment and death in heifer calves.

It was the aim to find out if a there was an association between *initially* being treated for an intestinal problem *followed* by respiratory disease. Further it was the aim to find out if there was an association between *initial* treatment for either an intestinal problem or respiratory disease and death and between different *initial* treatment combinations and death.

In order to answer the hypotheses, some calves and treatments were excluded in the respective X^2 tests: In the two-way tables in Table 1x and 2x (Appendix 2) the relationship between an initial intestinal problem and following respiratory disease was analyzed. All calves were included in the analysis, however if a calf had a respiratory disease treatment before a treatment for an intestinal problem, then only the respiratory disease treatment record was included. Only the respiratory disease treatment was included when this order of treatments occurred because it was the aim to look at the association between *initial* intestinal treatment *followed* by respiratory disease. Thus, if a calf was treated for an intestinal problem followed by respiratory disease both registrations were counted. If a calf had both a treatment for an intestinal problem and respiratory disease on the same day, then both registrations were included. In Table 3x and 4x (Appendix 2), where the relationship between treatment for an intestinal problem and death was investigated, calves that had treatment recordings for both an intestinal problem and respiratory disease, and calves only treated for respiratory disease were excluded from the two-way table. If calves with both treatments were included, the 'clean' effect of a treatment for only an intestinal problem would not be seen. Further, if the calves with only respiratory disease would be included in the count of calves with no treatments for an intestinal problem, then the 'untreated' group may be biased by a possible higher mortality amongst the calves which had been treated for respiratory disease. In Table 5x and 6x (Appendix 2), where the relationship between respiratory disease and death was investigated, the calves that had treatment recordings for both intestinal problems and respiratory disease and calves only treated for intestinal problems were excluded. The reasons for the exclusion of these calves are the same as explained for Table 3x and 4x. In Table 7x and 8x (Appendix 2) no calves were excluded, however the same treatments as described for Table 1x and 2x were excluded.

3.3 Results

3.3.1 Part 1 - Comparison of two herd-groups

Out of 3307 yield controlled herds in Denmark there was 610 herds in the 'Module 2 plus' agreement. Mean key-figure values and results from the two-sided unpaired *t*-test are shown in Table 3.3. The mean key-figures show that the 'Module 2 plus' herds are larger than the 'remaining yield controlled herds' and have more desireable key-figures for most of the key-figures analyzed, except for the amount of mastitis per cow-year and diseases per animal-year.

There is a significant difference ($p < 0.05$) between the *t*-test compared mean key-figures of the two groups, except for the percentage of calves born dead ($p = 0.219$) and the 61 to 180 day calf mortality ($p = 0.379$), as can be seen in Table 3.3. Thus, the null hypothesis (H_0) is rejected and the alternative hypothesis (H_1) is accepted for the key-figures with significant difference ($\mu_{2plus} \neq \mu_{remaining}$), which means that the 'Module 2 plus' herds are not equal to the 'remaining yield controlled herds' in these key-figures.

Table 3.3 Comparison of yield controlled 'Module 2 plus' herds with the remaining yield controlled herds in Denmark. Red values indicate no significant difference.*

	'Module 2 plus' herds Mean (μ_{2plus})	'Remaining yield controlled herds' Mean ($\mu_{remaining}$)	*p*-value
Animal years	216	145	< 0.001
SCC[1] (1000 cells/ml)	256	282	< 0.001
ECM[2]/cow-year (kg)	9801	9009	< 0.001
Mastitis/cow-year (cases)	0.38	0.31	< 0.001
Diseases/animal-year (cases)	1.40	0.91	< 0.001
Calves born dead (%)	6.05	6.26	0.219
CM[3], 1-14 days (%)	2.39	2.77	0.004
CM, 15-60 days (%)	2.29	2.60	0.032
CM, 61-180 days (%)	1.99	2.16	0.379
CM, 1-180 days (%)	6.28	7.18	0.004

[1] Somatic Cell Count, [2] Energy corrected milk, [3] Calf mortality

* Full *t*-test information is found in Appendix 1.

3.3.2 Part 2 – Mortality and treatment incidence

Mortality

During the 1-year birth period, 125,977 calves were born in 605 'Module 2 plus' herds and of these 4.7% of calves died between 1 and 180 days of age (Table 3.4). The highest death frequency was observed between 10 to 14 days of age, as can be seen in Figure 3.3.

The distribution in the percentage of 'Module 2 plus' herds with different mortality risks is shown in Figure 3.2. The figure shows that 4.8% of the 'Module 2 plus' herds had no 1 to 180 day calf mortality in their herd for calves born in 2012. The majority of herds (64.1%) had a mortality risk between 0.1% and 5%, while the second largest group (22.5%) had a mortality risk between 5.1% and 10% (Figure 3.2). Only 8.6% of the 'Module 2 plus' herds had a mortality risk between 10.1% and 35% and no herds with calf mortality risks above 35% were found.

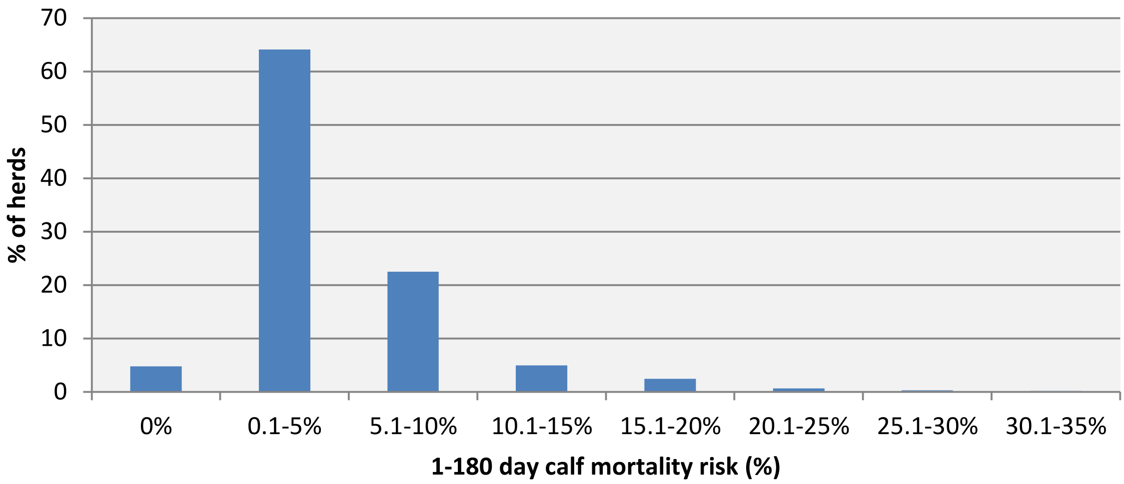

Figure 3.2 Percentage of 'Module 2 plus' herds (n = 605 herds) by 1-180 day calf mortality risk (%).

Treatment incidence

Treatment records were available for 125,977 dairy calves from 605 'Module 2 plus' herds. In total 32,069 treatment records on diarrhea, enteritis, coccidiosis, cryptosporidiosis or respiratory disease were made in the first six months of the included calves' life (Table 3.4).

Respiratory disease had the highest treatment incidence between 0 to 180 days of age (9.5%), followed by diarrhea (9.3%), as shown in Table 3.4. Further, 3.7% of calves were treated for coccidiosis and 3.0% of calves were treated for cryptosporidiosis in the first six months of life (Table 3.4). If the investigated intestinal problems were all added up, 16% of calves received treatment for an intestinal problem within the first six months of life. As illustrated in Figure 3.3, the treatment frequency for respiratory disease peaked between day 5 and 9 of the calf's life, and gradually declined throughout the 180-day period. Overall, respiratory disease was the predominant morbidity treated after approximately 3 weeks of age. The highest treatment frequency for diarrhea in 'Module 2 plus' herds was between day 5 and 9 (Figure 3.3). The predominant age for coccidiosis treatments in the 'Module 2 plus' herds was in the second and third month of the calf's life (between 30 to 94 days) and the frequency of cryptosporidiosis treatments was highest between 0 to 4 days life (Figure 3.3).

Table 3.4. Descriptive statistics of mortality and treatment incidence for 125,977 dairy calves in 'Module 2 plus' herds.

	Number of records	% of all calves
Dead[a]	5,887	4.7
Respiratory disease[b]	11,970	9.5
Diarrhea[b]	11,689	9.3
Coccidiosis[b]	4,607	3.7
Cryptosporidiosis[b]	3,803	3.0
Intestinal problems[b]	20,099	16

[a] calves that die between 1 to 180 days
[b] treatment registrations between day 0 to 180 for calves that survive day 0

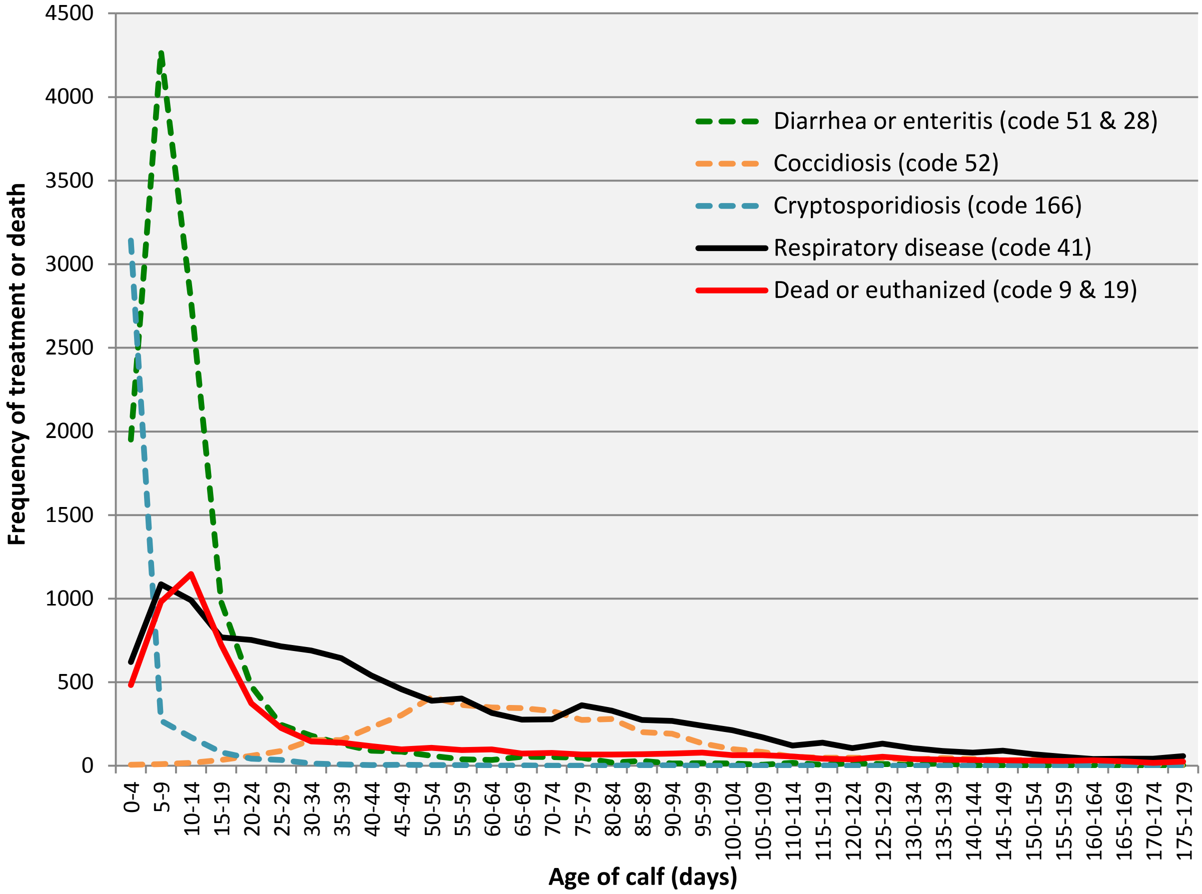

Figure 3.3 Treatment data and mortality data of 'Module 2 plus' herds. Overview of the amount of treatment records registered for calves that are treated for diarrhea or enteritis (code 51 and 28, respectively), coccidiosis (code 52), cryptosporidiosis (code 66) or respiratory disease (code 41) between 0 to 180 days after birth, for calves alive after 24 hours. And number of recorded deaths or euthanizations (code 9 and 19, respectively) between day 1 and 180.

The distribution in the percentage of herds with different treatment risks is shown in Figure 3.4. A large percentage of 'Module 2 plus' herds have no treatment recordings for the four investigated intestinal problems (diarrhea, enteritis, coccidiosis and cryptosporidiosis). When looking at respiratory disease, 43% of herds have treatment incidence risks of between 0.1% and 5%. Based on available data material it is not possible to distinguish whether it was the same herds that had high treatment risks for several diseases.

3.3.3 Part 3 – Associations between diseases and mortality

The two-way tables (Table 1x to 8x) for the eight different Chi-square analyses for the H_01 to H_08 hypotheses are listed in Appendix 2. The discussion will present and discuss some of the relevant descriptive statistics from the two-way tables. The Chi-square statistic and the associated p-value for the different null hypotheses (see Section 3.2.3) analyzed are presented in Table 3.5. As can be seen in Table 3.5, the null hypothesis is rejected in all but the H_01 and H_03 hypothesis. Thus, there is no association between treatment for an intestinal problem and respiratory disease treatment in bull calves (H_01). And there is no association between treatment for an intestinal problem and death in bull calves (H_03). The other significant differences show that there is an association between the investigated row variable and the column variable.

Table 3.5 Overview of the degrees of freedom (DF), Pearson Chi-square statistic (X^2) and the associated *p*-value for the different null hypotheses analyzed. Red values indicate that the H_0 hypothesis was not rejected.

	Bull calves			Heifer calves		
DF	**H_0**	**X^2**	**p-value**	**H_0**	**X^2**	**p-value**
1	H_01	0.0797	0.7777	H_02	2301.5701	$p < 0.0001$
1	H_03	1.2539	0.2628	H_04	1144.0986	$p < 0.0001$
1	H_05	11.1917	0.0008	H_06	1407.8210	$p < 0.0001$
3	H_07	16.8720	0.0008	H_08	2299.7328	$p < 0.0001$

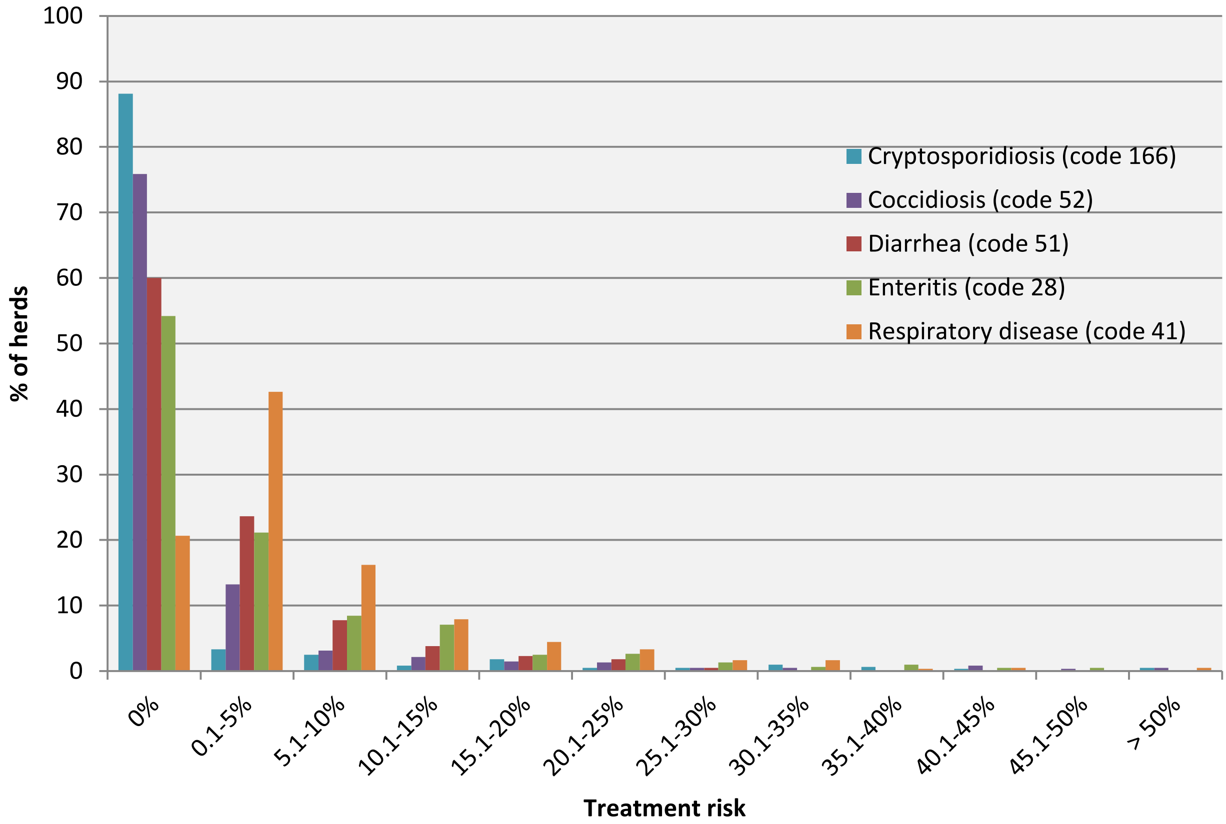

Figure 3.4 Distribution of 'Module 2 plus' herds (n= 605) with different treatment risks for 0 to 180 day old calves.

3.4 Partial discussion

The following section will include a discussion of the results found and comparison to the literature review, whereafter discussions regarding other considerations will be made.

3.4.1 Discussion of results

Part 1 –Comparison of two herd-groups

The *t*-test comparison between the 'Module 2 plus' herds and the 'remaining yield controlled herds' showed that there was a significant difference between the two herd groups in most key-figures, except for the '*percentage of calves born dead*' and the '*61 to 180 day calf mortality*'.

Most of the differences in the analyzed key-figures were favorable for the 'Module 2 plus' herds. However, the key-figures regarding mastitis cases per cow-year and diseases per animal-year were to the disadvantage for the 'Module 2 plus' herds. The lower SCC, higher ECM yield and lower calf mortality found in the key-figures may imply that, on average, the 'Module 2 plus' herds had a better herd management compared with the remaining yield controlled herds. There may be several reasons for the higher amount of diseases and mastitis cases amongst 'Module 2 plus' herds: **(i)** more diseases and mastitis cases in 'Module 2 plus' herds, **(ii)** more disease- and mastitis cases are found and treated, **(iii)** less reluctance to treat diseased animals compared with the remaining yield controlled herds or **(iv)** more treatments are electronically recorded. Reason (i) is found unlikely, as morbidity is positively associated with mortality (e.g. Gulliksen *et al*. (2009a) and Waltner-Toews *et al*. (1986a)), and the 'Module 2 plus' herds have a lower mortality compared with the remaining yield controlled herds. Thus, a disease incidence of either the same level or lower is expected in 'Module 2 plus' herds, which on average have a lower calf mortality. Further, it is known that inflammation of a mammary gland (i.e. mastitis) leads to an elevated SCC (Harmon 1994). As the average SCC in 'Module 2 plus' herds is lower compared with the remaining yield controlled herds, fewer cases of mastitis may occur in 'Module 2 plus' herds. Thus, the lower SCC amongst 'Module 2 plus' herds also does not agree with the higher amount of mastitis cases per cow-year. Reason (ii) might apply due to better herd management in 'Module 2 plus' herds, and reason (iii) may apply because of the fact that other farms, which are not in the 'Module 2 plus' agreement, have to call the veterinarian for at least some of the treatments, which may make a farmer in the group of the 'remaining yield controlled' herds more reluctant to treat an animal. Furthermore, a study conducted by the Knowledge Centre for Agriculture found that organic farms treat less than conventional farms (0.68 treatments per cow-year vs. 0.96 treatments per cow-year) and are more reluctant to treat with medication (Jørgensen *et al*. 2011; Martin *et al*. 2011). As there is no incentive for organic farms to sign up for the 'Module 2 plus' agreement, the remaining yield controlled herds could have fewer treatments per animal-year and fewer mastitis cases per cow-year partly due to the reason that the organic farms are part of the group of the remaining yield controlled herds. Reason (iv) applies to the higher amount of diseases per animal-year in 'Module 2 plus' herds: 'Module 2 plus' herds have to record treatments for all animal-age-classes, whereas the remaining yield controlled herds, apart from 'Module 2' herds, do not have to register any treatments into the Animal Register. 'Module 2' herds only have to report treatments for milk fever and retained placenta. In the remaining herds, the veterinarian or farmer may electronically register some of the treatments done, however, no legislation forces them to do so. Thereby the amount of treatments per animal-year could be higher in 'Module 2 plus' herds because they record all of their treatments.

Based on the findings from the *t*-test and the discussion it was assessed that the 'Module 2 plus' herds were not comparable with the remaining yield controlled herds. Further, it was assessed that the key-figures on 'mastitis cases' and 'treatments' are misleading and that 'Module 2 plus' herds do *not* have a higher level of morbidity compared with the remaining yield controlled herds. It was discussed that the 'Module 2 plus' herds on average may have a lower incidence of morbidity compared with the remaining yield controlled herds.

The results from Part 1 imply that the results found in Part 2 and Part 3 cannot be generalized for the remaining yield controlled herds in Denmark, but only apply to 'Module 2 plus' herds and herds which have similar key-figures as the 'Module 2 plus' herds. The results of the 'Module 2 plus' herds would however reflect the incidences for in the remaining Danish herds. Morbidity and mortality in the remaining yield controlled herds is expected to be higher than in the 'Module 2 plus' herds.

Part 2 – Mortality and treatment incidence

Mortality

The found 1-180 day mortality risk of 4.7% was within the range of calf mortalities found in the literature review (Table 2.2). The found mortality risk was lower than the Danish mortality risk found by Enemark *et al*. (2014) and Nielsen *et al*. (2002) and lower than the American results (Virtala *et al*. 1996a; Wells *et al*. 1996; Donovan *et al*. 1998b). However, the result from the Danish Cattle database was higher than results from Sweden, Norway and France (Svensson *et al*. 2006b; Gulliksen *et al*. 2009a; Raboisson *et al*. 2013). Possible reasons for the differences in mortality between studies may involve differences in for example herd size, disease pressure, data material included and method of data collection, housing or management, as discussed in the literature review (Chapter 2). The risk of mortality was highest in the second week of life, which is in accordance with the results found in the literature review (Sivula *et al*. 1996; Wells *et al*. 1996; Svensson *et al*. 2006b).

The average 1 to 180 day mortality of 4.7% implies that the aim of a 5.5% calf mortality between 1 to 180 days, as set by the Danish Agriculture and Food Council's cattle department (Landbrug & Fødevarer 2014), has been reached amongst the 'Module 2 plus' herds. The majority of 'Module 2 plus' farms (69%) had a mortality risk between 0% and 5%, however, calf mortality varies between farms, as was found in results from the Cattle database and in other studies (Svensson *et al*. 2006b; Raboisson *et al*. 2013; Windeyer *et al*. 2014). Thus, it is possible to achieve a mortality risk of 0%, however some farms still have a 1 to 180 day mortality risk above the goal of 5.5%.

Incidence of diarrhea and respiratory disease

The found treatment incidences of intestinal problems (16%), diarrhea (9.3%) and respiratory disease (9.5%) in 'Module 2 plus' herds are within the observed morbidity incidences from the studies in the literature review (see Table 2.4). If considering all treated intestinal problems which cause clinical signs of diarrhea, four studies found lower diarrhea incidence (Sivula *et al*. 1996; Svensson *et al*. 2003; Svensson *et al*. 2006a; Gulliksen *et al*. 2009b) and two American studies found higher diarrhea incidence (Virtala *et al*. 1996a; Wells *et al*. 1996). Further, all studies in the literature review, except from the study by Virtala *et al*. (1996b) found lower respiratory disease incidences than was found in the Danish Cattle database. However, most of the studies in the literature review investigated shorter age ranges for the included calves, which may reduce the found disease incidence in these studies. Other possible reasons for the differences morbidity between studies may involve risk factors such as differences in herd size, housing, air quality, colostrum management, management and genetics, disease pressure as discussed in the literature review. Further, as also discussed in the literature review, data material included and method of data collection could impact the results.

'True' disease incidence

The amount of treatments recorded in the Danish Cattle database most likely underestimate the 'true' disease incidence amongst dairy calves in 'Module 2 plus' herds as only treatments with prescribed drugs have to be registered into the Danish Cattle database. The incidence of diarrhea and intestinal problems is likely higher because a proportion of calves will only be 'treated' with electrolytes, which is not a treatment that requires registration in the Danish Cattle database. Further, the incidence of respiratory disease might be underestimated. This assessment is based on findings in Svensson *et al*. (2003), Svensson *et al*. (2006a) and Virtala *et al*. (1996b) that farmers detected less incidences of respiratory disease compared with veterinarians. Svensson *et al*. (2006a) reasoned that the lower detection of respiratory disease may be due to calves being housed in group pens when they have the highest risk of respiratory disease, which makes it harder to detect diseased calves.

The found disease incidences may not be the 'true percentage' of all calves included in the study, as one calf could receive several of the same treatments within the first 180 days of life, provided that enough days elapsed between treatments. However, by excluding the same treatments that were done within 8 days, it was attempted to find the disease incidence of different diseases amongst the calves. Thereby the reported disease incidence should reflect the amount of diseases occurring amongst all dairy calves. Data was not available to distinguish between individual calf treatments.

Although the found disease incidence might be underestimated, the treatment-data from the Danish Cattle database to my knowledge currently give the best estimate of the disease incidence in Denmark. Due to the underestimation of disease incidence, the found associations between intestinal problems, respiratory disease and death may also differ from what is found in reality.

The majority (83%) of all cryptosporidiosis treatments were given between 0 to 4 days of the calf's life. The high amount of treatment records for cryptosporidiosis is likely due to preventive treatment with the drug 'Halocur' against *Cryptosporidium pavum*. Preventive treatment against cryptosporidiosis is often done as part of a herd-strategy in order to prevent calves from developing the disease (Martin (2014) pers. comm.). If the treatment records for cryptosporidiosis are only for preventive treatments, then these treatment registrations will not reflect an actual disease incidence, and the incidence for cryptosporidiosis (3%) could be subtracted from the incidence reported for intestinal problems, in which case the incidence of intestinal problems would be 13%.

The incidence of diarrhea was highest in the first three weeks of the calf's life, with the highest incidence between day 5 and 9. This finding was to some extent in accordance with Virtala *et al*. (1996a) and Wells *et al*. (1996), who found that the peak occurrence of diarrhea was during the second week of life. The results of the period with the highest incidence of respiratory disease are not in accordance with each other; In 'Module 2 plus' herds the incidence for respiratory disease peaked between day 5 and 9, and gradually declined throughout the 180-day period. The literature review found that respiratory disease either had its highest incidence during the second week of the calf's life (Wells *et al*. 1996) or during the fifth week of life (Virtala *et al*. 1996b).

From the data material in the Danish Cattle database it was found that a large percentage of 'Module 2 plus' herds have no disease incidence for the four investigated intestinal problems (diarrhea, enteritis, coccidiosis and cryptosporidiosis) and that 43% of the 'Module 2 plus' herds have an incidence of between 0.1% and 5%. As previously described, it was assumed that the amount of treatments reflected the disease incidence in the herd. However, it is not possible to determine whether a herd had no treatments (or low levels of treatment) because the herd was free of disease or because the farmer has not detected and/or treated calves which are sick with prescription drugs. The distribution of herds does however give an indication, that some farms treat fewer of their calves than other farms. Other studies have also found that the disease incidence in dairy calves varies between farms (Svensson *et al*. 2006a; Windeyer *et al*. 2014).

Part 3 – Associations between morbidity and mortality

The following sections will discuss the findings of the Chi-square analysis based on results in the two-way tables in Appendix 2. Each section will first describe some main results from the two-way tables for bull calves and heifer calves, whereafter they are discussed.

Association between initial diarrhea and subsequent respiratory disease treatment ($H_0$1 and $H_0$2)

Bull calves ($H_0$1)

The two-way table for bull calves in Table 1x (Appendix 2) shows that approximately the same percentage of calves which were or were not treated for an intestinal problem initially, were later treated for respiratory disease (~18%) (red highlight). Thus, as the $H_0$1 hypothesis stated and the Chi-square test could not reject ($p = 0.7777$); bull calves that were initially treated for diarrhea were as likely to be treated for respiratory disease as bull calves that were not initially treated for diarrhea.

Heifer calves ($H_0$2)

When looking at the results in Table 2x (Appendix 2), it can be seen that 5.4% of heifers that were not previously treated for an intestinal problem got a respiratory disease treatment (red highlight) whereas 23.9% of heifer calves which were previously treated for an intestinal problem also received a respiratory disease treatment (red highlight). Opposite from the group of bull calves, the $H_0$2 hypothesis was rejected for the group of heifer calves ($p < 0.0001$). Heifer calves which were initially treated for an intestinal problem were more likely to be treated for respiratory disease compared with heifers that were not initially treated for an intestinal problem. This finding was in accordance with results found by Svensson *et al*. (2006a), who found that diarrhea during the first 90 days of life was significantly ($p < 0.001$) associated with clinical respiratory tract disease between 91 and 210 days of life. The calves which were diagnosed with diarrhea during the first 90 day of life had a 478-fold higher odds of clinical respiratory tract disease than calves which had no previous diarrhea (Svensson *et al*. 2006a). The Chi-square analysis by Hultgren *et al*. (2008) also found a significant association between respiratory disease and diarrhea between birth to 1 month, and 1 to 6 months of age in heifer calves (OR = 2.1–2.3; $p \leq 0.024$). Svensson *et al*. (2006a) and Waltner-Toews *et al*. (1986c) both reasoned that the association between diarrhea and respiratory disease may be linked to common predisposing management factors, such as inadequate colostrum management, or that heifers with diarrhea could be more susceptible to respiratory disease. Another reason for the association could be that once a calf has been treated for diarrhea, the animal may be watched more closely and thereby have higher chance of being diagnosed with respiratory disease compared with other heifers.

It is not known why there is a difference in association between intestinal problems and respiratory disease between heifer calves and bull calves. A higher percentage of bull calves are treated against an intestinal problem and/or respiratory disease than heifer calves (34.4% vs. 13.7%) (green highlights, Table 1x and Table 2x, Appendix 2). A reason for the higher treatment percentage could be that bull calves were housed in an inferior environment compared with the environment of the heifer calves. Barns with inadequate ventilation and low hygiene are risk factors associated with respiratory disease and diarrhea (Radostits & Blood 1985). Thus, if bull and heifer calves were housed in differing environments it could be the reason for more numerous treatments amongst bull calves. Comparison of Table 1x and 2x further indicates that there might be more awareness around treatment of heifer calves compared with bull calves which already have been treated for an intestinal problem, as 23.9% of heifer calves that had been treated for diarrhea initially later were treated for respiratory disease, whereas only 18.2% of bull calves that had initially been treated for an intestinal problem were treated for respiratory disease.

Association between treatment for an intestinal problem and death ($H_0$3 and $H_0$4)

Bull calves ($H_0$3)

The two-way table (Table 3x) in Appendix 2 shows that approximately 40% of bull calves died (red highlight), regardless of if they were previously treated for an intestinal problem or not. When looking at the total percentage of bull calves, 31.9% of untreated bull calves died (green highlight).

As shown in Table 4.5, the H_03 hypothesis could not be rejected ($p = 0.2628$), thus bull calves that were treated for an intestinal problem were as likely to die as bull calves that were not treated for an intestinal problem.

Heifer calves (H_04)

The two-way table (Table 4x, Appendix 2) testing for association between treatment for an intestinal problem and death (H_04) in heifer calves shows that 4.8% of the heifer calves without treatment for an intestinal problem died (red highlight) and that 18.2% of the heifer calves that were treated for an intestinal problem died (red highlight). The Chi-square test rejected the H_04 hypothesis for the heifer calves. Heifer calves which were initially treated for an intestinal problem were more likely to die compared with untreated heifer calves. Supporting the association found in the group of heifer calves, the study by Gulliksen *et al*. (2009a) found that diarrhea significantly ($p < 0.001$) increased the risk of death between 1 and 180 days of life. Depending on the age group of calves, calves which had diarrhea had a 5 to 5.7 times higher odds of dying compared with calves which had not been diseased (Gulliksen *et al*. 2009a).

In contrast to the group of bull calves investigated in Table 3x (Appendix 2), only 4.4% of all heifer calves which were not treated for an intestinal problem ended up dying (green highlight). An explanation for the fact that more than seven times as many bull calves (31.9% vs. 4.4%) die after not being treated for diarrhea may be that farmers are more reluctant to treat bull calves. The guess that farmers are more reluctant to treat bull calves may also show in the fact that only 1.3% of treated heifer calves died whereas 8.2% of bull calves ended up dying despite receiving a diarrhea treatment (orange highlight in Table 3x and 4x). However, as can be seen in Table 3x, 19.6% of the bull calves were treated for an intestinal problem, whereas only 7.1% of heifer calves were treated (Table 4x) (blue highlight). So out of the included calves, bull calves received more treatments but more of them ended up dying. This may be because many of the bull calves which were not moved from the CHR-number could not be sold for fattening because they were sick or had been sick and therefore were more fragile or too small for selling. Another reason for the difference in mortality and morbidity between the heifer calves and bull calves might be the fact that bull calves, which die from a disease (treated or untreated) or other reason obviously will not be sold or moved to a difference CHR-number. Because a large proportion of bull calves are moved, the proportion of bull calves which stayed in the initial CHR-number due to the fact that they died or were sick may be larger compared with the proportion of heifers which died or were sick. Thus, more bull calves which are sick and/or die may be represented in the group of bull calves that are not moved from the initial CHR-number.

Association between respiratory disease treatment and death (H_05 and H_06)

Bull calves (H_05)

The descriptive statistics of the relationship between respiratory disease treatment and death in bull calves is shown in Table 5x (Appendix 2). Of the bull calves receiving no respiratory disease treatment, 39.6% died, and 33.5% of the bull calves that received respiratory disease treatment died (red highlight). The H_05 hypothesis was rejected ($p = 0.0008$), implying that there is a relationship between respiratory disease treatment and death in bull calves. In this case, the bull calves which were not treated for respiratory disease were more likely to die compared with the bull calves which were treated for respiratory disease.

Heifer calves ($H_0$6)

The two-way table testing for association between respiratory disease treatment and death in heifer calves is shown in Table 6x (Appendix 2). Of the heifer calves that were not treated for respiratory disease 4.8% died and 21.8% of the heifer calves that were treated for respiratory disease died (red highlight). Although the $H_0$6 hypothesis was rejected for the heifer calves ($p < 0.0001$), the results differed from the ones found for the bull calves (Table 5x), as more of the treated calves end up dying compared with the untreated calves. Further, a smaller percentage (4.8%) of heifer calves end up dying after receiving no treatment for respiratory disease compared with the percentage of bull calves dying after no treatment (39.6%). Similar to the previous section, a greater number of bull calves were treated for respiratory disease (18.5%) compared with heifer calves (5.4%) (blue highlight, Table 5x and 6x). The possible reason for the different findings may be the same as explained above: maybe the proportion of dead and/or diseased the bull calves kept in Part 3 of the study is overrepresented because these bull calves were not moved because they died before being moved or because they had been sick and therefore not moved.

The results found for the heifer calves is supported by Gulliksen *et al*. (2009a), who found that respiratory disease significantly ($p < 0.001$) increased the risk of mortality up to 180 days of life. Depending on the age group of calves, calves which had respiratory disease had a 5 to 6.2 times higher odds of dying compared with calves with had not been diseased.

Association between treatment and death ($H_0$7 and $H_0$8)

The last two hypotheses ($H_0$7 and $H_0$8), tested the association between several treatment combinations, but always treatment for an intestinal problem before respiratory disease treatment and death for bull calves and heifer calves, respectively.

Bull calves ($H_0$7)

The two-way table of the bull calf analysis of the hypothesis $H_0$7 is shown in Table 7x (Appendix 2). During the first half year of life, 38.80% of the bull calves died, and 39.6% of the bull calves were not treated nor died in the first 180 days of life (red highlight). The highest percentage (41.6%) of calves died following treatment for an intestinal problem and the lowest percentage (33.5%) of bull calves died following treatment for both an intestinal problem and respiratory disease or following respiratory disease (green highlight). The null hypothesis ($H_0$7) was rejected ($p = 0.0008$), indicating a relationship between treatment and death in bull calves. In the group of bull calves, the relationship may be that less animals which had been treated for an intestinal problem and respiratory disease or only treated for respiratory disease ended up dying (33.5% died in each group) compared with the bull calves treated for an intestinal problem (41.6%) or not treated for any of the two diseases (39.6%).

Heifer calves ($H_0 8$)

The two-way table for the heifer calf analysis of the hypothesis $H_0 8$ is shown in Table 8x (Appendix 2). During the first 180 days of life 6.8% of the heifer calves died (Table 8x) and 82.2% of heifer calves received no treatments for an intestinal problem or respiratory disease nor died during the first 180 days of life (red highlight). The mortality rate of 4.8% in the non-treated heifer calf group was the lowest compared with the other treatment groups (green highlight). In the group of heifer calves that were only treated for respiratory disease the largest percentage (21.8%) of calves died (green highlight). The mortality rate was found to be 18.5% amongst heifer calves treated for both an intestinal problem and respiratory disease (green highlight). The null hypothesis ($H_0 8$) was rejected ($p < 0.0001$), thus there is a relationship between treatment and death in heifer calves. For the heifer calves, fewer animals that had not been treated ended up dying (4.8%) compared with the groups of animals that had been treated for either an intestinal problem, respiratory disease, or both (18.2% to 21.8%).

As stated above, the Chi-square analyses for bull calves and heifer calves both rejected the null hypotheses ($H_0 7$ and $H_0 8$). However, based on the results in the two-way tables the relationship between treatment and death in heifer calves does not look similar to the relationship between treatment and death found amongst bull calves: only 4.8% of the heifer calves which received no treatments died whereas 39.6% of bull calves died after receiving no treatment. Further, the highest percentage (21.8%) of heifer calves died after being treated for respiratory diseases, whereas this treatment combination gave one of the lowest mortality percentages (33.5%) amongst bull calves.

Surprisingly, none of the two calf groups found that treatment for both diarrhea and respiratory disease gave the highest percentage of dead calves. This finding may be due to the fact that calves which were treated for both diseases had more attention by the farmer. However, amongst the heifer calves the percentages of dead calves per treatment combination were similar.

When comparing the percentage of dead heifer or bull calves with found case-fatalities (Table 2.3), the percentage of dead bull calves and heifer calves following a treatment is higher in the Danish Cattle database data. Only the case-fatality of diarrhea (17.9%) found by Sivula *et al*. (1996) was similar to the percentage of heifer calves dying after receiving a treatment for an intestinal problem (18.2%). However, the calves from the Danish Cattle database may not necessarily have died due to the intestinal problem or respiratory disease that they had been treated for. Further, in the group of bull calves and heifer calves, 67% and 60.6% of the calves that died were in the group of untreated calves, respectively. These untreated calves might have died due to untreated cases of respiratory disease or intestinal problem. Other causes of death for both treated and untreated calves might also have been trauma, septicemia or navel inflammation. Other factors, such as age at treatment for disease, number of treatments, type of intestinal problem, herd, season of birth, breed of the calf and management may also affect the mortality of the calves. These factors could however not be included or analyzed in the Chi-square analysis and requires a more complex statistical model.

Summary

Based on the above discussion, care should be taken when concluding on the results found in the Chi-square analysis. This mostly applies to the analyses investigating the association of disease with death ($H_0$3-$H_0$8). This is because calves might have died due to other factors. Further, results of the group of bull calves might be biased due to sale of healthy calves for fattening. This would leave the investigated group of bull calves overrepresented with treated and dead calves. This overrepresentation may be seen through the higher treatment percentage and higher mortality amongst the bull calves compared with the heifer calves. Moreover, the descriptive results found in the two-way tables of the heifer calves were supported by other studies, whereas the two-way table results for the bull calves could not be supported. Hence, the results found in the group of heifer calves may be more reliable.

3.4.2 Other considerations

Data material validation

Although farmers in 'Module 2 plus' herds are obliged to report all treatments by law, it cannot be guaranteed that all treatments have been entered. Further, there is a risk that the treatment registrations made are incorrect. For instance, if a farmer has a herd diagnosis for 'diarrhea' and not for 'cryptosporidiosis', the farmer may register a diarrhea treatment, but the actual disease treated is cryptosporidiosis.

It is difficult to validate how good the used data material is and it has been attempted in varying ways in other studies; a Norwegian study by Gulliksen *et al*. (2009b) tried to validate their data through a) sampling of diseased calves, b) dehorning-registrations as an indicator for a well-functioning recording system, or c) farmer feedback on degree of commitment to calf health recording. The study by Gulliksen *et al*. (2009b) found an underestimation of calf disease records of approximately 40%. In this study, validation of data material has not been done. *Firstly* because it would be too time consuming to verify data material through herd visits or feedback from farmers and *secondly* it was assumed that validation through other herd registrations may not indicate how good the calf treatment data is.

Considerations regarding excluding Jersey calves

Many Jersey bull calves are euthanized after birth as it is not possible to sell them as fattening calves due to their small size. Some of these euthanizations may be recorded later than within the first days after birth and count as being part of the 1-180 day calf mortality. Therefore it was investigated if any of the included breeds have a higher amount of euthanizations compared with the other breeds. When comparing the calves that were included in Part 1 of the analysis, then the percentage of calves euthanized was 0.46%, 0.44%, 0.85%, 0.59%, 0.36% and 0.57% for Red Danish Dairy breed, Danish Holstein, Danish Jersey, Danish Red Holstein, other milk breeds and crossbreds, respectively. The greatest amount of euthanizations was done amongst Jersey calves (0.85%). It was analyzed that overall, 0.43% of the bull calves and 0.55% of the heifer calves were euthanized. Furthermore, 39.3% of all euthanizations are of bull calves and 60.7% of euthanizations were of heifer calves. Based in this information it was assessed that the data material does not include data on bull calves that are systematically euthanized due to their sex or breed and it was decided to include all dairy breeds.

3.5 Partial conclusion

3.5.1 Part 1 - Comparison of two herd-groups

The 'Module 2 plus' herds were significantly different from the remaining yield controlled herds. It is assessed that the incidence of morbidity and mortality in 'Module 2 plus' herds lower compared with the incidence found in the remaining yield controlled herds in Denmark. Hence, the conclusions for the estimated incidence of diarrhea, respiratory disease and mortality are only indirectly applicable to the remaining yield controlled herds.

3.5.2 Part 2 - Mortality and treatment incidence

The 1 to 180 day calf mortality in 'Module 2 plus' herds was estimated to be at 4.7%, which is below the aim of the Danish Agriculture and Food Council, and below the 7.8% mortality which is the average 1 to 180 day mortality of all dairy herds in Denmark. The mortality in the included 'Module 2 plus' herds was distributed between 0% and 35%, with 69% of herds below a 5% mortality. The treatment incidence amongst 'Module 2 plus' herds for intestinal problems (diarrhea, enteritis, coccidiosis, cryptosporidiosis), diarrhea, and respiratory disease was estimated to be 16%, 9.3% and 9.5%, respectively. The distribution of treatments given vary between diseases and herds (0% to >50% of calves are treated). The majority of herds treated 0% of their calves for an intestinal problem and the majority treated between 0.1% and 5% of their calves for respiratory disease.

3.5.3 Part 3 - Associations between morbidity and mortality

Associations between diarrhea, respiratory disease and death varied depending on sex of the calf. The results from the heifer calf group indicated that heifers are at a significantly higher risk of dying following treatment and at a significantly higher risk of contracting respiratory disease following an intestinal problem. The risk of dying was highest (21.8%) among heifers treated for respiratory diseases and the second highest risk of dying (18.5%) was among heifers treated for both diseases. In total 4.1% of all heifer calves died following no treatment, 1.1% died following treatment for respiratory disease, 1.2% died following treatment for an intestinal problem and 0.4% of all heifers died following treatment for both diseases. Association results from the heifer calves were in agreement with the found literature. The association-results for the bull calves were either opposite from the heifer calves or non-significant. Compared to the heifer calves, a large percentage of bull calves were treated for respiratory disease or an intestinal problem (13.7% vs. 34.4%). Bull calves treated for an intestinal problem had a risk of dying of 41.6% followed by a 39.6% risk of dying after no treatment. Out of all bull calves 26% died following no treatment, 5% died following treatment for respiratory disease, 6.6% of all bull calves died following treatment for an intestinal problem and 1.2% died following treatment for both diseases. For the association analysis it is noted that calves might have died due to other reasons than what they were treated for and non-treated calves might also have died from respiratory disease or diarrhea. It is assumed that the group of bull calves has an overrepresentation of dead and diseased calves in its group, due to sale of healthy calves for fattening.

Chapter 4 Economic effects of calfhood diarrhea

"Economic arguments are important to persuade dairy farmers to allocate more of their resources to calf and young stock management" (Svensson & Hultgren 2008). Thus, it is the aim of this chapter to simulate found production effects of diarrhea in order to estimate the economic effect of diarrhea attained in the first 6 months of the heifer calf's life. The economic effect on the gross margin per cow-year will be simulated for an average Danish dairy herd and a Danish dairy herd with poor reproduction. These two herds will be used to illustrate both the most representative loss (average herd) and the loss in herds with poor reproduction, where more severe economic losses due to calf diarrhea are expected because of scarcity of replacement animals. Further, the effect of increasing and decreasing the incidence of diarrhea will be simulated. The economic results can be used to inform dairy farmers of eventual economic benefits of decreasing the incidence of calfhood diarrhea.

The results of this section are based on simulation of parameter values of production effects of diarrhea found in the literature review (Chapter 2) and from data material from the Danish Cattle database (Chapter 3). The computer program SimHerd will be used to estimate the economic consequence associated with diarrhea in heifer calves. This section firstly gives an introduction to the computer model SimHerd. Secondly, parameter value estimation and simulation set up are described. Finally, results of the simulation are presented and discussed and a partial conclusion for this section will be made.

Production effects of respiratory disease were not simulated due to missing information on how the production effects of diarrhea and respiratory disease interact with each other when a calf has had both diseases.

4.1 Background

The background section will give an introduction to the computer model SimHerd.

4.1.1 Development of SimHerd

SimHerd is a computer model of a dairy herd. The first version of SimHerd (SimHerd I) was published in 1992 by Sørensen *et al*. (1992). SimHerd has continually been refined and developed through research in the field of herd management and animal health economics in dairy herds (Ettema & Østergaard 2010). The current SimHerd model (SimHerd V) was developed to simulate genetic progress (Ettema *et al*. 2011) and is also able to simulate relationships among feeding, health, and production (SimHerd II) (Østergaard *et al*. 2000), milk fever (SimHerd III) (Østergaard *et al*. 2003), and somatic cell count and mastitis (SimHerd IV) (Østergaard *et al*. 2005) in a dairy herd. SimHerd I to V are extended and modified versions developed from the previous version (Figure 4.1). Several other SimHerd versions have been developed from the SimHerd 'main stem' (SimHerd I to V). The PTB-SimHerd version (Kudahl *et al*. 2007) and Dublin-SimHerd (Nielsen *et al*. 2013) were for instance developed from SimHerd III (Figure 4.1) and are able to simulate paratuberculosis and *Salmonella* Dublin in a dairy herd. Specific calf diseases and their production effects have not yet been modeled into SimHerd at animal-level. It is however possible to simulate production effects at calf-population–level which will be explained in detail later.

The SimHerd model has recently been developed into a user friendly web application (Østergaard *et al*. 2010). It has been applied commercially as a herd health advisory tool for decision support in dairy herds in Denmark since 2010. The current SimHerd version used in the web application is SimHerd V (Ettema (2014b) pers. comm.). The web-based version of SimHerd will be applied in this project.

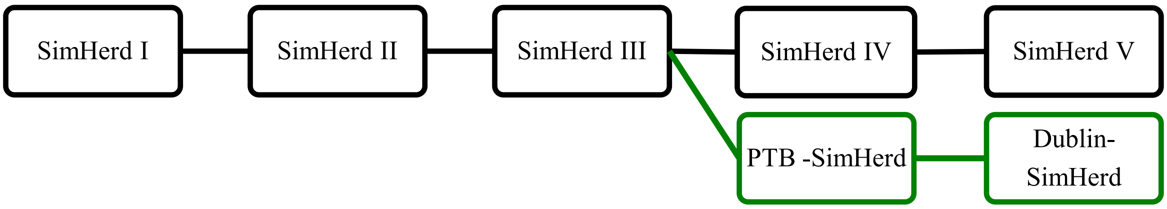

Figure 4.1 Overview of the development of the SimHerd model. The blue boxes are the 'main stem' of SimHerd, and the green boxes are an example one of several side branches developed from the 'main stem'.

4.1.2 The SimHerd model

SimHerd is a computer model which simulates the production- and state-changes of dairy cows and young stock in a dairy herd (Østergaard *et al*. 2003). The state of an animal is defined by parity, age, body weight, reproductive status, lactation stage, milk yield potential, actual milk yield, somatic cell count, disease status and culling status (Østergaard *et al*. 2003). SimHerd is a dynamic, stochastic and mechanistic dairy herd model; it is *dynamic* as the current state of each cow and heifer in the herd is extrapolated in weekly steps (Østergaard *et al*. 2003). Thus, for each week, the state of the individual animal is updated and the production (milk, meat, young stock) and consumption (e.g. feed, inseminations, treatments) of the herd is calculated. The SimHerd model is *stochastic*, as random numbers from relevant probability distributions are drawn to trigger variation among animals and discrete events such as heat detection, conception, abortion, sex and viability of the calf, diseases, variation in milk-yield potential, involuntary culling and death (Østergaard *et al*. 2003). Finally, the model is *mechanistic* as it simulates management decisions of the farmer; SimHerd simulates buying and selling heifers and culling of cows based on the current herd demography and the milk yield and reproductive performance of each cow (Østergaard *et al*. 2003). The lowest yielding, non-pregnant cow would be the first one to be culled in the simulation.

The web-based version of SimHerd simulates real herds with herd specific data, but if these are not available simulations can be based on one of seven different standard dairy herds. The computer model simulates both the current management and herd demography of the farm (the calibrated, current herd (*nudrift*)) and a different management strategy (scenario herd), which can be set up by changing user-modifiable model input parameters (e.g. somatic cell count, calf mortality rate). In this way the production related and economic effects of adjusting or improving management can be analyzed. Furthermore, prices on e.g. feed, livestock and milk can be adjusted in the model. SimHerd simulates the development over 10 years in the current herd and in the scenario herd and generates a report, which includes technical and economic results. Both technical results and economic results are shown over a 10-year period for the current herd, the scenario herd and the difference between the two herds. An example of a SimHerd report is shown in Appendix 3.

4.2 Materials and methods

The materials and methods section will specify the input parameter values used for the simulation and describe the different scenarios and the simulation set up of SimHerd.

4.2.1 Input parameters applied in SimHerd

SimHerd only simulates heifer-calves, heifers and cows, and the model assumes that each bull calf is sold when it is 2 weeks old. Thus, where possible, the following input parameters were estimated based on findings in the literature review and/or data material from the Danish Cattle database for heifer calves.

In the literature review found effects of diarrhea on production were based on registrations of calves which were treated for diarrhea, or on calves which had clinical signs without necessarily needing treatment. Because of this, the incidence of diarrhea (Section 4.2.1.1) was estimated based on the amount of calves found with clinical signs in the literature review.

The aim was to estimate the diarrhea incidence (Section 4.2.1.1) and mortality risk (Section 4.2.1.2) based on the most current Danish or Scandinavian values found in the data material from the Danish Cattle Database section and literature review.

Out of the found effects of diarrhea on production, and mortality and morbidity information from the literature review and data material from the Danish Cattle database it would be possible to modify the following parameters in SimHerd:

- 'incidence of diarrhea' (indirectly through each estimated production effect)
- 'total mortality risk' (parameter #2)
- 'mortality risk due to diarrhea' (parameter #2)
- 'distribution of diarrhea-related mortality' (parameter #222-225)
- 'growth rate' (indirectly through changed feed intake) (parameter #236-245)
- 'age at first calving' (indirectly through 'start of insemination of heifers') (parameter #3)
- 'increase in first lactation milk yield after 2 years' (parameter #246)

Other potential production effects of diarrhea, like survival after calving and risk of dystocia, could have been modified through parameters in SimHerd, but did not show a significant effect in the literature review and were therefore not included in the model. The following paragraphs will derive parameter values, which will be used in the simulation.

4.2.1.1 Incidence of diarrhea

The literature review found that 9.8% and 2.7% of Swedish calves were treated or had clinical signs of diarrhea between 0-90 days and 91-210 days of age, respectively (Svensson *et al*. 2003;

Svensson *et al*. 2006a). Further, Gulliksen *et al*. (2009b) found that only 3.9% of calves had diarrhea in the first six months of life, based on data from the Norwegian Dairy Herd Recording System. It was not clear whether this percentage of calves were only treated calves or calves which had clinical signs. In the USA, the incidence risks of diarrhea were at between 15.2% and 28.8% (Sivula *et al*. 1996; Virtala *et al*. 1996a; Wells *et al*. 1996), where 15.2% of calves were treated and the 28.8% included calves which had clinical signs. 15.2% of calves were treated within 4 months of life and 29.8% of calves had clinical signs or were treated within 3 months of life. As calves are at the highest risk of attaining diarrhea in the first months of life, these numbers were assessed to be applicable for estimating the morbidity due to diarrhea within the first 6 months of life.

Data material from the Danish Cattle database, found that 9.3% of all calves between 0-180 days of life in 'Module 2 plus' herds were treated for diarrhea, 3.7% for coccidiosis and 3.0% for cryptosporidiosis (Table 3.4). It is assumed that the majority of cryptosporidiosis treatments were preventive treatments, thus these calves were not diseased before treatment. When looking at heifers in 'Module 2 plus' herds in the Danish Cattle database chapter, 8.7% of heifer calves were treated for either diarrhea, coccidiosis or cryptosporidiosis at least once during the first six months of their life (Table 2x , Appendix 2). The numbers in Table 3.4 included both bull- and heifer calves, and included all treatments given. The cited number from Table 2x included only heifer calves, however, only one treatment of either diarrhea, coccidiosis or cryptosporidiosis counted in the analysis.

Applying the above information, it is assumed that around 9% of heifer calves were treated for intestinal problems (diarrhea, coccidiosis or cryptosporidiosis) and using the information that twice as many calves have clinical signs for diarrhea in the USA, the incidence of diarrhea amongst heifer calves in Danish dairy herds was set to **18%.** The incidence of diarrhea cannot be used directly as a parameter in the SimHerd model. Thus it will be implemented in each parameter that shows the production effect of diarrhea.

4.2.1.2 Total mortality risk

In the literature review, the total mortality risk for heifer calves in Denmark was found to be 6.5% between 1-180 days in 2012 (Enemark *et al*. 2014) (Figure 2.1). The extracted data material from the Danish Cattle database found a mean 1-180 day mortality risk in 2012 of 7.2% for the 'remaining yield controlled herds' and 6.3% for 'Module 2 plus' herds (Table 2.3) including heifer- and bull calves. Amongst heifers in 'Module 2 plus' herds the 1-180 day mortality risk was 6.8% (Table 8x, Appendix 2).

Based on the above information, the total heifer mortality risk between 1-180 days was set to be **6.7%.** In SimHerd, the mortality risk for heifers is specified by several parameters: the total mortality for the whole period from day 1 until first calving is specified together with distribution of mortality through the four age groups: 0-14 days, 14-60 days, 60-180 days and 180 days till first calving. No Danish mortality risk from 181 days to first calving was found in the literature review, and data with this information was not extracted from the Danish Cattle database. However in Norway 0.4 to 0.6 percentage points of all calves died between day 181 and 365 (Gulliksen *et al*. 2009a) and in Sweden 1.1 percentage points died from day 210 to first calving or 27 months of age

(Svensson *et al*. 2006b). By assuming that the mortality in this age group is also valid/applicable in Denmark, a total mortality from birth to first calving of **7.2%** was estimated. The total mortality risk can be changed in parameter #2 in SimHerd.

4.2.1.3 Mortality due to diarrhea

The percentage of calves dying due to diarrhea was estimated through found case-fatality. No Scandinavian estimate of case-fatality was found in the literature review, so estimates from the USA were utilized. Donovan *et al*. (1998b) and Virtala *et al*. (1996a) found that around 8% of calves who contracted diarrhea ended up dying, whereas 17.9% of the calves who contracted diarrhea in Sivula *et al*. (1996) ended up dying. The finding by Sivula *et al*. (1996) is in agreement with the Chi-square analysis of data material from the Danish Cattle database (Table 8x, Appendix 2), where 18.2% of the heifer calves that were treated for an intestinal problem ended up dying in the first six months of life. The heifer calves that were treated for an intestinal problem in the Danish Cattle database might however also have died for other reasons such as trauma, navel inflammation, septicemia or respiratory disease. Taking the average of the 8% and 18% case-fatalities, it was estimated that **13%** of calves that contract diarrhea end up dying from diarrhea. Thus, if 13% of the heifer calves that have diarrhea (18% of all calves) end up dying, then **2.34%** (18% * 0.13) of all calves die from diarrhea within the first 180 days of life. Taking that the total 1-180 day mortality risk is 6.7% (including diarrhea mortality risk), then 2.34 percentage points are due to diarrhea and the remaining 4.36 percentage points die from something else between 1-180 days of life. Another 0.5% of all calves die after 6 months of life. The mortality rate can be changed in parameter #2 in SimHerd.

4.2.1.4 Distribution of diarrhea-related mortality

From the paper of Svensson *et al*. (2006b) it could be derived that of the calves who die due to diarrhea between 1-210 days, 62% die between 1-30 days of age, 30% die between 31-90 days and 8% die between 91-210 days of age. From the extracted data material from the Danish Cattle database it was found that 73% of all treatments for an intestinal problem (diarrhea, enteritis, coccidiosis or cryptosporidiosis) were recorded between 1-30 days, 21% between 31-90 days and 6% between 91-180 days of age (Figure 3.3). The extracted distribution of total mortality from the Danish Cattle database shows that 67% of calves die between 1-30 days of life, 20% die between 31-90 days and 13% die between 91 and 180 days of life (Figure 3.3). Overall, the three distributions follow each other well. Because the mortality distribution in SimHerd goes in 1-14 day, 15-60 day, 61-180 day and >180 day steps, this information was adjusted such that the mortality distribution due to diarrhea is estimated to be **55%** between **1-14 days**, **40%** between **15-60 days**, **5%** from **61-180 days** and **0%** above **180 days**. These parameters could be changed in parameter #222-#225 in SimHerd.

4.2.1.5 Growth rate

Virtala *et al*. (1996c) found no significant effect of diarrhea on calf weight at 3 months of age, when estimating weight gain based on heart-girth measurement. Also using heart-girth measurements, Windeyer *et al*. (2014) found that calves that were treated for diarrhea before 3 months of age had a

1.1 kg lower body weight at 3 months of age compared to non-affected calves. By weighing heifer calves on a scale, Donovan *et al*. (1998a) found a significant lower body weight of 9 kg at 6 months of age for heifers which had been treated for diarrhea. However, after 14 months of age there was no significant difference in body weight (Donovan *et al*. 1998a). Based on these findings a body weight difference of **0.5 kg** after **3 months**, **9 kg** after **6 months** and **no difference** after **14 months** was specified. In SimHerd the growth rate is modeled indirectly by adjusting the growth curve and daily feed-intake for calves and heifers. Jehan Ettema (SimHerd A/S) developed an excel-spreadsheet where these parameters can be estimated. Both the input parameters which adjust the growth curve in SimHerd (parameter #152, 153 and 154) and input parameters regarding feed intake of roughage, concentrate feed and grass (parameter #233, 234 and 236-245) have to be adjusted in SimHerd.

4.2.1.6 Age at first calving

Only three studies investigated the effect of diarrhea on age at first calving. Both Britney *et al*. (1984) and Correa *et al*. (1988) found no impact on 1st calving age. However, Waltner-Toews *et al*. (1986a) found that calving was delayed by 1.3 months (i.e. 39 days). All three studies are of older age, however, Britney *et al*. (1984) only included two institutional dairy herds in their study, which might be less representative than conducting the study on commercial dairy herds, as was done by Correa *et al*. (1988) and Waltner-Toews *et al*. (1986a). Moreover, results from Correa *et al*. (1988) and Waltner-Toews *et al*. (1986a) may be more creditable as they included 21 and 34 dairy herds with a total of 948 and 1968 calves, respectively. A difference of zero days in first calving age is assumed for the study by Correa *et al*. (1988), as no other numbers were given. Based on the two most creditable studies, a delayed first calving age of **20 days** was estimated for heifer calves with calfhood diarrhea. Later calving age could be simulated in SimHerd by changing the 'start of insemination of heifers' (parameter #3).

4.2.1.7 First lactation milk yield

Only 3 studies investigated the effect of calfhood diarrhea on first lactation milk yield. Both Britney *et al*. (1984) and Warnick *et al*. (1995) found no impact on 1st lactation milk production. Svensson & Hultgren (2008) found no effect of severe diarrhea, however mild diarrhea showed a significant decrease in first lactation 305-day milk production of 344 kg ECM per year per cow. Compared to Svensson & Hultgren (2008) the study by Britney *et al*. (1984) is of older age and only involves two institutional herds and the study by Warnick *et al*. (1995) is also of older age and it was stated that heifers which were affected by morbidity were less likely to enter the milking herd. Thus, it is assessed that the Swedish study by Svensson & Hultgren (2008) is the most reliable source. The *median* 305-day milk production was 8006 kg ECM per cow in Svensson & Hultgren (2008). A 344 kg ECM-reduction in 305-day milk yield would mean that a first lactation cow that had mild calfhood diarrhea would produce 4.3% less milk throughout the year. The current (mid-April) 12-months rolling *average* milk production amongst all yield controlled dairy breeds in Denmark is at 9676 kg ECM per year per cow (Lauritsen & Flagstad 2014). Applying the 4.3% decrease in first lactation milk production on an average Danish dairy herd would mean a decrease of **416 kg ECM per year per animal** with calfhood diarrhea (i.e. **1.14 kg ECM less per day per animal** with calfhood diarrhea). The decrease in first lactation milk yield could be simulated by changing the parameter 'increase in first lactation milk yield in 2 years' (parameter #246) in SimHerd.

Summary

In summary, the parameters for the effect of diarrhea on production at a normal (18%) diarrhea incidence were estimated to the following values:

- Diarrhea incidence in first 180 days: **18%**
- Total mortality risk: **7.2%** (day 1 - first calving), **6.7%** (1-180 days)
- Mortality risk due to diarrhea: **13%** of diseased calves (e.g. 2.34% of all calves die due to diarrhea at a diarrhea incidence of 18%)
- Distribution of diarrhea-related mortality: **55%** (1-14 days), **40%** (15-60 days), **5%** (61-180 days), **0%** (>180 days)
- Growth rate: **-0.5 kg** at 3 months, **-9 kg** at 6 months, **0 kg** at 14 months for diseased calf
- Age at first calving: **+20 days** for diseased calf
- First lactation milk yield: **-1.14 kg ECM/day** for diseased calf

4.2.2 Set up of SimHerd

This section will explain how SimHerd was set up before running different simulations.

4.2.2.1 Model dairy herds

The economic effect of calf diarrhea is estimated by simulating calf diarrhea in two different model herds: ***a)*** an 'average' dairy herd and ***b)*** a dairy herd with 'poor reproduction'. These two herds were used to illustrate both the most representative loss (average herd) and the loss in herds with poor reproduction, where more severe economic losses due to calf diarrhea are expected because of scarcity of replacement animals.

Both model dairy herds are calibrated based on the median values in the Danish key-figure database (Ettema (2014b) pers. comm.). The 'average' herd thus represents the Danish average herd in all aspects (disease levels, reproduction, management and herd demographics). The model herd with 'poor reproduction' has the same median values as the 'average' herd, however the 'poor reproduction' herd has different values for the reproduction parameters for the dairy cows. The heat detection rate in the 'poor reproduction' herd is lower (0.26 vs. 0.36) and the conception rate is higher (0.47 vs. 0.42) compared with the average herd. The reproduction parameter values for the 'average' herd and 'poor reproduction' herd are based on scenario 1a and 3a in the advising concept '*ReproManagement – sund fornuft'* (Ancker & Nørremark 2009). Compared to the 'average' herd, the 'poor reproduction' herd detects less dairy cows in heat, but of the cows detected and inseminated, more become pregnant. The resulting calving interval will be higher in the 'poor reproduction' herd compared with the 'average' herd.

4.2.2.2 Scenarios, current herds and scenario herds

In a scenario, a 'scenario herd' is compared with a 'current herd' through simulation. A scenario herd in SimHerd is the alternative management strategy that will be compared with the calibrated current herd. The scenario herd is a 'clone of the current herd' but has one or more parameters changed such that the alternative management strategy is represented. In SimHerd a calibration is done in order to calibrate the current herd to its current values for herd demography, production and consumption.

Unlike the cows in SimHerd, calf diseases are not modelled at animal level. Therefore, the parameters which describe the effect of diarrhea (growth rate, age at first calving and first lactation milk yield) on one animal had to be specified as an average effect on the whole calf population; if the herd has an 18% incidence of diarrhea, this incidence and the parameters for the effect of diarrhea were incorporated into the model by saying that 18% of each included parameter which describes the effect of diarrhea would affect each animal in the herd. For instance, the start insemination age would be changed such that every heifer was inseminated 18% later than the found effect on one affected animal. So instead of 18% of the herd having a 20-day delayed insemination start, now every animal in the herd would have a 3.6-day delayed insemination start (as illustrated in Figure 4.2).

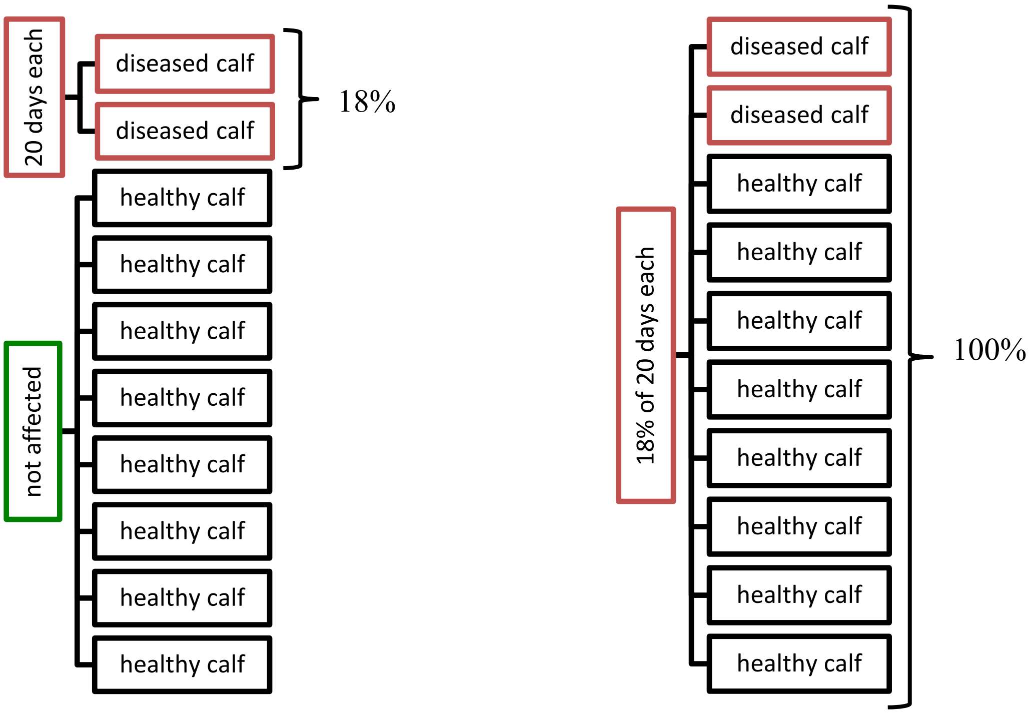

Figure 4.2 Illustration of using the parameter 'calving age' on animal level (left) and population level (right) at an 18% incidence of diarrhea. In SimHerd the calving age needs to be specified as an average effect on the whole population.

The following sections will describe the different scenarios that were run, the parameters changed in the scenario herd, and which parameters were re-calibrated in the current herds.

Simulation of separate production parameter effects (Scenario 1 and 2)

In Scenario 1 and 2 one parameter was simulated at a time in order to investigate how much each production effect of diarrhea impacted the gross margin[7] (**GM**) per cow-year. Further, all the changed parameters were run at the same time. Scenario 1 simulated the 'average' herd and Scenario 2 simulated the 'poor reproduction' herd. These two scenarios applied the estimated parameters on herds that have an 18% diarrhea incidence. Because SimHerd cannot simulate a disease incidence on calf-level, only 18% of each parameter value was inserted into the scenario. The parameters originally planned to apply in SimHerd and the actual values applied are shown in Table 4.1.

In the end, some of the parameters could not be simulated by SimHerd: To get an average effect for the calf population the growth curve was adjusted such that there was a difference of 0.09 kg at 3 months and 1.62 kg at 6 months and no difference at 14 months. However, the results of adjusting the growth curve were not satisfactory, as the rather small weight difference at 3 and 6 months of age would also lead to a weight difference at 14 months of age. As the literature study indicated a compensatory growth which could not be mimicked in SimHerd it was decided not to simulate any effect on growth rate. The indication of compensatory growth was also a reason to not simulate the growth rate.

Table 4.1 Overview of parameters originally planned to apply at animal level and parameter values for application on population level at an 18% diarrhea incidence.

	Effect on animal level	Effect on population level
Delayed insemination age	20 days	3.6 days*
Decreased 1st lactation milk yield	-1.14 kg ECM/day	-0.21 kg ECM/day
Growth rate, 3 months	-0.5 kg	-0.09 kg*
Growth rate, 6 months	-9 kg	-1.62 kg*
Growth rate, 14 months	0 kg	0 kg*
Mortality risk	13% of diarrheic animals die due to diarrhea	2.34% of all animals in herd die due to diarrhea

* could not be simulated in SimHerd.

Another problem is that SimHerd simulates in weekly steps, thus the delayed insemination age of 3.6 days could not be simulated through the delayed insemination age. If changing the delayed insemination age to 7 days it would mean that a 36% diarrhea incidence was being simulated, which was not the purpose. Thus, it was decided that the effect on delayed insemination age could not be simulated through this parameter in SimHerd. Finally, only the effect of diarrhea on heifer mortality risk and first lactation milk yield could be simulated. An overview of the parameters changed in Scenario 1 and 2 is given in Table 4.2. In both herds the parameters for heifer mortality risk and first lactation milk yield were simulated one at a time and simultaneously in order to investigate how much each production effect of diarrhea impacted the GM per cow-year.

[7] *Dækningsbidrag*: income (e.g. from milk or slaughter cows) minus variable costs (e.g. feed for cows and young stock, treatments, inseminations). Fixed costs are e.g. salaries, mortgage payments of buildings and equipment, insurance.

The 'current herd' of the average herd and poor reproduction herd were overall applied as they were calibrated by SimHerd A/S (see Section 4.2.2.1). However, the current herd in Scenario 1 and 2 was calibrated to a mortality risk of 0%. This was done in order to estimate the effect of mortality due to diarrhea on its own. Further, the distribution of mortality was calibrated to the derived 'diarrhea-related mortality' (see Section 4.2.1.4) as it was the effect of calves dying due to diarrhea that was simulated in Scenario 1 and 2. Moreover, the amount of repetitions of the simulation was calibrated to 300 repetitions and the herds were calibrated to include around 500 milking cows, 250 calves and 250 heifers in order to reduce the uncertainty of the simulation (Ettema 2011). Results of the different scenarios will be presented in Section 4.3.1.

Table 4.2 Overview of parameters changed in Scenario 1 and 2 where the economic effect of 18% diarrhea between day 1-180 is investigated for an average herd and a herd with poor reproduction.

Scenario	*Parameters changed*	
	Heifer calf mortality risk*	1st lactation increase in milk yield after 2 years
Average herd		
1.2 Mortality risk	2.34%	-
1.3 Milk yield	-	-0.21 kg ECM/day
1.6 Both parameters	2.34%	-0.21 kg ECM/day
Poor reproduction herd		
2.2 Mortality risk	2.34%	-
2.3 Milk yield	-	-0.21 kg ECM/day
2.6 Both parameters	2.34%	-0.21 kg ECM/day

* Mortality distribution was calibrated to the derived 'diarrhea-related mortality' (1-14 days: 55%, 15-60 days: 40%, 61-180 days: 5%, >180 days: 0%)

Increasing or reducing the incidence of diarrhea (Scenario 3, 4 and 5)

In Scenario 3, 4 and 5 it was the aim to simulate the economic effects of doubling the incidence of diarrhea (to 36%), increasing it by 50% (to 27%) and halving it (to 9%) in an average herd and a herd with poor reproduction. It was assumed that the effect of 18% diarrhea was already included in the calibrated parameter values of the poor reproduction and average herd. This was assumed because the 18% diarrhea incidence is estimated to be the average incidence of diarrhea in Danish dairy herds and the production effects of diarrhea should therefore already be in the calibrations of the model herds from SimHerd A/S. The assumption of 18% diarrhea incidence already being included in the calibrated current herd meant that; When simulating the 36% diarrhea incidence (Scenario 3) only an increase in diarrhea incidence of 18% is simulated in the scenario herd. When simulating the 27% diarrhea incidence (Scenario 4) only an increase in diarrhea incidence of 9% is simulated in the scenario herd. When simulating the 9% diarrhea incidence (Scenario 5) a decrease of 9% in diarrhea incidence is simulated.

Again, only the heifer mortality risk and first lactation increase in milk yield could be simulated and either 18% or 9% of the estimated parameter value was inserted into the scenario to be run on population level. Table 4.3 gives an overview of the different scenarios run and the values of the parameters in the different scenarios.

The 'current herd' of the average herd and poor reproduction herd were overall applied as they were calibrated by SimHerd A/S (see Section 4.2.2.1). However, the current herd in Scenario 3, 4 and 5 was calibrated to a mortality risk of 7.2%. Further, the mortality distribution as specified in SimHerd A/S was used. The standard distribution was used because these simulations would include mortality due to diarrhea and other possible reasons. Moreover, the amount of repetitions of the simulation was 300 and the herds were calibrated to include around 500 milking cows, 250 heifer-calves and 250 heifers in order to reduce the uncertainty of the results in the simulation (Ettema 2011). Results of the different scenarios will be presented in Section 4.3.2.

Table 4.3 Parameters changed in Scenario 3, 4 and 5, where the effect of 18% of diarrhea is assumed to be in the current average herd and current poor reproduction herd.

	Parameters changed in the Scenario	
Scenario	Heifer calf mortality risk*	1st lactation increase in milk yield after 2 years
3.0 36% diarrhea		
3.1 Average herd	9.54%[a]	-0.21 kg ECM/day
3.2 Poor reproduction herd	9.54%[a]	-0.21 kg ECM/day
4.0 27% diarrhea		
4.1 Average herd	8.37%[b]	-0.1 kg ECM/day
4.2 Poor reproduction herd	8.37%[b]	-0.1 kg ECM/day
5.0 9% diarrhea		
5.1 Average herd	6.03%[c]	+0.1 kg ECM/day
5.2 Poor reproduction herd	6.03%[c]	+0.1 kg ECM/day

* Mortality distribution was the default value of SimHerd A/S (1-14 days: 40%, 15-60 days: 40%, 60-180 days: 15%, >180 days: 5%)

[a] 4.68% die from diarrhea (13% of 36%), 4.36% die due to other reason and 0.5% die after 180 days of life.

[b] 3.51% die from diarrhea (13% of 27%), 4.36% die due to other reason and 0.5% die after 180 days of life.

[c] 1.17% die from diarrhea (13% of 9%), 4.36% die due to other reason and 0.5% die after 180 days of life.

4.2.2.4 Prices in SimHerd

It is possible to adjust prices regarding milk and livestock, feed, treatment of disease, reproduction, certain mastitis types, values of individual animals and working-hours needed for different jobs on the farm (e.g. calving of heifer takes 1 hour, drying off takes 0.25 hour). Labor time is not included in the GM estimate but specified separately. This is because the price for a working-hour varies considerably between farms. The extra labor time that a sick calf would necessitate, and the price for veterinary treatment and medication for a sick calf is not included in the model. The prices in SimHerd are updated monthly by SimHerd A/S and reflect current prices in Denmark. These updates are based on prices in 'Farmtal Online' which are estimated by the Knowledge Centre for Agriculture, Skejby. Each scenario was run without any price adjustments. Moreover, a sensitivity analysis was made for Scenario 1.6 and 2.6, where prices were adjusted to estimate the effect of a 10% increase and 10% decrease in the price of milk, young stock feed, cow feed, a slaughter cow, and the value of a pregnant heifer.

4.2.2.5 Results from SimHerd

After calibration of the model herd and setup of a scenario herd the model is run at its set repetitions. After running the model, SimHerd generates a report which describes the development of the scenario herd and the current herd from year 1 to 10 (see Appendix 3). The report includes both technical and economic results and takes into account the monthly updated prices for e.g. feed, milk and replacement heifers. *Technical results* show the development in herd demography (the number of cow-years, number of 1st, 2nd, and 3rd or more parity cows, number of heifers and calves) and the kg of ECM per cow-year and mastitis treatments per 100 cow- years over the first 10 years. Further there are technical results (average of simulation years 6-10) on the topics ‘milk yield and feeding’, ‘herd dynamics’, ‘reproduction’, ‘disease treatments per 100 cow-years’, ‘animals in different categories’ and ‘labor requirement in hours per week’. The *economic results* lists the income and expenses of the herd, and shows the GM which is calculated as GM per year, GM per cow-year and GM per ECM. Both technical results and economic results are shown over a 10-year period for the current herd, the scenario herd, and the difference between the current herd and scenario herd.

In this project, the difference in economic results in GM per cow-year between the current herd and the scenario herd of will be presented. The technical results, herd income and herd expenses will be applied to discuss the difference GM results.

4.3 Results

The following section will present the results for the differences in GM per cow-year between the current herd and the scenario herd of the simulations. The reasons for the difference in GM per cow-year will be discussed in Section 4.4.

4.3.1 Simulation of separate production parameter effects (Scenario 1 and 2)

The results for Scenario 1 and 2 on the differences between the current herd and the scenario herd in GM per cow-year are shown in Table 4.4.

Table 4.4 Results of Scenarios 1 and 2. Difference in the average 6-10 year gross margin per cow-year when the production effect of 18% diarrhea incidence in the scenario herds is compared with no production effect of diarrhea in the current herd.

	Average herd		**Poor reproduction herd**	
Parameter changed	Scenario	Difference in GM per cow-year between scenario and current herd	Scenario	Difference in GM per cow-year between scenario and current herd
Mortality risk	1.2	-21	2.2	-189
Milk yield	1.3	-76	2.3	-40
Both parameters	1.6	-84	2.6	-261

Increasing the *mortality risk* from 0% to 2.34% in the average herd (Scenario 1.2) gives a GM difference between the current herd and the scenario herd of -21 DKK per cow-year, whereas the poor reproduction herd (Scenario 2.2) has a GM difference of -189 DKK per cow-year. Thus, the increase in mortality risk has a larger impact on the herd with poor reproduction. When reducing the *first lactation milk yield* with 0.21 kg ECM per day, a difference in GM per cow-year of -76 DKK is seen in the average herd (Scenario 1.3) and a difference in GM per cow-year of -40 DKK was estimated for the herd with poor reproduction (Scenario 2.3). These results show that milk yield reduction in first parity cows has a larger impact on the average herd than the poor reproduction herd. Both *increasing the mortality risk and reducing the first parity milk yield* gives a GM difference between the current herd and the scenario herd of -84 DKK per cow-year for the average herd (Scenario 1.6) and -261 DKK per cow-year for the poor reproduction herd (Scenario 2.6). Diarrhea had a larger impact on the herd economy in the poor reproduction herd, compared with the average herd.

From the results in Ettema (2011) it is estimated that when simulating a 500 cow herd with 300 repetitions a difference in GM per cow-year of around 18 DKK is significant. All scenarios had significant differences between the current herd and the diarrhea-affected scenario herd. However, the difference between Scenario 1.3 and 1.6 was not significant. The two diarrhea effects investigated in Scenario 1.2 and 1.3 were not additive when simulating them at the same time (Scenario 1.6) and the poor reproduction herd had a more than additive result when simulating the two parameters together (Scenario 2.6).

4.3.2 Increasing or reducing the incidence of diarrhea (Scenario 3, 4 and 5)

Simulated economic effects of doubling the incidence of diarrhea (to 36%), increasing it by 50% (to 27%) and halving it (to 9%) in an average herd and a herd with poor reproduction which both already have the effect of 18% diarrhea incidence in their standard values are shown in Table 4.5.

Table 4.5 Results of Scenarios 3, 4 and 5. Difference in the average 6-10 year gross margin (GM) when the effect of 36%, 27% or 9% diarrhea incidence in the scenario herds is compared with an 18% diarrhea incidence in the current herd.

	Average herd		**Poor reproduction herd**	
Parameters changed for	Scenario	Difference in GM per cow-year between scenario and current herd	Scenario	Difference in GM per cow-year between scenario and current herd
36% diarrhea	3.1	-120	3.2	-192
27% diarrhea	4.1	-58	4.2	-123
9% diarrhea	5.1	+54	5.2	+128

Based on estimates by Ettema (2011) all differences were significant. In agreement with the results from Scenario 1 and 2, herds with poor reproduction are more affected by diarrhea than an average Danish dairy herd. A 9% increase in diarrhea incidence (Scenario 4.1 and 4.2) approximately gives the same difference in GM per cow-year as a 9% decrease in diarrhea incidence (Scenario 5.1 and 5.2) for both the average (around ±56 DKK) and poor reproduction herd (around ±125 DKK). Comparing the results of a 18% increase in diarrhea incidence (Scenario 3.1 and 3.2; 18% to 36%) with Scenario 1.6 and 2.6 (0% to 18% diarrhea incidence), the difference in GM per cow-year in the average herd is more affected by an increase in incidence from 18% to 36% (GM: -120 DKK per cow-year) then by the increase in incidence from 0% to 18% (GM: -84 DKK per cow-year). Opposite from this, the poor reproduction herd is more affected by an increase in diarrhea incidence from 0% to 18% (GM: -261 DKK per cow-year) than by the increase of incidence from 18% to 36% (GM: -192 DKK per cow-year).

4.4 Partial discussion

4.4.1 Simulation of separate production effects (Scenario 1 and 2)

The most important technical and economic results from the different SimHerd reports, which help explain the difference in results between the average herd and poor reproduction herd are shown in Table 4.6. The following sections will apply these numbers to explain the mechanisms behind the different outcomes.

Table 4.6 Overview of major technical and economic differences between the current herd and scenario herd of Scenario 1 and 2. The difference is the average difference from year 6 till 10.

	Average herd			Poor reproduction herd		
Scenario	1.2	1.3	1.6	2.2	2.3	2.6
Parameter simulated	mortality	milk	milk & mort.	mortality	milk	milk & mort.
GM/cow-year	-21	-76	-84	-189	-40	-261
Technical results						
Kg ECM/cow-year	-7	-28	-33	-87	-17	-117
FU/cow-year	-6	-12	-18	-44	-7	-57
# of cow-years	0	0	0	-1	0	-1
Sold heifers	-3	-1	-4	0	0	0
Calves < 6 months	-5	0	-5	-6	0	-6
Calves 6-12 months	-5	0	-5	-6	0	-6
Heifers (>1 year)	-11	0	-11	-12	1	-12
1st parity cows	-3	0	-3	-3	-1	-4
2nd parity cows	0	0	0	-1	0	0
3rd + parity cows*	3	-1	2	3	1	3
Economic results						
Total farm income (DKK)						
Milk	-9,900	-45,800	-51,500	-170,700	-23,400	-209,700
Slaughter cows	-26,000	4,100	-21,900	-39,100	2,500	-37,900
Heifers (sale/slaughter)	-37,000	-8,400	-38,900	-3,880	2,200	-4,200
Total farm expense (DKK)						
Feed, cows	-3,900	-9,900	-13,100	-45,500	-4,700	-52,600
Feed, young stock	-54,100	-100	-53,200	-59,300	3,800	-56,600

*3rd + parity cows = 3rd or more parity cows

4.4.1.1 Why is the poor reproduction herd more affected by mortality? (1.2 vs. 2.2)

For Scenario 1.2, the *technical results* amongst others show that the increased mortality risk contributes to fewer heifers being sold in the scenario, and that there is a reduction in the amount of calves, heifers and 1st parity cows in the scenario herd (Table 4.6). Further, there is an increase in the amount of 3rd+ parity cows. However, as heifers are still being sold in the average of year 6 to 10 of the simulation (data not shown), the increase in mortality risk has not affected the ability of the average scenario herd to replace its cull cows in the milking herd. The *economic results* show that the largest differences in income between the current herd and the scenario herd are income from slaughter cows and sale of heifers. This difference is plausible, as three more 3rd+ parity cows were kept (i.e. not slaughtered) and fewer heifers are sold in the scenario due to the increased calf mortality rate. The average scenario herd has fewer expenses compared with the current herd, especially as expenses on young stock feed are saved. This is plausible, as there is overall less young stock present in the scenario herd compared with the current herd.

The *technical results* for the poor reproduction herd for Scenario 2.2 amongst others show that the increased mortality risk reduced the amount of ECM produced per cow-year. This ECM reduction was higher than for the average herd (-87 vs. -7 kg ECM/cow-year; Table 4.6). The reason for the larger impact of mortality risk on milk yield in the poor reproduction herd will be given further on in the section. The reduction in milk yield is reflected in the reduced amount of feed given per cow-year. Further, the technical results show that the amount of calves, heifers, 1st and 2nd parity cows in the scenario herd are reduced compared with the current herd (Table 4.6). Only the amount of 3rd+ parity cows is increased in the scenario herd. No heifers are being sold in the current, nor scenario herd (data not shown). The *economic results* show that the largest differences in income are from milk and slaughter cows. The balance displacement has a difference of -16,100 DKK (data not shown) which reflects the reduced amount of animals in the scenario herd. The largest differences in expenses are savings in the scenario herd on feed for cows and young stock (Table 4.6). Again, the savings on feed is due to the smaller amount of young stock and due to the fact that the cows are fed less because of the lower milk yield. The reduced intake from slaughter cows is due to less cows being culled.

Comparing the graphs showing the development in the '*number of heifers*' and '*number of calves*' from year 0 to 10 at a 18% diarrhea incidence in the average herd (Scenario 1.6, Figure 1x, Appendix 4) with the development in the poor reproduction herd (Scenario 2.6, Figure 2x, Appendix 4), it can be seen that the average herd quickly comes to a stable or even increasing amount of young stock. The poor reproduction herd however has a declining number of young stock throughout the simulation. Furthermore it can be seen that the poor reproduction herd (Scenario 2.6, Figure 2x, Appendix 4) cannot maintain a stable number of young stock even at a calf mortality of 0% (which is show in the simulation for the 'current' herd).

The reason for the large difference in milk yield compared with the current poor reproduction herd and compared with the average herds is summarized below:

(i) As can be seen in the figures in Appendix 4, the poor reproduction herd cannot maintain a stable number of heifers, which can be used as replacements in the milking herd. This trend is even present when there is no mortality risk in the herd. The poor reproduction herd cannot maintain a stable number of animals due to a poor reproductive efficiency which results in a lower calving interval and thereby less calves born per year.

(ii) The added mortality causes even bigger problems to the poor reproduction herd, as even fewer heifers can be 'produced' for replacement in the milking herd.

(iii) Number (i) and (ii) have an effect on the milking herd, as the cows which should be culled due to poor reproduction and milk yield are in the milking herd longer (until a replacement heifer has calved) and thereby extending their lactation period.

(iv) Number (iii) will bring a reduction in the total amount of ECM produced per cow-year, as, on average, more animals of the poor reproduction milking herd are at a later stage in the lactation curve compared with the current herd.

The reduced milk yield is the largest reason for the difference in GM per cow-year between the current and scenario herd. As the average herd has a stable or slightly increasing number of young stock (and can even sell young stock), the average herd does not run into problems of replacing its cull-cows when the mortality risk is increased and thus the effect of mortality is not as large for the average herd. Compared to the poor reproduction herd, on average, the animals in the average milking herd are in the earlier stage of the lactation curve.

4.4.1.2 Why is the average herd more affected by milk yield decrease? (1.3 vs. 2.3)

The major *technical results* for Scenario 1.3, show that the scenario herd produces 28 kg ECM less per cow-year and that less feed is fed per cow-year (Table 4.6). Further, the *economic results* show that the largest difference in income between the current herd and the scenario herd is in income from milk. In the scenario herd, some money is saved on feed for the cows (Table 4.6). For Scenario 2.3 the major *technical results* show that each cow-year produces 17 kg ECM less and in the *economic results* the only large difference in income was from milk, which as lower for the scenario herd.

The poor reproduction herd was less affected by reduced milk yield amongst 1st parity cows compared with the average herd. The reason for this may be that the average herd on average has more 1st parity cows in the beginning of the lactation curve and the poor reproduction herd on average has more 1st parity cows in the end of the lactation curve. Because the reduced milk yield has the largest effect in the beginning of the lactation curve, the average herd is affected more by reduced milk yield compared with the poor reproduction herd.

4.4.1.3 Why is the poor production herd more affected by diarrhea? (1.6 vs. 2.6)

The result of Scenario 1.6 is not statistically significant from the result in Scenario 1.3 and the two parameter effects investigated in Scenario 1.2 and 1.3 were not additive when simulating them at the same time. Thus, the effect of increased mortality and reduced milk yield has less economic consequences in the average herd when they are run together. This may be due to several interactions between the parameters in the SimHerd model. When comparing the technical and economic results of Scenario 1.2, 1.3 and 1.6 in Table 4.6, the parameters which contribute the most to ‘no additivity’ are the income from milk and heifers. Thus the effect of decreased milk yield and increased mortality risk have less effect on the amount of heifers sold and the milk yield per cow-year when simulated together.

The *technical results* for Scenario 1.6 (Table 4.6) further show a decrease in 1st parity cows, calves, and heifers equal to the results in Scenario 1.2. *Economic results* show that the major differences in income in the scenario herd are from milk, slaughter cows, and heifers. These three major differences in income were also found either in Scenario 1.2 or Scenario 1.3. Further, savings are made on feed for young stock and cows.

In Scenario 2.6, the economic effect of reduced milk yield and increased mortality due to diarrhea is more than additive when both production effects are simulated together. This may be due to several interactions between the parameters in the SimHerd model causing a strengthened negative effect on the poor reproduction herd, which was already lacking replacement animals before adding the diarrhea effects. The *technical results* show that the scenario herd produces less milk and feeds the cows less feed (Table 4.6). The difference in amount of life stock is similar to the results from

Scenario 2.2. *Economic results* show large differences in the income from milk and less income from slaughter cows. The scenario herd saves expenses especially on feed for young stock and feed for cows. The differences in technical and economic results were especially also found in Scenario 2.2, where an increased mortality risk was simulated. As explained for Scenario 2.2, the reduced milk yield per cow-year and reduced income from milk probably is due to the larger amount of cows in the scenario herd that have reached the lower stage of their lactation curve.

The poor reproduction herd is most likely more affected because it struggles to produce a sufficient amount of replacement heifers for the milking herd. This problem is amplified when the mortality risk due to diarrhea is added. The ripple effect (as explained in Section 5.4.1.1 point (i) to (iv)) starting from the compromised amount of heifers for the milking herd and ending at an increased amount of cows at the later stage of the lactation curve is ultimately the reason for a higher impact of diarrhea on the poor reproduction herd.

4.4.2 Increasing or reducing the incidence of diarrhea (Scenario 3, 4 and 5)

The most important technical and economic differences in the SimHerd reports of Scenario 3, 4 and 5 are shown in Table 4.7.

Table 4.7 Overview of major technical and economic differences between the current herd and scenario herd of Scenario 3, 4 and 5. The difference is the average year 6 till 10 difference.

	Average herd			Poor reproduction herd		
Scenario	3.1	4.1	5.1	3.2	4.2	5.2
Incidence of diarrhea	36%	27%	9%	36%	27%	9%
GM/cow-year	-120	-58	+54	-192	-123	+128
Technical results						
Kg ECM/cow-year	-57	-28	27	-76	-51	54
FU/cow-year	-29	-14	14	-37	-25	26
# of cow-years	0	0	0	-9	-7	4
Sold heifers	0	0	0	0	0	0
Bought heifers	0	0	0	2	1	-1
Calves <6 months	-5	-2	3	-5	-3	3
Calves 6-12 months	-5	-2	3	-5	-3	3
Heifers (>1 year)	-10	-5	6	-10	-6	6
1st parity cows	-3	-1	2	-6	-4	3
2nd parity cows	-1	0	0	-3	-2	1
3rd + parity cows*	3	2	-2	0	0	0
Economic results						
Total farm income (DKK)						
Milk	-90,500	-42,900	40,700	-372,300	-266,500	189,100
Slaughter cows	-32,700	-14,500	22,400	-15,800	-8,600	10,500
Heifers	-6,800	-3,400	6,000	-4,600	-2,500	700
Total farm expense (DKK)						
Feed, cows	-22,800	-11,000	10,600	-116,300	-84,200	56,300
Feed, heifers	-48,300	-22,600	29,800	-47,200	-30,500	27,200

*3rd + parity cows = 3rd or more parity cows

4.4.2.1 Why is the poor reproduction herd more affected by diarrhea incidence?

The same mechanisms as explained for Scenarios 1 and 2 are valid for Scenario 3, 4 and 5. The poor reproduction herd is more affected by diarrhea incidence due to its poorer reproductive efficiency which makes it difficult for the poor reproduction herd to supply a sufficient amount of new 1st parity cows to the milking herd. This 1st parity cow-deficiency in turn reduces the milk yield per cow-year as more cows are at the later stage of lactation. As shown in Table 4.7, the income from milk is highly reduced compared with the other economic 'posts' and compared with the difference in income from milk in the average herd. Increasing the calf mortality risk of the poor reproduction herd increases the difficulty of keeping the milking herd at a preferred size and demography as even fewer heifers are available. As can be seen in Table 4.7, both the 27% (Scenario 4.2) and 36% (Scenario 3.2) diarrhea incidence reduce the number of cow-years in the poor reproduction herd and increase the number of heifers bought. On the other hand, the average herd stays at the same amount of cow-years regardless of the diarrhea incidence simulated (Scenario 3.1, 4.1 and 5.1), indicating that the average herd is more stable. Another reason for the reduction in income from milk for the poor reproduction herd is that the amount of cow-years decreases. The reduction in cow-years would lower the total amount of milk produced and thereby also the income from milk.

4.4.2.2 Why does the effect of diarrhea not increase with increasing incidence?

If taking into account the number of cow-years present on the farm it can be seen that the average herd had a steady amount of cows whereas the poor reproduction herd has a reduced number of cow-years at a 36% diarrhea incidence (Table 4.7). The reduced number of cow-years in the 36% scenario herd 'hides' the economic effect of diarrhea per cow-year. When looking at the total GM per year (Table 4.8), it can be seen that the poor reproduction herd is also more affected by an increase in diarrhea incidence from 18% to 36% (Scenario 3.2) compared with an increase in diarrhea incidence from 0% to 18% (Scenario 2.6). An increase in economic effect with increasing diarrhea incidence can also be seen when comparing the total GM per year for the 9% change in incidence from 9% to 18% (Scenario 5.2) and from 18% to 27% (Scenario 4.2). Here the change from 18% to 27% has a higher economic impact (Table 4.8). This implies, that a higher return should be possible when reducing the diarrhea incidence from e.g. 36% to 27% compared with reducing the diarrhea incidence from 18% to 9%.

The reason for the increasing economic effect of diarrhea with increasing incidence is due several indirect effects, where the replacement is affected by the increase in mortality.

Table 4.8 Overview of difference in gross margin (GM) per year in different scenarios.

	Average herd		Poor reproduction herd	
Change in incidence	Scenario	Difference in GM per year (DKK)	Scenario	Difference in GM per year (DKK)
0-18%	1.6	-41,800	2.6	-146,600
9-18%	5.1	-26,500	5.2	-125,100
18-27%	4.1	-29,200	4.2	-170,100
18-36%	3.1	-61,000	3.2	-242,500

4.4.3 Other considerations

4.4.3.1 Diarrhea and respiratory disease

Calves are at a higher risk of contracting respiratory disease following diarrhea as discussed in the literature review and several effects of calfhood respiratory disease on production have been found

(Section 3.3). Thus, it would have been evident to simultaneously simulate the effects of diarrhea together with the effects of respiratory disease on the calves which attain it following diarrhea. However, it was not possible to simulate both diseases in the same SimHerd scenarios as no studies were found that investigated the interaction between the two diseases, and it could not be assumed that the two diseases have an additive effect.

Knowing that calves are at a higher risk of contracting respiratory disease following diarrhea and that respiratory disease affects production, it is likely that the effect of respiratory disease following diarrhea increases the economic consequence of diarrhea. Thereby the found results of economic effect of diarrhea may be underestimated.

4.4.3.2 Parameters not simulated

The economic effect of delayed calving age and reduced growth rate in the beginning of the calf's life were not simulated in SimHerd. It might have been an option to indirectly simulate delayed calving age by reducing the insemination rate in SimHerd, however this was not done in the current simulations. How large of an economic consequence these two parameters could have is not known. However, it is assessed that they would also have an economic impact. Furthermore, SimHerd V is not set up to simulate the effect of diarrhea at calf level. A simulation at calf level might have given different results, however this is not known.

4.4.3.3 Uncertainty of simulation results

The more times the SimHerd model is run and the larger the herd is, the more precise should a simulation result be (Ettema 2011). It was expected that the rather small changes in the input parameters in the SimHerd model would give small economic differences between the current herd and scenario herd. Therefore the smallest possible uncertainty was wanted in the simulation. However, although it was tried to keep the uncertainty in the simulations at the minimum by choosing the highest amount of repetitions possible (300) and by increasing the amount of livestock in the model herds, some degree of uncertainty is still present in the difference in GM per cow-year.

The analysis by Ettema (2011) found that an uncertainty of ±20 DKK in the difference in GM per cow-year could be expected at 200 repetitions with 500 cows. Thus a simulation with 300 repetitions and 500 cows was estimated to give an uncertainty of around ±18 DKK in the difference in GM per cow-year. Applying this knowledge, the difference in GM per cow-year when for instance reducing the diarrhea incidence from 18% to 9% in an average herd would be 54 ±18 DKK. Thus, if having a 500 cow-year herd an extra income of between 18,000 and 36,000 DKK may be expected with 95% certainty. Hence, the economic effect of diarrhea on 'average' herds could be small, when taking the uncertainty into account.

4.4.3.4 Sensitivity analysis of ±10 % change in price

The price of e.g. milk, feed, and cows for slaughter can vary over time and impacts the GM per cow-year. A sensitivity analysis was made for Scenario 1.6 and 2.6 to investigate how sensitive the results are towards a 10% increase and 10% reduction in prices specified in SimHerd.

The simulations of Scenario 1.6 and 2.6 showed that the largest economic 'posts' which cause a large amount of the GM difference between the 'current herd' and 'scenario herd' were the income from milk and cows sold for slaughter, and the income from selling pregnant heifers. The largest differences in expenses were in cow feed and young stock feed. One 'post' was increased or reduced with 10% at a time, keeping the other prices at the level specified by SimHerd A/S.

The average herd in Scenario 1.6 initially found a difference in GM per cow-year of -84 DKK. The tornado diagram in Figure 4.4 shows that changing the price of milk or the feed price for young stock with ±10% would have the largest impact on the difference in GM per cow-year. The difference in GM per cow-year is not as sensitive towards the value of a pregnant heifer and even less sensitive towards a change in the kilogram price of a slaughter cow or the feed price for cows.

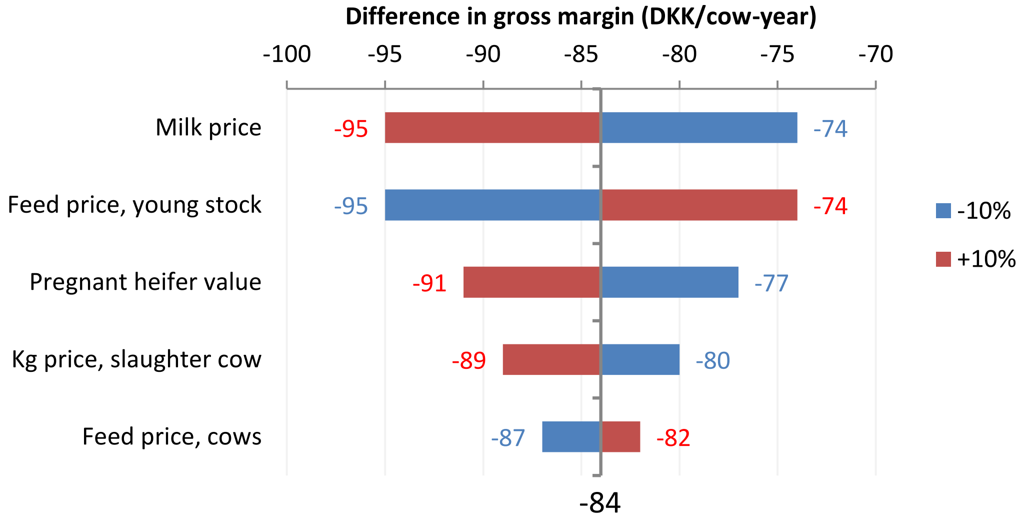

Figure 4.4 Sensitivity analysis of the DKK difference in gross margin (GM) per cow-year for Scenario 1.6 towards ±10% change in price for milk, young stock feed, value of a pregnant heifer, cow feed and price per kg slaughter cow. The 'original' GM difference of the analysis is -84 DKK per cow-year.

The herd with poor reproduction in Scenario 2.6 initially found a difference in GM per cow-year of -261 DKK. The tornado diagram in Figure 4.5 shows that the difference in GM per cow-year is most sensitive towards changes in milk price. Note that the units in difference in GM Figure 4.5 differ from the units used in Figure 4.4. The difference in GM per cow-year is not as sensitive towards the price of feed for cows and young stock, the kilogram price of a slaughter cows and little sensitive towards the value of a pregnant heifer.

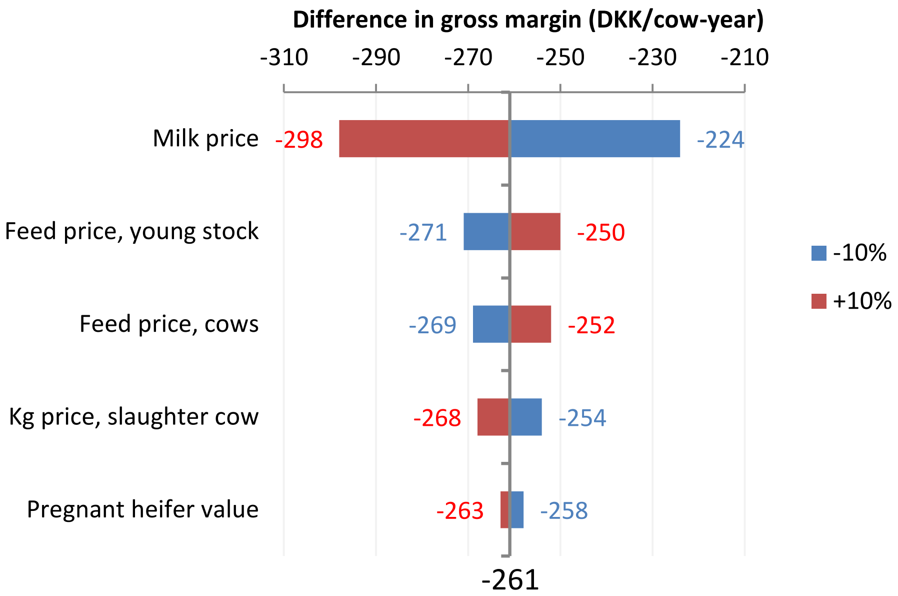

Figure 4.5 Sensitivity analysis of the DKK difference in gross margin (GM) per cow-year for Scenario 2.6 towards ±10% change in price for milk, young stock feed, value of a pregnant heifer, cow feed and price per kg slaughter cow. The 'original' GM difference of the analysis is -261 DKK per cow-year.

Both the average herd and poor reproduction herd are equally sensitive towards the feed price for young stock (around ±10 DKK change in GM per cow-year) and also the price of a slaughter cow gives the same sensitivity (around ±5 DKK change in GM per cow-year).

Compared with the average herd, the poor reproduction herd is more sensitive towards change in the price of milk. This is because the difference in income from milk is 4-fold higher for the poor reproduction herd compared with the average herd (-51,500 DKK vs. -209,700 DKK). The value of a pregnant heifer does not affect the GM of the herd with poor reproduction as heifers are generally not sold from the poor reproduction farm due to a lack of replacement heifers for the milking herd.

4.4.3.5 Extra expenses

Having a certain incidence of diarrhea brings extra expenses for veterinary, drugs and labor. However, reducing the diarrhea incidence or preventing diarrhea also implies extra costs. The following will estimate the expenses of treatment and increased labor time and cost of reducing the diarrhea incidence

Cost of treatment and increased labor time

Neither veterinary costs, medicine costs nor increased labor time due to treatment and extra care of calves with diarrhea are included in the SimHerd model. These costs can however be estimated and added after running the model. The following will estimate the extra expenses from diarrhea.

On the basis of Berge *et al*. (2009) and a Swedish estimate (MSD Animal Health 2009), it was estimated by Ettema (2014a), that a severe case of diarrhea costs 400 DKK and a mild diarrhea case costs 150 DKK in Denmark. The estimate included costs for drugs, electrolytes, veterinarian, laboratory and extra working hours due to diseased calves. The Swedish study by Svensson *et al*.

(2003) found that 68% of recorded (treated and untreated) diarrhea cases between 0 and 90 days of age were mild, 9% were moderate and 23% severe. If calves had lost their appetite for more than 2 days or had suffered obvious weight loss while diseased, the diarrhea case was categorized as 'severe'. If the effect on the calf had not been as described for the sever case, then the calf had 'mild' diarrhea, and cases that were difficult to grade into one of these categories were 'moderate' cases of diarrhea. Svensson *et al*. (2003) further found that 30% of diarrhea cases were treated with antibiotics. Assuming that the distribution of diarrhea severity in Danish herds is similar to the distribution found in the Swedish study it is estimated that 25% of diarrhea cases are severe and 75% of cases are mild.

For both the average and poor reproduction herd in SimHerd with 250 heifer calves a 18% diarrhea incidence would imply that 45 out of 250 heifer calves contract diarrhea. Out of the 45 calves, 11 calves would have severe diarrhea and 34 calves would contract mild diarrhea cases. Extra expenses for each of the 11 severely diseased calves are 400 DKK and the price for the 34 calves with mild diarrhea is 150 DKK per calf. This means that a 18% diarrhea incidence on a farm with around 500 milking cows would cost 9,500 DKK for treatment and increased labor time. A 9% diarrhea incidence would cost 4950 DKK, 27% incidence would cost 14,450 DKK and 36% diarrhea incidence would cost around 20,250 DKK (Table 4.9).

Table 4.9. Extra expense of diarrhea in a 500 cow dairy herd.

	Diarrhea incidence			
	9%	18%	27%	36%
# calves affected	23	45	68	95
# severe (25%)	6	11	17	24
# mild (75%)	17	34	51	71
Expense (severe)	2,400	4,400	6,800	9,600
Expense (mild)	2,550	5,100	7,650	10,650
Total expense	4,950	9,500	14,450	20,250

Cost of reducing diarrhea incidence/prevention of diarrhea

The SimHerd estimates and calculation on treatment and labor expenses due to diarrhea show that savings can be made by reducing the incidence of diarrhea. However, it should be considered that reducing the incidence of diarrhea might imply both initial costs for equipment and labor time to implement the strategy.

The cost of reducing the diarrhea incidence and the strategy for doing so would vary between farms. Obviously the most economic and effective strategy should be chosen. The choice would depend on the current management of the calves and environmental circumstances that the calves are raised in.

A recent survey amongst 127 dairy farmers showed that only 34% of the farmers always tested the quality of colostrum and that 40% of farmers tested colostrum quality before adding to a colostrum bank (Rasmussen 2014). If general recommendations (Boysen & Vesterager 2009; Thøgersen *et al*. 2013) on e.g. timely feeding of colostrum (within 6 hours after birth) of a sufficient quality (at least 50 mg IgG per ml) and quantity (3-4 liters for large breeds) are not implemented, decreasing the diarrhea incidence should be rather inexpensive. Establishment of a colostrum bank with quality-controlled colostrum would be beneficial in order to ensure that every newborn calf can be fed properly. Colostrum quality is determined through its immunoglobulin (i.e. antibody) content. For measurement of the colostrum quality, a digital refractometer (i.e. *brixmåler*) is recommended over a colostrometer, as the refractometer has been found to give more precise results (Marstal 2013). A colostrometer measures the density of milk while a refractometer measures the refraction of light in the milk, which only takes a couple of seconds. The price of a digital refractometer starts at around 3000 DKK (Marstal 2013). Further, the establishment of a colostrum bank at a minimum requires a refrigerator or freezer and containers or plastic bags for storage of the colostrum. The price of a freezer or refrigerator starts at around 3000 DKK. Apart from that, labor time for feeding a newborn calf from a colostrum bank should not differ from the normal time used on feeding colostrum. Another strategy that could be implemented would be 'increased hygiene level', this strategy would require an amount of extra working hours throughout the year used towards e.g. cleaning of milk-bowls, increased frequency of mucking out calf pens, frequent bedding of pens, and pressure washing of calf pens. This strategy was set to a cost of 1 hour per day, such that 150 DKK * 365 days would give a cost of 54,800 DKK for increased hygiene per year.

The rather inexpensive strategy-example includes one-time investments for a refractometer and equipment for a colostrum bank starting from 6,000 DKK and reoccurring investments for the hygiene strategy. Implementing the colostrum, colostrum bank and hygiene strategy is assessed to cost around 60,000 DKK in total in the first year, whereafter the price one-time investments would disappear.

The strategy should reduce the price of labor and veterinary visits shortly after and reduce the economic effect of diarrhea by reduced calf mortality and reduced effect of milk-yield loss, and eventual costs of reduced growth rate and delayed calving age of diseased calves.

Implementation of inexpensive 'strategies' would especially have a positive effect on the economy on farms that suffer from poor reproduction. Compared with an average herd, a poor reproduction herd could also spend more money on lowering the diarrhea incidence, as a larger difference in the GM per cow-year was estimated for a reduction of diarrhea in a poor reproduction herd. Also a large difference in the cost for each calf lost due to diarrhea was found between the poor reproduction and average herd (Figure 4.3)

Not least, reducing the amount of diseased calves also improves the 'happiness at work' as it is easier and more fun to take care of calves when they are not sick. The value of content and happy employees or farmers cannot be estimated in money. Most likely, a decreased calf morbidity will motivate employees and the farmer to improve and develop herd management further.

Summing up

Summing up on the findings regarding the difference GM per year (Table 4.8), extra costs for treatment and labor (Table 4.9) and costs for reducing the diarrhea incidence, a calculation estimating the savings potentially made by reducing the diarrhea incidence from 27% to 18% in an average and poor reproduction 500 milking cow herd is made:

For the 500 milking cow *poor reproduction* herd (Scenario 4.2) savings of around 170,100 DKK per year could be made based on the SimHerd calculation and savings of 4950 DKK could be made on reduced expenses for treatment and labor. If only using the reoccurring extra labor time expense for hygiene in this calculation (55,000 DKK), in order to see what the extra income would be after some years, it is estimated that **120,050 DKK** could be made per year after some years. The extra income in GM would easily pay for the cost of the one-time investment made for proper colostrum feeding and a colostrum bank and colostrum quality strategy. It should be noted that the effect of a reduced milk yield is not evened out until the calves with the colostrum and hygiene strategy enter the milking herd around 2 years later. Further, there is an uncertainty in the SimHerd simulation of around ±9000 DKK per year (Ettema 2011) and the result from SimHerd (GM per year) is especially sensitive towards changes in the milk price. If the milk price for instance would be decreased with 10% (from 3.07 DKK per kg ECM to 2.76 DKK per kg ECM), savings of around 143,200 DKK per year instead of 170,100 DKK are estimated in SimHerd. Thus the increase in annual income would be around **93,200 DKK** after some years.

The *average herd* (Scenario 4.1) found that a reduction in diarrhea incidence from 27% to 18% could increase the GM with around 29,200 DKK per year and save 4,950 DKK on veterinary and labor. Subtracting the extra hygiene costs of 55,000 DKK leaves a loss of **-20,850 DKK** after some years. The loss would clearly not help pay for the colostrum bank and colostrum quality strategy. Again, the effect of a reduced milk yield is not evened out until the calves with the colostrum strategy enter the milking herd. Further there is an uncertainty of approximately ±9000 DKK per year (Ettema 2011) in the GM estimate in SimHerd and the result from SimHerd is most sensitive towards changes in the milk price and feed price for young stock. However, the SimHerd estimate for the average herd is not as sensitive as for the poor reproduction herd. If the milk price was reduced with 10% (from 3.07 DKK to 2.76 DKK) savings of 24,800 DKK instead of 29,200 DKK could be made per year based on the SimHerd estimate. Including the cost of improved hygiene and savings implied with a diarrhea incidence reduction, a loss of **-25,250 DKK** would be made per year. If the feed price for young stock would also decrease with 10% on top of the 10% milk price reduction, savings of 27,100 DKK could be made per year based on the SimHerd simulation of the average herd. This would give an overall loss in income of **-22,950 DKK** per year if including other savings and expenses for improved hygiene level.

Based on these estimates, it is clear that a reduction in diarrhea incidence would not pay off for the average herd. However, maybe less expensive strategies can be found. Further, the effect of calves which potentially contract respiratory disease and the effect of other parameters not simulated would also have an impact on the herd economy, which might 'turn' the outcome for the average herd, such that increased income can be made. The ethical worth and the increased 'happiness at work' of reducing calf diarrhea incidence and thereby mortality might also have a big value to the farmer.

4.4.3.4 'Real' farms

The two model farms used in the simulations are not real farms, but are based on key-figure values from Danish dairy farms. Whether diarrhea would have an economic impact on a specific real dairy farm would require herd-specific simulations. The simulations do however give an indication of the economic effects that can be expected in real herds.

4.4.3.7 Comparativeness to other studies

Only one study was found that investigated economic consequence of diarrhea in cattle. The study by Gunn & Stott (1997) had estimated an average loss of approximately £33 per calf at risk for diarrhea in Northern Scotland. At present, £33 equal around 300 DKK. In the study, 3619 calves (48%) out of 7574 calves at risk had diarrhea. The price found by Gunn & Stott (1997) was compared through the cost per sick calf for the scenarios calculating the cost of a 18% diarrhea incidence for the average herd (Scenario 1.6) and the poor reproduction herd (Scenario 2.6). The results from Gunn & Stott (1997) would give a cost per sick calf of £69 (~ 630 DKK) [8]. For the average herd in Scenario 1.6 the price per sick calf would be 1,140 DKK[9] if the GM per year and extra costs for treatment, labor and veterinarian are included. Doing the same calculation for the poor reproduction herd (Scenario 2.6) the price per sick calf would be at 3470 DKK[10]. The price per sick calf is higher in the SimHerd simulation. A factor that would influence the results would be the possibly lower expenses for drugs and veterinary treatments in the time of the study by Gunn & Stott (1997) compared to the current prices. The labor price in the study by Gunn & Stott (1997) was only set at £1, however their calculation included a high amount of working hours (0.5 hours per day per sick calf and an extra 14 hours if the calf died). The labor time estimate in this thesis assumed that a total of 1 hour would be used on a severe case of diarrhea and that a total of 0.5 hour would be used on a mild case. The study by Gunn & Stott (1997) may have included other cattle sectors than dairy as it was stated that the study area predominantly had cow-calf beef herds, making the study results less comparable with the SimHerd estimates. Moreover, Gunn & Stott (1997) did not include reduced milk yield or an effect of having less calves for the milking herd (or for the cow-calf beef herd) in their calculations, making the results less comparable. If the majority of cattle farms were cow-calf beef herds or fattening units, an effect of reduced milk yield would obviously also not be as important. Further, a cow-calf beef herd may not have as high of a replacement rate as a dairy herd, making the loss of a calf less detrimental for the future herd demography. Gunn & Stott (1997) accounted for the cost of a dead calf, loss in calf value, expenses for extra working hours and veterinary and treatment costs. These parameters were not directly accounted for in the SimHerd simulation. However, the cost of a dead calf is indirectly accounted for through the long term effect of a dead calf on the herd and the calculation made for comparison included an estimate of extra labor and treatment. In summary, the parameters included in the calculation of economic consequences of diarrhea are different in the study by Gunn & Stott (1997) compared with the SimHerd simulation and the study might also differ from the SimHerd simulation in the type of cattle investigated. However, if considering that the cost of reduced milk yield and cost of possible needed replacement heifers is not included, the estimates by Gunn & Stott (1997) might be similar to the results found in SimHerd.

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[8] 33£ * 7574 calves at risk = 249,942 £ in total cost, 249,942£ / 3619 sick calves= 69.1£/sick calf.

[9] 18% of 250 calves get sick. 41,813 DKK (difference in GM per year) + 9500 (extra cost) =51,313 DKK, 51,313 DKK/45 sick calves = 1140.29 DKK/sick calf.

[10] 18% of 250 calves get sick. 146,585DKK (difference in GM per year) + 9500 (extra cost) =156,085 DKK, 156,085 DKK/45 sick calves = 3468.56 DK/sick calf.

4.5 Partial conclusion

The average incidence of diarrhea amongst Danish herds was estimated to be 18%, further it is estimated that 13% of the diarrheic calves end up dying. Diarrhea has a significant *negative effect on the economy* of both the average herd and the herd with poor reproduction. For both the average and poor reproduction herd the gross margin loss increases with increasing diarrhea incidence.

An average herd with a diarrhea incidence of 18% would on average lose 85 DKK in gross margin per cow-year due to the effects of diarrhea. A herd with poor reproduction and a diarrhea incidence of 18% would an average have a 260 DKK lower gross margin per cow-year due the effects of diarrhea. At an 18% diarrhea incidence the loss per diarrheic calf is higher in the poor reproduction herd (3470 DKK) compared with the loss per sick calf in the average herd (1140 DKK). The economic effect of diarrhea is expected to be larger than the estimate as some effects of diarrhea on production could not be simulated into SimHerd. Further, effects on calves which have respiratory disease following diarrhea were not included because of lacking knowledge about the interactions between these two diseases.

Chapter 5 Overall conclusions

The *literature review* showed that the incidence of dairy calf diarrhea in countries comparable to Denmark varied between 3.9% and 28.8%. Respiratory disease varied between 2.9% and 25.6%. It was further found that the dairy calf mortality varied between 3.6% and 12.6% in the first 6 to 7 months of life. Data material from the *Danish Cattle database* showed a treatment incidence of 16% for intestinal problems (diarrhea, coccidiosis and cryptosporidiosis), a treatment incidence of 9.3% for diarrhea, and a treatment incidence of 9.5% for respiratory disease in 'Module 2 plus' herds. The mortality risk amongst 'Module 2 plus' hers was at 4.7%. It was assessed that the 'true' disease incidences amongst 'Module 2 plus' herds are higher than the found treatment incidences, as only treatments have to be recorded into the Animal Register. Further, it was assessed that the average disease incidence and mortality amongst Danish dairy herds is higher compared with the incidences found in the 'Module 2 plus' herds. The estimated treatment incidences for the 'Module 2 plus' herds are within the incidence levels found in the literature review. However, the results are higher than the incidences found in other Scandinavian countries. The estimated mortality levels are also within found results from other countries with similar production systems.

The *association* between diarrhea, respiratory disease and death varied depending on sex of the calf. The results from the heifer calf group indicated that heifers are at a significantly higher risk of dying following treatment and at a significantly higher risk of contracting respiratory disease following an intestinal problem. The risk of dying was highest (21.8%) among heifers treated for respiratory disease. The second highest risk of dying (18.5%) was among heifers treated for both diseases. Out of all the included heifer calves 4.1% died following no treatment, 1.1% died following treatment for respiratory disease, 1.2% died following treatment for an intestinal problem and 0.4% of all heifers died following treatment for both diseases. The association-results for the bull calves were either opposite from the heifer calves or non-significant. Compared to the heifer calves, a large percentage of bull calves were treated for respiratory disease or an intestinal problem (13.7% vs. 34.4%). Bull calves treated for an intestinal problem had a risk of dying of 41.6% followed by a 39.6% risk of dying after no treatment. Out of all bull calves 26% died following no treatment, 5% died following treatment for respiratory disease, 6.6% of all bull calves died following treatment for an intestinal problem and 1.2% died following treatment for both diseases.

Information on the *effect of diarrhea and respiratory disease on production* was limited and the found studies mostly gave ambiguous results. Following assessment of the found effects of diarrhea on production, results on mortality, diarrhea incidence and first lactation milk yield were applied in the simulation of economic effects of diarrhea.

Although all effects of diarrhea were not simulated it was found that diarrhea has a significant negative effect on the *economy* of the average herd and the poor reproduction herd. The herd with poor reproduction is more affected by the simulated effects of diarrhea on production than the average herd, making it more profitable to lower the disease incidence in the poor reproduction herd compared with the average herd. An average herd with a diarrhea incidence of 18% would on average lose 85 DKK in gross margin per cow-year due to the effects of diarrhea. A herd with poor reproduction and a diarrhea incidence of 18% would an average have a 260 DKK lower gross margin per cow-year due the effects of diarrhea. At an 18% diarrhea incidence the loss per diarrheic calf is higher in the poor reproduction herd (3470 DKK) compared with the loss per sick calf in the average herd (1140 DKK).

Chapter 6 Overall discussion and perspectives

Economic effect of respiratory disease

The economic effect of respiratory disease was not estimated in this thesis. Nevertheless, based on found production effects of respiratory disease, it is assessed that respiratory disease also has a negative impact on the dairy herd economy. As the effect of respiratory disease on production was similar to the effect of diarrhea, an economic effect of respiratory disease by itself of around the same size is assumed. Other studies have made estimates of the economic effect of respiratory disease: van der Fels-Klerx *et al*. (2001) modelled a Dutch dairy herd with a 60% incidence of respiratory disease amongst heifers below 3 months of age and found an average cost of €31.2 (233 DKK) per heifer present on the farm. Further, a seasonal outbreak of respiratory disease amongst heifers up to 15 months of age would cost €27 (202 DKK) per heifer present (van der Fels-Klerx *et al*. 2001). Gunn & Stott (1997) estimated the average economic effect of respiratory disease to be at £21 (190 DKK) per calf at risk (7976 calves at risk) which was lower than the estimated economic effect of diarrhea (£33 per calf at risk, 7574 calves at risk).

Realistic results?

Comparing the findings for the association between treatment and death of the bull calves and heifer calves, the heifer calf findings are found most logic as it is assessed that the calves which are for instance treated for diarrhea (other than the preventive treatment against cryptosporidiosis) may be quite ill, which reduces the chance of survival compared with calves that are not treated. In general, the chance of survival should be higher amongst the group of 'untreated diseased' calves and 'untreated healthy' calves compared with the group of treated calves. An exception could be that many diseased calves that are in need of treatment are missed by the farmer. The association showing that the risk of respiratory disease treatment is higher following diarrhea treatment is also understandable, as the calf may be weaker and more receptive towards other diseases following diarrhea. The non-significant or opposite findings for the bull calves can make sense, if it is assumed that the group of bull calves includes an overrepresentation of diseased and dead calves.

Utilization of the Danish Cattle database

The Danish Cattle database could be utilized to follow the heifer calves that had diarrhea and/or respiratory treatment registrations within the first 6 months of life. It would for instance be interesting to investigate whether these heifers differ from their herd mates which were untreated as heifers in for instance milk yield, reproduction, longevity, dystocia, ketosis or mastitis. This information would be useful in order to estimate the effect of diarrhea and respiratory disease on production. It would be useful if even more farmers make treatment registrations that reflect the total amount of treatments amongst the calves. Preliminary data analysis showed that 'Module 2' herds had a percentage of treatment registrations similar to the 'Module 2 plus' herds, thus, if a larger dataset was needed it could be considered to include these calves in the data material as well. There is however no legal requirement for the remaining 'Module 2' herds to record all treatments done on their calves, which makes the data material more uncertain.

The amount of treatments and the risk of mortality varied between 'Module 2 plus' herds. If assuming that the mortality risk also varies in the remaining Danish dairy herds it could be recommended to focus on the dairy farms with a high mortality as associations between mortality and morbidity exist.

'SimHerd VI'

Development of a SimHerd version that can simulate calfhood diseases such as diarrhea and respiratory disease would be relevant. The possibility to simulate the economic effect of calf diseases would help bring more attention to diarrhea and respiratory disease, as veterinarians or other advisors could use SimHerd when advising farmers. SimHerd with a calf-disease version could for instance be used when new focus-areas need to be found. Economic effects of diarrhea or respiratory disease might work as an incentive to start focusing more on calf morbidity. In order to make better simulations of the effect of diarrhea and respiratory disease on production, studies that investigate several production effects simultaneously need to be done. For instance, the effect of diarrhea and respiratory disease on reproduction, later lactation stages and health status in the milking herd would be interesting. Further the effect of being diseased to both diarrhea and respiratory disease on production needs to be investigated, such that these two diseases can be simulated together.

Farmer motivation –or believe

The fact that calf mortality is only slowly decreasing amongst Danish dairy herds might indicate that an increased focus towards dairy calves is needed. A reason for the lack of interest on calf management improvement may be that it takes more work to implement for instance hygiene measures and that there is no spare time to implement the strategy. However, a recent study by Vaarst & Sørensen (2009) amongst Danish dairy farmers with either high calf mortality (≥17%) or no calf mortality found that the way of thinking about calf management was an important factor contribution to calf mortality. Overall, calf managers in the high mortality herd did not believe that they could avoid permanent crisis (crisis = dead or sick calves), whereas the calf manager in the no-mortality herd believed that permanent crisis can be avoided (Vaarst & Sørensen 2009). According to Vaarst & Sørensen (2009), showing a calf manager who has 'accepted' the permanent crisis that this permanent crisis can be broken may be an important step toward implementation of management recommendations. The study recommended that the circle can be broken by letting the calf manager experience that she or he is able to control and solve a crisis with the calves. Most likely this step will require that the herd advisor or other farm workers support the calf manager with 'breaking the circle'. Further, Vaarst & Sørensen (2009) identified that the calf manager of a high calf mortality herd was missing structure in his or her daily calf management. The lack of structure may be due to the lack of believe that a problem can be solved, but it may also be due to lack of overview (Vaarst & Sørensen 2009). Thus it was recommended that the farm advisor or other farm workers help the calf manager to feel in control of the situation by making a work structure. A tool which could be used to give a structure on calf management may be a standard operational procedure (SOP) on calf management as for instance developed by the Knowledge Centre for Agriculture.

As explained above, regular campaigns on calf management would not work for the farmer who has accepted a permanent crisis amongst the calves. Thus, new ways of reaching the farmer need to be implemented. Stable schools and focus-groups may help some farmers get going, as they may get encouragement from other farmers or advisors to try a new strategy. Advisors might need to focus more on calf management, and it may especially be important to follow up on farm visits and make agreements on what the calf manager needs to implement until the next visit.

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Appendix 1

Full t-test information for Part 1 in Chapter 2

Comparison of yield controlled 'Module 2 plus' herds with the remaining yield controlled herds in Denmark. H_0: $\mu_{2plus} = \mu_{remaining}$.

	'Module 2 plus' herds			Remaining yield controlled herds			t statistic value	Degrees of freedom	*p*-value
	Number of herds	Mean (μ_{2plus})	Variance (s^2_{2plus})	Number of herds*	Mean ($\mu_{remaining}$)	Variance** ($s^2_{remaining}$)			
Animal years	610	216	14813	2697	145	11477	14.46	3305	< 0.001
SCC[1] (1000 cells/ml)	610	256	5196	2697	282	7372	-6.88	3305	< 0.001
ECM[2]/cow-year (kg)	610	9801	889966	2697	9009	1599011	14.59	3305	< 0.001
Mastitis/cow-year (cases)	610	0.38	0.04	2697	0.31	0.05	7.30	3305	< 0.001
Diseases/animal-year (cases)	610	1.40	0.53	2697	0.91	0.50	15.33	3305	< 0.001
Calves born dead (%)	605	6.05	8.41	2681	6.26	15.45	-1.23	3284	0.219
CM[3], 1-14 days (%)	606	2.39	5.62	2681	2.77	9.30	-2.88	3285	0.004
CM, 15-60 days (%)	606	2.29	9.24	2685	2.60	10.30	-2.14	3289	0.032
CM, 61-180 days (%)	607	1.99	16.89	2689	2.16	19.27	-0.88	3294	0.379
CM, 1-180 days (%)	607	6.28	37.45	2689	7.18	51.41	-2.85	3294	0.004

* Yield controlled farms in Denmark in 2012 (not including 'Module 2 plus' herds)
** Variance of *all* yield controlled farms in Denmark (including 'Module 2 plus' herds)
[1] Somatic Cell Count, [2] Energy corrected milk, [3] Calf mortality

Appendix 2

In each cell of the two-way tables the values printed are the cell count, table percentage, row percentage, and column percentage, respectively.

Association between initial treatment for intestinal problem and subsequent pneumonia treatment

Table 1x Two-way table of Chi-square test, testing for association between initial treatment for an intestinal problem followed by respiratory disease treatment in 5734 bull calves in 'Module 2 plus' herds ($H_0$1).

		Respiratory disease		
	Intestinal problem	No	Yes	Total
Frequency Percent Row % Col %	No	3761 65.6 81.5 80.4	855 14.9 18.5 80.8	4616 80.5
Frequency Percent Row % Col %	Yes	915 16.0 81.8 19.6	203 3.5 18.2 19.2	1118 19.5
	Total	4676 81.6	1058 18.4	5734 100

$X^2 = 0.0797$
$p = 0.7777$

Table 2x Two-way table of Chi-square test, testing for association between initial treatment for an intestinal problem followed by respiratory disease treatment in 55,634 heifer calves in 'Module 2 plus' herds ($H_0$2).

		Respiratory disease		
	Intestinal problem	No	Yes	Total
Frequency Percent Row % Col %	No	48026 86.3 94.6 92.9	2760 5.0 5.4 70.4	50786 91.3
Frequency Percent Row % Col %	Yes	3690 6.6 76.11 7.1	1158 2.1 23.9 29.6	4848 8.7
	Total	51716 93.0	3918 7.0	55634 100

$X^2 = 2301.5701$
$p < 0.0001$

Association between treatment for an intestinal problem and death

Table 3x Two-way table of Chi-square test, testing for association between treatment for an intestinal problem and death or euthanization in 4676 bull calves in 'Module 2 plus' herds ($H_0$3).

		Dead		
	Intestinal problem	No	Yes	Total
Frequency Percent Row % Col %	No	2271 48.6 60.4 81	1490 31.9 39.6 79.6	3761 80.4
Frequency Percent Row % Col %	Yes	534 11.4 58.4 19	381 8.2 41.6 20.4	915 19.6
	Total	2805 60	1871 40	4676 100

$X^2 = 1.2539$
$p = 0.2628$

Table 4x Two-way table of Chi-square test, testing for association between treatment for an intestinal problem and death or euthanization in 51716 heifer calves in 'Module 2 plus' herds ($H_0$4).

		Dead		
	Intestinal problem	No	Yes	Total
Frequency Percent Row % Col %	No	45738 88.4 95.2 93.8	2288 4.4 4.8 77.3	48026 92.9
Frequency Percent Row % Col %	Yes	3019 5.8 81.8 6.2	671 1.3 18.2 22.7	3690 7.1
	Total	48757 94.3	2959 5.7	51716 100

$X^2 = 1144.0986$
$p < 0.0001$

Association between respiratory disease treatment and death

Table 5x Two-way table of Chi-square test, testing for association between treatment for respiratory disease and death or euthanization in 4616 bull calves in 'Module 2 plus' herds (H_05).

		Dead		
	Respiratory disease	No	Yes	Total
Frequency Percent Row % Col %	No	2271 49.2 60.4 80	1490 32.3 39.6 83.9	3761 81.5
Frequency Percent Row % Col %	Yes	569 12.3 66.6 20	286 6.2 33.5 16.1	855 18.5
	Total	2840 61.5	1776 38.5	4616 100

$X^2 = 11.1917$
$p = 0.0008$

Table 6x Two-way table of Chi-square test, testing for association between treatment for respiratory disease and death or euthanization in 50,786 heifer calves in 'Module 2 plus' herds (H_06).

		Dead		
	Respiratory disease	No	Yes	Total
Frequency Percent Row % Col %	No	45738 90.1 95.2 95.5	2288 4.5 4.8 79.2	48026 94.6
Frequency Percent Row % Col %	Yes	2159 4.2 78.2 4.5	601 1.2 21.8 20.8	2760 5.4
	Total	47897 94.3	2889 5.7	50786 100

$X^2 = 1407.8210$
$p < 0.0001$

Association between treatment and death

Table 7x Two-way table of Chi-square test, testing for association between treatment and death or euthanization in 5734 bull calves in 'Module 2 plus' herds (H_07).

		Dead		
	Treatment	No	Yes	Total
Frequency Percent Row % Col %	No int. prob. No resp. dis.	2271 39.6 60.4 64.7	1490 26.0 39.6 67.0	3761 65.6
Frequency Percent Row % Col %	No int. prob. Yes resp. dis.	569 9.9 66.5 16.2	286 5.0 33.5 12.9	855 14.9
Frequency Percent Row % Col %	Yes int. prob. No resp. dis.	534 9.3 58.4 15.2	381 6.6 41.6 17.1	915 16
Frequency Percent Row % Col %	Yes int. prob. Yes resp. dis.	135 2.4 66.5 3.9	68 1.2 33.5 3.1	203 3.5
	Total	3509 61.2	2225 38.8	5734 100

$X^2 = 16.8720$
$p = 0.0008$

Table 8x Two-way table of Chi-square test, testing for association between treatment and death or euthanization in 55,634 heifer calves in 'Module 2 plus' herds (H_08).

		Dead		
	Treatment	No	Yes	Total
Frequency Percent Row % Col %	No int. prob. No resp. dis.	45738 82.2 95.2 88.2	2288 4.1 4.8 60.6	48026 86.3
Frequency Percent Row % Col %	No int. prob. Yes resp. dis.	2159 3.9 78.2 4.16	601 1.1 21.8 15.9	2760 5.0
Frequency Percent Row % Col %	Yes int. prob. No resp. dis.	3019 5.4 81.8 5.8	671 1.2 18.2 17.8	3690 6.6
Frequency Percent Row % Col %	Yes int. prob. Yes resp. dis	944 1.7 81.5 1.8	214 0.4 18.5 5.7	1158 2.1
	Total	51860 93.2	3774 6.8	55634 100

$X^2 = 2299.7328$
$p < 0.0001$

Appendix 3

Example of a SimHerd report

Scenario 3.2: Poor reproduction herd with 36% diarrhea.

Side 1 af 10

SimHerd

Printet af: bruger8

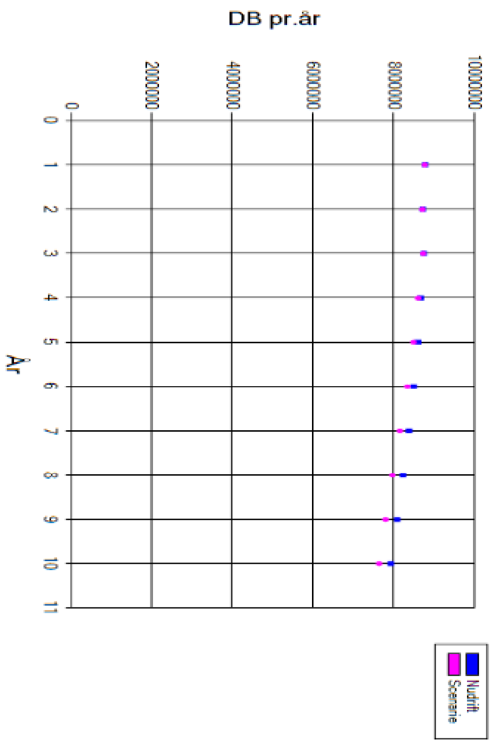
Oversigt Besætninger
Poor repro, 18% diarrhea included, 300 repetitions

xxxx7

Kommentar
Scenario 3.2, 36% diarrhea
9.54 % mortality risk
-0.21 kg ECM/day

Forskel pr. år efter 5 år (gns. af modelleringsår 6 til 10)

	Nudrift	Scenarie	Forskel
DB pr. år	kr. 8.240.424	kr. 7.997.888	kr. -242.536
DB pr. årsko	kr. 16.491	kr. 16.300	kr. -192
DB pr. EKM	kr. 1,786	kr. 1,780	kr. -0,006



Side 2 af 10

Ydelse og fodring (gns. af år 6 til 10)

	Nudrift	Scenarie	Forskel
kg EKM pr. årsko	9235	9158	-76
kg EKM pr. årsko (malkedage)	9953	9866	-88
Tankcelletal, leveret	262744	264193	1449
Leveringsprocent	99,2	99,2	0,0
Kg EKM pr. dag, 0-24 uger, 1. kalvs	28,8	28,6	-0,2
Kg EKM pr. dag, 0-24 uger, ældre køer	34,6	34,6	0,0
Kg EKM pr. dag, alle malkende køer	27,3	27,1	-0,2
FE pr. dag, alle malkende køer	18,3	18,2	-0,1
FE pr. årsko	6435	6398	-37
Gram metan pr. kg EKM	17,88	17,87	-0,01
Antal DyreEnheder (DE, gælder kun for stor race)	724	707	-17
kg EKM pr. DE	6374	6358	-17

Besætningsdynamik og ungdyr (gns. af år 6 til 10)

	Nudrift	Scenarie	Forskel
Antal årskøer	500	491	-9
Antal kælvninger	437	424	-13
Udskiftningsprocent	35,7	35,4	-0,4
- Antal ufrivillige udsætninger og dødelighed	77	75	-2
- Antal frivillige udsætninger	104	102	-2
Inseminering pr. årsko (køer + kvier)	1,8	1,7	0,0
Dødfødsel, pct.	6,1	6,1	0,0
Kalvedødelighed efter fødsel, pct.	7,0	9,2	2,3
Alder 1. kælvning, mdr.	25,8	25,8	0,0
Antal fødte tyrekalve (renracet)	212	205	-7
Antal fødte krydsningskalve (kvier + tyre)	0	0	0
Antal købte kvier	1	3	2
Antal solgte kvier	0	0	0

Reproduktion (gns. af år 6 til 10)

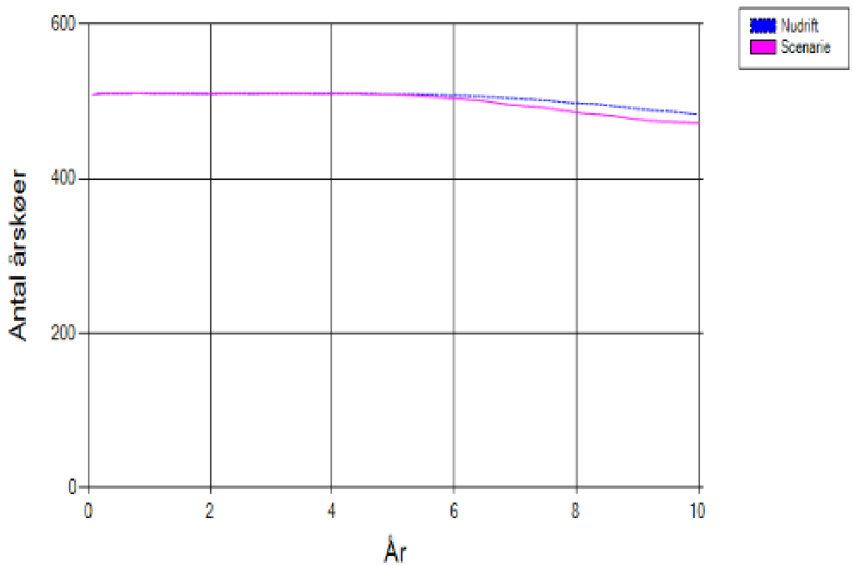
	Nudrift	Scenarie	Forskel
Insemineringsprocent	0,26	0,26	0,00
Drægtighedsprocent	0,47	0,47	0,00
Kælvningsinterval	419	419	0

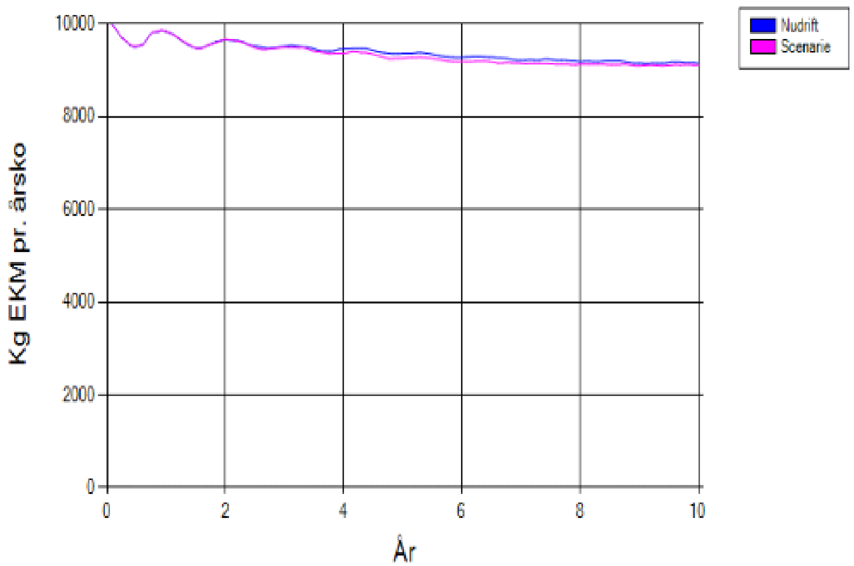
Sygdomsforekomst (behandlinger pr. 100 årskøer, gns. af år 6 til 10)

	Nudrift	Scenarie	Forskel
Mælkefeber	3,2	3,2	0,0
Kælvningsbesvær	0,7	0,7	0,0
Tilbageholdt efterbyrd	6,9	6,9	-0,1
Børbetændelse	6,8	6,7	-0,1
Løbedrejning	1,4	1,4	0,0
Ketose	4,6	4,6	0,0
Yverbetændelse	30,5	30,4	-0,1
Digital dermatitis	36,1	36,1	0,0
Klovbrandbyld	5,2	5,1	-0,1
Klov og ben problemer	20,1	20,0	-0,1
Døde køer	5,2	5,2	0,0

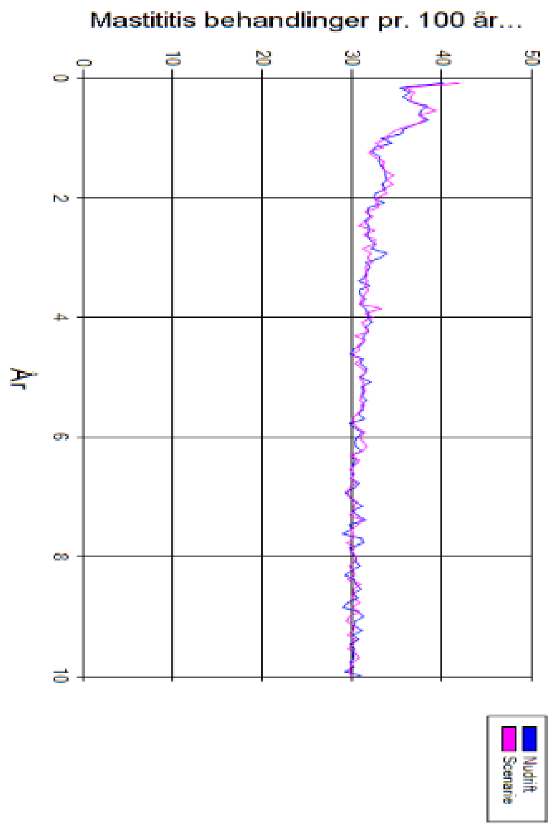
Antal dyr i forskellige kategorier (gns. af år 6 til 10)

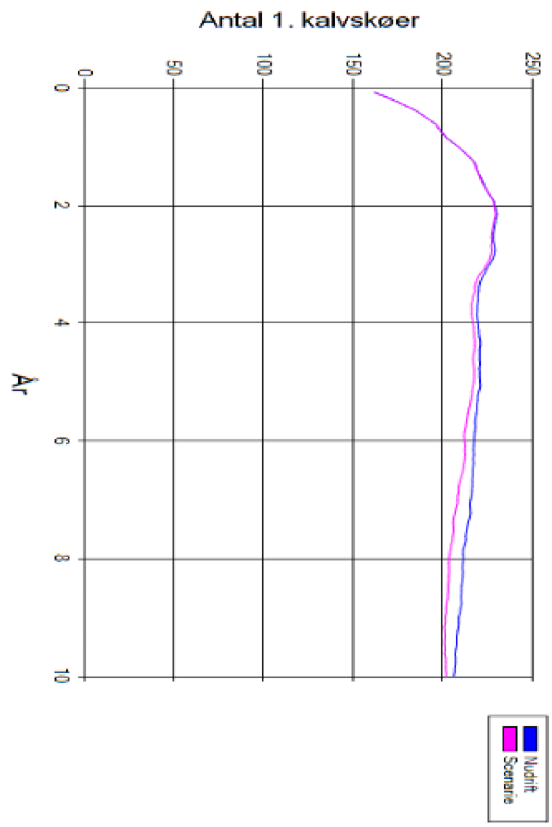
	Nudrift	Scenarie	Forskel
1. kalvskøer	214	207	-6
2. kalvskøer	131	128	-3
3. og ældre kalvskøer	155	155	0
Malkende køer	464	456	-8
Golde køer	36	35	-1
Kalve < 6 mdr.	104	99	-5
Kalve 6-12 mdr.	96	91	-5
Kvier (ungdyr > 1 år)	207	197	-10



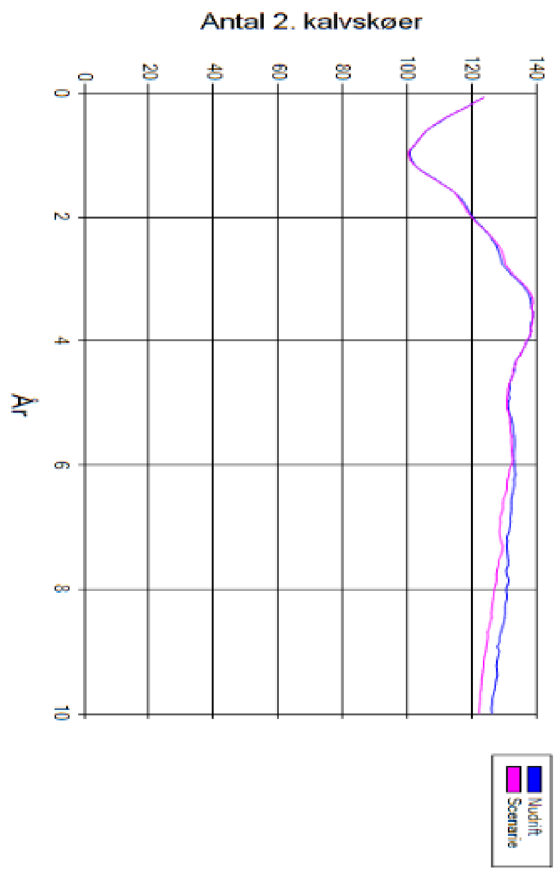


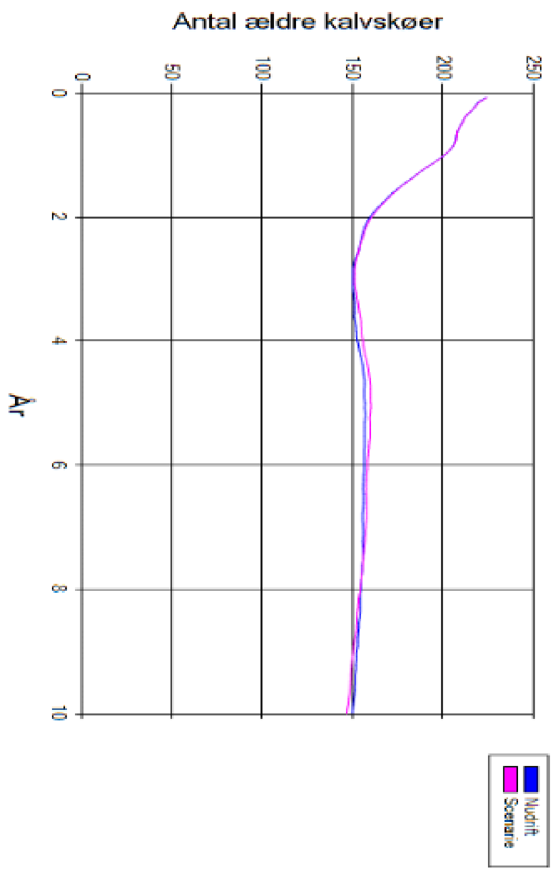
Side 5 af 10

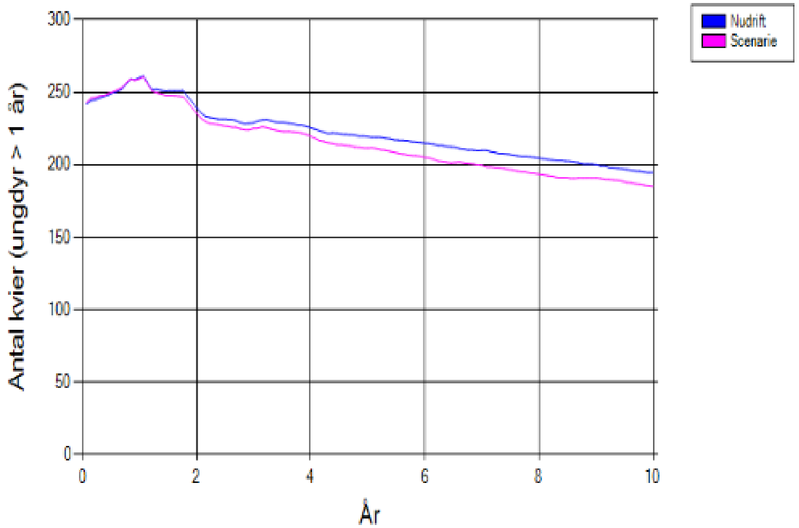


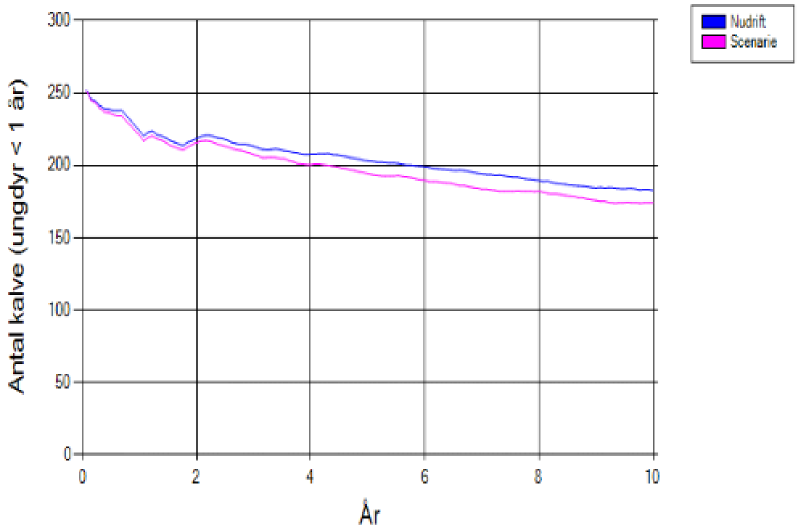


Side 6 af 10









Indtægter (gns. af år 6 til 10)

	Nudrift	Scenarie	Forskel
Mælk	kr. 14.132.097	kr. 13.759.770	kr. -372.328
Slagtekøer	kr. 752.832	kr. 737.055	kr. -15.777
Kalve	kr. 127.198	kr. 123.262	kr. -3.936
Kvier	kr. 92.840	kr. 88.240	kr. -4.600
Statusforskydning	kr. -68.900	kr. -80.805	kr. -11.905
Indtægter i alt	kr. 15.036.067	kr. 14.627.522	kr. -408.545

Udgifter (gns. af år 6 til 10)

	Nudrift	Scenarie	Forskel
Foder køer	kr. 4.915.214	kr. 4.798.890	kr. -116.324
Foder ungdyr	kr. 984.161	kr. 936.998	kr. -47.163
Kælvekvier	kr. 10.146	kr. 28.614	kr. 18.468
Behandlinger	kr. 106.946	kr. 104.814	kr. -2.132
Inseminceringer	kr. 97.805	kr. 94.355	kr. -3.450
Øvrige udg. køer	kr. 547.075	kr. 537.197	kr. -9.879
Øvrige udg. kvier	kr. 134.295	kr. 128.765	kr. -5.530
Udgifter i alt	kr. 6.795.643	kr. 6.629.633	kr. -166.009

Dækningsbidrag (gns. af år 6 til 10)

	Nudrift	Scenarie	Forskel
DB pr. år	kr. 8.240.424	kr. 7.997.888	kr. -242.536
DB pr. årsko	kr. 16.491	kr. 16.300	kr. -192
DB pr. kg EKM	kr. 1,786	kr. 1,780	kr. -0,006

Dækningsbidrag pr. år

År	Nudrift	Scenarie	Forskel
1	kr. 8.793.253	kr. 8.787.069	kr. -6.183
2	kr. 8.737.994	kr. 8.726.775	kr. -11.219
3	kr. 8.762.917	kr. 8.748.883	kr. -14.034
4	kr. 8.685.924	kr. 8.620.191	kr. -65.733
5	kr. 8.620.923	kr. 8.507.627	kr. -113.296
6	kr. 8.508.828	kr. 8.358.574	kr. -150.254
7	kr. 8.393.676	kr. 8.176.629	kr. -217.047
8	kr. 8.247.464	kr. 7.983.639	kr. -263.825
9	kr. 8.108.323	kr. 7.814.043	kr. -294.280
10	kr. 7.943.829	kr. 7.656.555	kr. -287.274

Samlede forskel i besætningens DB i de første 5 år

Total forskel i DB	kr. -210.465
Total forskel i DB, nutidsværdi	kr. -178.104

Samlede forskel i besætningens DB i de første 10 år

Total forskel i DB	kr. -1.423.146
Total forskel i DB, nutidsværdi	kr. -1.055.394

Tidsbehov (udtrykt i timer pr. uge, medmindre andet er specificeret. Gns. af år 6 til 10)

	Nudrift	Scenarie	Forskel
Ungdyr pasning	61,5	59,2	-2,3
Malkning	99,9	98,1	-1,8
Kælvning og Goldning	7,1	6,9	-0,2
Sygdomsbehandling	10,7	10,5	-0,2
Andet (fodring mm.)	104,6	103,3	-1,4
I alt	283,8	277,9	-5,9
I alt, timer pr. årsko	29,5	29,5	-0,1
I alt, antal årsværk pr. 100 årskøer	1,74	1,73	0,00

Ændrede parametre i scenariet ift. nudriften

	Nudrift	Scenarie
Dødsrisiko for levendefødte kvier, %	7,2	9,5

Appendix 4

Comparison of the development in the amount of heifer-calves and heifers in the average herd and poor reproduction herd

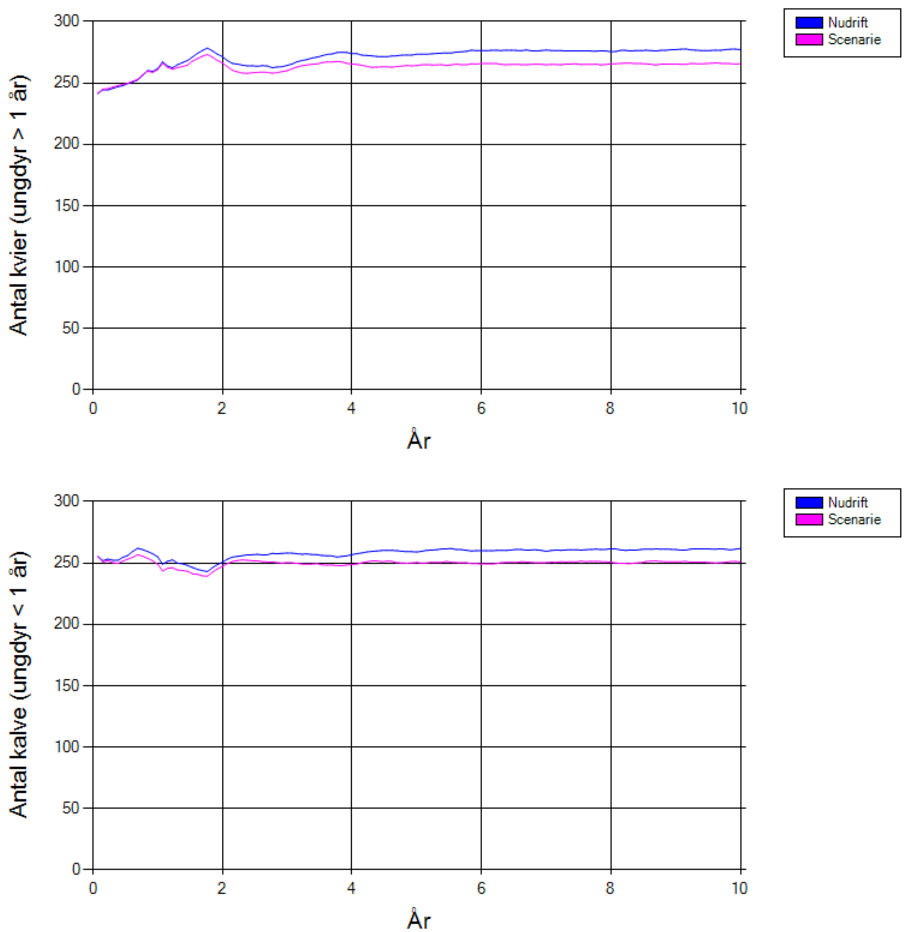


Figure 1x. Scenario 1.6, 18% diarrhea incidence in average herd.

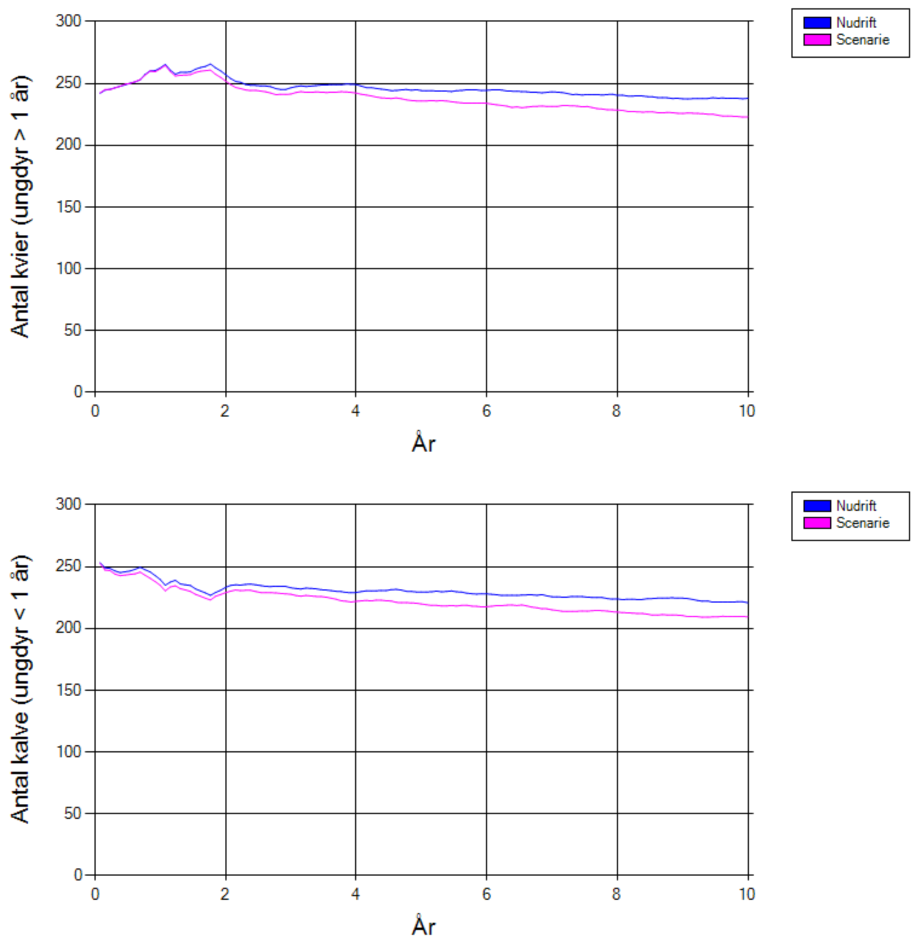


Figure 2x. Scenario 2.6, 18% diarrhea incidence in herd with poor reproduction.