Production Diseases in European Organic Dairy Farms – Current Status and Identification of Drivers for Improvement by Means of a Systemic Approach

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By Margret Carola Krieger, M.Sc. agr.

Department of Animal Nutrition and Animal Health

Main Supervisor: Prof. Dr. Albert Sundrum

Co-Supervisor: Prof. Dr. Ulf Emanuelson

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Main Supervisor: Prof. Dr. Albert Sundrum, University of Kassel

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Examiner: Prof. Dr. Detlev Möller, University of Kassel

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Abstract

Production Diseases in European Organic Dairy Farms – Current Status and Identification of Drivers for Improvement by Means of a Systemic Approach

The aims of this thesis were to determine the animal health status in organic dairy farms in Europe and to identify drivers for improving the current situation by means of a systemic approach. Prevalences of production diseases were determined in 192 herds in Germany, France, Spain, and Sweden (Paper I), and stakeholder consultations were performed to investigate potential drivers to improve animal health on the sector level (ibid.). Interactions between farm variables were assessed through impact analysis and evaluated to identify general system behaviour and classify components according to their outgoing and incoming impacts (Paper II-III).

The mean values and variances of prevalences indicate that the common rules of organic dairy farming in Europe do not result in consistently low levels of production diseases. Stakeholders deemed it necessary to improve the current status and were generally in favour of establishing thresholds for the prevalence of production diseases in organic dairy herds as well as taking actions to improve farms below that threshold. In order to close the gap between the organic principle of health and the organic farming practice, there is the need to formulate a common objective of good animal health and to install instruments to ensure and prove that the aim is followed by all dairy farmers in Europe who sell their products under the organic label. Regular monitoring and evaluation of herd health performance based on reference values are considered preconditions for identifying farms not reaching the target and thus in need of improvement.

Graph-based impact analysis was shown to be a suitable method for modeling and evaluating the manifold interactions between farm factors and for identifying the most influential components on the farm level taking into account direct and indirect impacts as well as impact strengths. Variables likely to affect the system as a whole, and the prevalence of production diseases in particular, varied largely between farms despite some general tendencies. This finding reflects the diversity of farm systems and underlines the importance of applying systemic approaches in health management. Reducing the complexity of farm systems and indicating farm-specific drivers, i.e. areas in a farm, where changes will have a large impact, the presented approach has the potential to complement and enrich current advisory practice and to support farmers' decision-making in terms of animal health.

Keywords: dairy cow, animal health, decision support, impact matrix, management

Author's address: Margret Krieger, University of Kassel, Department of Animal Nutrition and Animal Health, Faculty of Organic Agricultural Sciences, Nordbahnhofstrasse 1a, D-37213 Witzenhausen, Germany, E-mail: margret.krieger@uni-kassel.de

Zusammenfassung

Produktionskrankheiten auf ökologischen Milchviehbetrieben in Europa – Ist-Situation und Bestimmung von Antriebsfaktoren für deren Verbesserung mithilfe eines systemischen Ansatzes

Ziel dieser Arbeit war es den Tiergesundheitsstatus auf ökologischen Milchviehbetrieben in Europa zu ermitteln und mithilfe eines systemischen Ansatzes Antriebsfaktoren für die Verbesserung der Ist-Situation zu identifizieren. Für 192 Betriebe in Deutschland, Frankreich, Spanien und Schweden wurden Krankheitsprävalenzen bestimmt. Weiterhin wurden Konsultationen mit Stakeholdern durchgeführt, um Antriebsfaktoren für die Verbesserung der Tiergesundheit auf Sektorebene zu erörtern (Paper I). Interaktionen zwischen Betriebsvariablen wurden mittels Einflussanalyse erhoben. Anhand der Ergebnisse wurde das generelle Systemverhalten bestimmt sowie die Variablen hinsichlich ihrer eingehenden und ausgehenden Wirkungen beurteilt (Paper II-III).

Die Mittelwerte und Verteilungen der Prävalenzen deuten darauf hin, dass die Vorschriften für die ökologische Erzeugung nicht in einem einheitlich niedrigen Krankheitsniveau resultieren. Die konsultierten Stakeholder erachteten es als notwendig, die Ist-Situation zu verbessern und befürworteten die Einrichtung von Grenzwerten hinsichtlich der Prävalenz von Produktionskrankheiten bei ökologischen Milchkühen sowie die Ergreifung von Maßnahmen, um Betriebe unterhalb des Grenzwertes zu verbessern. Um die Lücke zwischen dem ökologischen Gesundheitsprinzip und der ökologischen Praxis zu schließen, besteht die Notwendigkeit Tiergesundheit als gemeinsames Ziel zu etablieren und Instrumente einzusetzen, die sicherstellen und belegen, dass dieses Ziel von allen Landwirten in Europa verfolgt wird, die ihre Produkte unter dem ökologischen Siegel vermarkten. Die kontinuierliche Überwachung und Bewertung der Gesundheitsleistung anhand von Referenzwerten ist eine Voraussetzung dafür, Betriebe zu identifizieren, die das Ziel nicht erreichen und wo Verbesserungsbedarf besteht.

Die Graphen-basierte Einflussanalyse eignet sich zur Modellierung und Bewertung der vielfältigen Interaktionen zwischen Betriebsfaktoren und zur Bestimmung der einflussreichsten Variablen auf Betriebsebene unter Berücksichtigung direkter und indirekter Einflüsse sowie Einflusstärken. Variablen, die das gesamte System, und insbesondere das Auftreten von Produktionskrankheiten, beeinflussen, variierten stark zwischen den Betrieben. Dieses Ergebnis spiegelt die Diversität der Betriebe wider und unterstreicht die Bedeutung, die der Anwendung von systemischen Ansätzen im Gesundheitsmanagement zukommt. Indem der Ansatz die Komplexität reduziert und betriebsspezifische Antriebsfaktoren aufzeigt, d.h. Betriebsbereiche in denen Veränderungen sich stark auswirken, hat er das Potential die aktuelle Beratungspraxis zu ergänzen und zu bereichern sowie die Entscheidungsfindung von Landwirten im Bereich der Tiergesundheit zu unterstützen.

To Janosch who will always be missed. You are in my heart.

Preface

This thesis is submitted to the Faculty of Organic Agricultural Sciences of the University of Kassel as a partial fulfilment of the requirements for the degree of Doctor of Agricultural Sciences (Dr. agr.). The research of this work was carried out within the IMPRO project (*Impact matrix analysis and cost-benefit calculations to improve management practices regarding health status in organic dairy farming*) which was funded by the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 311824. With farmers' permission, data were kindly provided by the milk recording organisations (LKV) of Baden-Württemberg, Bavaria, Hesse, Mecklenburg-Western Pomerania, and Schleswig-Holstein as well as by Vereinigte Informationssysteme Tierhaltung (VIT) in Germany, by the Spanish Holstein Association (CONAFE), by the Spanish Ministry of Agriculture, Food and Environment, by the French Ministry of Agriculture and France Genetique Elevage (FGE), and by Växa Sverige AB.

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List of Publications

This thesis is based on the work contained in the following publications referred to by Roman numerals in the text:

I. Krieger, M., Sjöström, K., Blanco-Penedo, I., Madouasse, A., Duval, J.E., Bareille, N., Fourichon, C., Sundrum, A., Emanuelson, U., 2016. Prevalences of production diseases in European organic dairy herds and potential drivers for improvement as identified by stakeholders. (*submitted to Livestock Science, LIVSCI-S-16-00391*)

II. Krieger, M., Hoischen-Taubner, S., Emanuelson, U., Blanco-Penedo, I., de Joybert, M., Duval, J.E., Sjöström, K., Sundrum, A., 2016. Capturing systemic interrelationships by an impact analysis to improve animal health in dairy farms. (*submitted to Agricultural Systems, AGSY_2016_196*)

III. Krieger, M., Schwabenbauer, E.-M., Hoischen-Taubner, S., Emanuelson, U., Sundrum, A., 2016. Farm factors related to the prevalence of production diseases in organic dairy cows – Results of graph-based impact analysis involving farmers, advisors and veterinarians. (*submitted to Animal, ANIMAL-S-16-00657*)

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List of Abbreviations

a.k.a.	also known as
ADVIAN	Impact analysis method developed by Linss and Fried (2009)
AI	Activity index/indices
AS	Active sum
cf.	Latin *conferre*, meaning 'compare'
CH	Calf and heifer management (variable)
CI	Criticality index/indices
d	days
d.h.	das heißt
DC	Dry cow management (variable)
DE	Germany/German
e.g.	Latin *exempli gratia*, meaning 'for example'
ECM	Energy-corrected milk
ES	Spain/Spanish
FE	Feeding (variable)
FR	France/French *or* Financial resources (variable)
HC	Housing conditions (variable)
HM	Herd health monitoring (variable)
HY	Hygiene (variable)
i.e.	Latin *id est*, meaning 'that is'
ibid.	Latin *ibidem,* meaning 'in the same place'
ICAR	International Committee for Animal Recording
IFOAM	International Federation of Agricultural Movements
IMPRO	EU research project (*Impact matrix analysis and cost-benefit calculations to improve management practices regarding health status in organic dairy farming*)
inter alia	Latin for 'among other things'
IQR	interquartile range
KRAV	Swedish organic certification organisation
KRAV	Swedish private organic label organisation
KS	Knowledge and skills (variable)
LC	Labour capacity (variable)
m / Med	median
MICMAC	Impact analysis method developed by Godet (1979)
MP	Milk performance (variable)
p	probability
PD	Production diseases (variable)
PI	Proportionate incoming impact
PO	Proportionate outgoing impact
PS	Passive sum
Q	quartile
RE	Reproduction management (variable)
SCC	somatic cell count
SE	Sweden/Swedish
TR	Treatment (variable)
UK	United Kingdom

1 General Introduction

Organic farming worldwide is based on four principles, namely health, ecology, fairness, and care (IFOAM, 2006). In the European Union, organic food production and processing is goverened by law. Regulation No. 2092/91 was introduced in 1991, setting out rules for crop production, certification, and labelling, and was supplemented in 2000 with production rules for organic livestock production (Sundrum, 2014). At the time, the idea was to guarantee animals in organic systems better living conditions that would ultimately lead to a higher animal health status (EC, 2007). The specific production rules led consumers to associate organic production with a higher animal welfare and higher product quality (Harper and Makatouni, 2002; McEachern and Willock, 2004). Disease prevalences described in the literature, however, are in contradiction with the principles of organic livestock farming, in particular the principles of health and fairness. A study on organic dairy farms in Germany conducted in 2005 reported a third of the animals suffering from mastitis, a quarter having foot disorders and 10 percent being diagnosed with metabolic disease (Brinkmann and March, 2010). Thamsborg et al. (2004), who reviewed numerous studies dealing with the animal health status in organic dairy farms in Europe, concluded that the specific practices in organic farming, e.g. the non-use of prophylactic antibiotics, less slatted floors, more straw bedding and grazing, present different health risks but ultimately lead to similar problems to the ones found in conventional systems. Hence, stricter production rules by themselves cannot be regarded as sufficient to guarantee good animal health in organic dairy farming. Different approaches to influence the mindset and consequently the behaviour of farmers have been identified by Wessels et al. (2014). Their RESET model summarises five categories of stimuli, namely regulation, education, social pressure, economic incentives, and tools. They argue, that with a differentiated approach, one can hope to reach a wide range of people by appealing to the motives of different groups. With the organic principle of health in mind, it could be useful to identify suitable stimuli that can be expected to have a positive effect on the prevalence of production diseases in the organic dairy sector.

The current legal framework for organic farming in Europe is EU Regulation (EC) No. 834/2007. The regulation is enforced in the same way in all EU countries which means the same minimum standards apply in terms of animal housing, feeding and management. Hence, it is reasonable to evaluate the regulation's impact, e.g. in the area of animal health, on a European level. Newly published studies on the prevalence of production diseases in organic dairy farms taking a European perspective, however, are scarce. There is but one recent study that reports treatment frequencies and health parameters of organic dairy farms in several European countries, with a focus mainly on Central and Northern Europe (Ivemeyer et al., 2012). Besides this paper, there are numerous publications reporting disease prevalences on a national level (see for instance Blanco-Penedo et al., 2012; Fall and Emanuelson, 2009; Garmo et al., 2010; Müller and Sauerwein, 2010; Rutherford et al., 2009; Sundberg et al., 2009; Winckler and Brinkmann, 2004). The results of these studies are hardly comparable, because different indicators were used or, if indicators were similar, they were determined using different methods. Thus, comprehensive and comparable knowledge on the prevalence of production diseases in European organic dairy farms is limited. In order to verify whether good animal health is achieved, or to evaluate if the implementation of additional measures results in the desired changes, it is necessary to determine the status quo based on readily available herd data and standardised methods allowing for comparison between farms and countries.

In dairy herds the most dominant health problems are multifactorial diseases in their clinical and subclinical forms, such as mastitis, lameness, impaired fertility, and metabolic disorders. This is true for both organic and conventional systems (Thamsborg et al., 2004). Management is one major factor related to the emergence of these so-called ‘production diseases’, which play also an important role in their control. Although there has been a lot of research in the field of production diseases in dairy cattle and significant progress has been made in terms of disease prevention and disease control (LeBlanc et al., 2006), this knowledge cannot be directly used to advise farmers. For once, there is a myriad of different management measures with potential effects (Dufour et al., 2011). Furthermore, farms are so diverse and under such economic pressure, that if an interventions is meant to be effective, measures need to be tailored to the specific risk factors as well as efficient (Green et al., 2007; Sundrum, 2012). In order to decide which measure will have a high efficacy in the farm context whilst also being economic, it is necessary to understand the complex interrelationships between the numerous farm factors and to identify those factors with a high impact on the system.

There has been recognition that farms are complex systems and that the identification of drivers within a farm thus requires a system approach (Bawden, 1997). System approaches, however, are rarely applied in livestock science with most approaches searching for mono-factorial cause-effect relationships and trying to identify risk factors while ignoring the complexity of the system in focus (Darnhofer et al., 2010). Knowledge on the functional relationships, however, forms the basis for understanding behaviour and attributes of systems and is necessary to achieve significant improvements in system performance (Conway, 1986). One tool that was developed for the analysis of impacts within complex systems is the ‘impact matrix’ or ‘paper computer’ (Vester and Hesler, 1980). Impact analyses are characterisation methods that are used to study the relationships between impact factors and to draw conclusions as to which factors are the most important in order to influence, e.g. optimise, the whole system (Linss and Fried, 2009). Impact matrices have been used in a variety of research contexts (see for instance Cole et al., 2007; Messerli, 2000; Wenzel and Igenbergs, 2001; Wiek and Binder, 2005). Hoischen-Taubner and Sundrum (2012) were the first to apply an impact analysis in the context of animal health. Studying organic pig farms in Germany, they had 10 farmers assess their farms by means of an impact matrix. Using the Sensitivity Model by Vester (2007) for evaluation of the matrices, the authors identified drivers for improving animal health in each system. Their study showed that the complex effect structure of a farm system can be captured and reduced by the means of impact analysis and that the results can be utilised for animal health planning.

External perspectives only played a marginal role in the study on organic pig farms. In terms of animal health management, however, outside views are of great importance since they form a frame of reference and have the potential of breaking up established routines (Hall and Wapenaar, 2012; Lam et al., 2011). Veterinarians are experts in animal health and advisors, depending on their qualification, are highly knowledgeable in feeding, husbandry, and/or economy. Both can thus give valuable input to specific questions, where farmers, due to their many occupations, may have only a limited understanding. Extending the impact assessment to involve external perspectives can thus be expected to have substantial benefits.

Another weakness of the approach applied by Hoischen-Taubner and Sundrum is that only direct impacts between farm factors were studied, whereas indirect effects were not considered. There are methods that take indirect impacts into account, such as MICMAC or ADVIAN (Godet, 1979; Linss and Fried, 2009), but with other shortcomings. Improving the approach to take into account the indirect effects between impact factors can be expected to lead to a better understanding of the system dynamics of farms and to produce better results with respect to the identification of driving factors for improving animal health.

2 Aims of the Thesis

The overall aims of this thesis were to determine the current animal health status in organic dairy farms in Europe and to identify drivers for improving the current situation.

The specific aims were

i. to determine the prevalence of production diseases in organic dairy farms in Germany, France, Spain, and Sweden,

ii. to identify drivers for improving animal health in the organic dairy sector,

iii. to develop a method for evaluating the complex relationships between impact factors and production diseases in individual farms, and

iv. to identify drivers for improving animal health on the farm level.

3 Prevalences of production diseases in European organic dairy herds and potential drivers for improvement as identified by stakeholders

M. Krieger [a, *], K. Sjöström [b], I. Blanco-Penedo [c], A. Madouasse [d], J.E. Duval [d], N. Bareille [d], C. Fourichon [d], A. Sundrum [a], U. Emanuelson [b]

* Corresponding author: Tel.: +49 561 804 1661; fax: +49 561 804 1581.
E-mail address: margret.krieger@uni-kassel.de (M. Krieger)

[a] University of Kassel, Department of Animal Nutrition and Animal Health, Nordbahnhofstrasse 1a, D-37213 Witzenhausen, Germany

[b] Swedish University of Agricultural Sciences, Department of Clinical Sciences, SE-750 07 Uppsala, Sweden

[c] IRTA, Animal Welfare Subprogram, ES-17121 Monells, Girona, Spain

[d] BIOEPAR, INRA, Oniris, 44307, Nantes, France

Abstract

High levels of animal health and welfare are a key target of organic animal husbandry and a reason why consumers purchase organic products. Compliance with the organic production rules is inspected on a yearly basis whilst the achievement of good animal health and welfare in most European countries is not. The aims of this study were to assess the current prevalence of production diseases in organic dairy farms and to identify potential drivers for improvement by consulting stakeholders. Milk and breeding records as well as animal registration and movement data of 192 farms in Germany, Spain, France, and Sweden were retrieved and analysed. Lameness scoring according to Welfare Quality® was performed on all farms by trained observers. Herd-level indicators were used to describe udder health, metabolic disorders, reproductive disorders, claw health, longevity and mortality. Prevalences of production diseases varied widely between farms and countries. The median prevalences (interquartile range) were 51.3% (15.4) for subclinical mastitis, 10% (7.7) for risk of ketosis, 3.2% (4.7) for risk of acidosis, 63% (19.2) for suboptimal nutrient supply, 42% (20.7) for prolonged calving interval, and 14.2% (20.4) for clinical lameness. Preliminary results were discussed in focus groups with 39 stakeholders in the four countries. The participants saw the need for improvement and were generally in favour of establishing minimum health standards for organic farms although differences between countries became apparent. Introducing a premium segment within the organic sector for the best farms and penalties for the poorest farms received comparably little support whereas incentives for good health performance or admonishment, and ultimately exclusion, for bad health performance were thinkable options. Future research should focus on ways to improve the availability of data and on strategies for using that information most effectively to improve

the current situation. Opportunities and risks of different strategies must be elaborated and concerns of stakeholders must be considered.

Keywords: dairy cow, organic farming, animal health, indicators

3.1 Introduction

One of the key principles of organic agriculture is to sustain and enhance health in general, and the health of farm animals in particular (IFOAM, 2006). Based on the IFOAM Basic Standards the EU regulation on organic production was introduced in 1991 to legally ensure better living-conditions for animals kept in organic farming systems compared to those in conventional husbandry. According to Regulation (EC) 834/2007, animal health and welfare in organic farming are to be achieved by suitable breed and strain selection, good husbandry management practices, high quality feed and exercise, appropriate stocking density, and adequate and appropriate housing maintained in hygienic conditions (EC, 2007). Private organisations, like Bioland in Germany, KRAV in Sweden, and Bio Cohérence in France, are using rules for organic production that are more detailed and stricter than the EU regulation in certain areas (Arcuri, 2015). Both the EU regulation and private standards specify practices that when followed promise the delivery of additional ethical values (Padel et al., 2009). As a consequence, consumers directly associate organic products to enhanced animal welfare (Harper and Makatouni, 2002; McEachern and Willock, 2004). Whereas the compliance with the production rules is inspected on a yearly basis in all organic certified operations in Europe, there is no common monitoring of the fulfilment of the organic principles, particularly the principle of animal health (Sundrum, 2014). Only recently, some private label organisations have expanded their standards to also include a selection of outcome-oriented indicators of welfare, e.g. KRAV in Sweden in 2012 and the four biggest German organic farmer associations (Bioland, Naturland, Demeter, and Biokreis) in 2014.

Numerous studies assessing the animal health status on organic dairy farms in Europe were reviewed by Thamsborg et al. (2004) who concluded that health levels under organic conditions do not vary much from those in conventional herds. Newer studies carried out in Norway (Garmo et al., 2010), Sweden (Blanco-Penedo et al., 2012; Fall and Emanuelson, 2009; Sundberg et al., 2009), and Germany (Müller and Sauerwein, 2010; Winckler and Brinkmann, 2004) revealed no major differences between conventional and organic herds in relation to udder health, reproductive performance, and metabolic disorders. Rutherford et al. (2009) found lameness prevalence to be lower in organic herds comparing them with non-organic farms in the United Kingdom. Despite this finding they described a substantial overlap between both systems. The organic sector in Europe is growing rapidly with the number of producers having almost doubled between 2003 and 2012 (Willer et al., 2014). The structural changes accompanying this development have led to slightly bigger and more specialised farms. According to Best (2008) new farmers adopt organic farming because they expect economic improvement or higher subsidies rather than for environmental or animal welfare related reasons. This may particularly be the case in dairy farming where margins have become increasingly volatile (EC, 2015) and profitability can be higher in organic than in conventional production (Kiefer et al., 2014; Patel et al., 2013). A Norwegian study found that new organic dairy producers had higher inputs of concentrates, achieved higher milk yields, and had a higher incidence of veterinary treatments than earlier entrants (Flaten et al., 2006). Newly published results with respect to the health status of organically farmed dairy cows in Europe are scarce and health status' in previous studies are hardly comparable between countries because methods are so different. Thus, the aim of this study was to re-assess the animal health status on organic dairy farms across Europe focusing on production diseases. Another objective was to identify potential drivers for improvement by consulting experts from the organic food chain.

3.2 Material and methods

The study was performed in two steps, namely:

1. The prevalence of production diseases on organic dairy farms in Europe was assessed for a sample of farms from four countries, Germany (DE), Spain (ES), France (FR), and Sweden (SE).
2. Focus groups were conducted in the same countries to explore possible indicators and actions with stakeholders from the whole food chain.

3.2.1 Assessing the prevalence of production diseases

3.2.1.1 Sample

The study enrolled 200 certified organic farms. The selection of farms was based on the following requirements: organic certification for a period of at least one year at the time of the first visit, availability of test-day milk records beginning before January 2012, expected to be in operation for at least the immediate future, and a herd size within the average national range.

In DE and FR organic advisors in six different regions were asked to pre-select farms corresponding to the criteria and to conduct an initial enquiry. Of 102 DE farms that were first-contacted 68 were willing to participate and 60 were selected considering location and herd size. In FR, farms were recruited in two geographic regions, i.e. Morbihan/Loire-Atlantique and Lorraine. The lists of farmers willing to participate were completed with farmers' organisations' clients due to non-participation of some farmers in official milk recording, leading to a total of 55 participating farms. In ES all registered organic dairy farms were initially phoned by the researchers, the inclusion criteria substantially reducing the number of eligible farms. The surveyed farms comprised approximately 35% of the total official census of organic dairy farms in ES (MAGRAMA, 2014). In SE, an invitation letter was sent to 300 organic dairy farms geographically located within driving distance from Uppsala and within the 'milk-belt', an area with relatively many dairy farms. Fifty-seven of the 150 farms that answered were purposively selected to reflect SE farms in structure and herd size.

3.2.1.2 Data collection and analysis

All farms were visited once between March and August 2013. General characteristics and resources were assessed through a specifically designed on-farm protocol that was administered during the visit. A face-to-face interview was carried out with the owner or a member of the farm staff, depending on who was responsible for animal health, and a sample of the lactating cows was scored for lameness on each farm. Determining the sample size and the scoring were performed according to the guidelines of the Welfare Quality® protocol for dairy cattle. Thereby an animal's gait score is assessed distinguishing three different categories: not lame (timing of steps and weight-bearing equal on all four feet), moderately lame (imperfect temporal rhythm in stride creating a limb) and severely lame (strong reluctance to bear weight on one limb, or more than one limb affected). All six observers had been trained with both live cows and video clips before the visits. Clinical lameness prevalence was calculated by summing up the shares of moderately and severely lame animals.

Secondary data from the national recording systems was retrieved according to the specifics of each country. All countries had access to data from the official milk recording schemes, breeding companies and received data from the animal movement databases. In Spain milk recording data could only be accessed via the Spanish Holstein Association. Therefore, the Spanish sample consisted entirely of farms with pure Holstein cattle or Holstein crosses. Four Spanish farms keeping different breeds were excluded from analysis. The different databases were in most cases separate entities, except in Sweden where all the information is maintained in a common cattle database for herds that participate in the official milk recording scheme. Permissions from the participating farmers and database managers were necessary for data retrieval.

As national recording systems are not harmonized and record keeping is vastly different, as is the amount of information that is recorded, raw data that were available in all participating countries were used, and transformed into a common file structure. Common procedures for calculations were written as scripts in R (r-project.org), and were applied by all countries to arrive at similar data sets with information on herd-level indicators. Indicators were calculated for the time period from January until December 2013, which involved data from before that period as well, e.g. the previous calving date for calculating calving interval. Indicators related to the level of production diseases were allocated to four areas of disorders, i.e. mastitis, lameness, metabolic disorders, and impaired reproduction. Additionally, health related indicators such as replacement rate and mortality were included. Where possible, indicators were expressed at the herd level as percentage of measurements beyond predefined thresholds.

All descriptive statistics and production disease related indicators are reported using the median (m) as measure of central tendency taking into consideration non-homogeneity of variance and non-normal distribution of some data. The interquartile range (IQR) is used as measure of spread. Mood's Median Test was employed to assess group differences in terms of the assessed production disease related indicators. R was used for all calculations, with results considered significant if $p < 0.05$.

3.2.1.3 Indicators

Herd size was calculated as cow-years, i.e. dividing the sum of all days each cow was present during the study period by 365. Days present were based on milk recording information and calving dates. Milk yield was defined as the cumulative milk yield produced by the cows present during the time period of interest divided by number of cow-years. The milk production per cow was estimated using the test interval method described by the International Committee of Animal Recording (ICAR, http://www.icar.org/). For comparative purposes, individual test-day milk yield was converted into energy-corrected milk (ECM) using the formula suggested by Sjaunja et al. (1990).

Udder health indicators were determined based on the concentration of somatic cells (SCC) in composite samples from milk recording. The physiological threshold of 100,000 cells/mL at quarter level (DVG, 2012; Hamann, 2005; IDF, 2013) was applied to composite samples for detection of cows with at least one infected quarter (Ruegg and Pantoja, 2013). Prevalence of subclinical mastitis was defined as the proportion of all test-days, during the time period of interest, with an SCC > 100,000 cells/mL. Samples with a missing SCC or a value < 1,000 cells/mL were excluded from the analysis (cf. Schwarz et al., 2010).

Milk composition was used for indicating metabolic disorders. For each indicator the percentage of test-day observations beyond predefined thresholds was calculated. Fat percentage below 3.0 at test-days, except for the first 30 days in milk, was used to indicate animals at risk of subacute ruminal acidosis (Allen, 1997; Enemark, 2009). A fat/protein ratio above 1.5 at test-days during the first 100 days in milk indicates an imbalanced energy supply with risk of ketosis (Buttchereit et al., 2010; Heuer et al., 1999) and was thus included. Milk protein and milk urea were evaluated simultaneously to determine the equilibrium between energy and protein supply (Kirchgessner et al., 1986). The optimum was defined as 2.5 − 5 mmol/L milk urea (150 − 300 mg/kg) and 3.2 − 3.8 % milk protein (Jeroch et al., 2008). The percentage of test-day results outside the optimum indicating an imbalanced nutrient supply according to the reference levels was calculated for each herd (Härle and Sundrum, 2013). All records with milk urea < 1 mmol/L (< 60 mg/kg) were excluded from analysis due to a high probability of measurement errors.

Prolonged calving interval, as a proxy indicator associated with reproductive disease and poor fertility (Erb et al., 1981; Pryce et al., 2004), was calculated. Percentage of animals with prolonged calving interval was defined as the proportion of all individual calving intervals longer than 400 days (Dubuc et al., 2010; LeBlanc et al., 2002). Calving intervals were calculated for all calvings occurring during the studied time period and restricted to calving intervals ≥ 270 days.

Replacement rate was defined as the number of heifers starting milk production during the study period (primiparous calvings) expressed as percentage of the average herd size. The mean parity of culled cows during the observed time period was used as an indicator for longevity (Knaus, 2009).

On-farm mortality was determined for calves and cows separately. The mortality rate for calves was calculated as the number of calves that died between 1 and 90 days of life using calf-month at risk within the studied time period in the denominator. The total number of days contributed by each animal was divided by 30.4375 (average days/month) to give the number of months at risk. Cow mortality was calculated as the number of cows that died or were euthanized on farm divided by the sum of cow-years. Sold animals were censored at the day of leaving the herd.

3.2.2 Focus groups

Focus groups were organized in the four countries from January to February 2015 to reflect on the status of production diseases and to achieve an orientation on the perceived potential use and usefulness of the selected indicators. Invited were stakeholders along the organic food chain: advisors, veterinarians, dairy farmers, scientists, people working for certification bodies, dairies, food retailers, and farmer organisations. Two persons belonging to each stakeholder category were asked to attend, not as representatives but as experts to give their personal view on the topic. In order to achieve similar discussions in the different countries, a roadmap (available from the first author upon request) was developed, which was followed in all focus groups. In order to minimize potential influences of the research team on the results, an external chairperson acted as facilitator. Each focus group started with a short key note emphasising animal health as one key objective of organic animal husbandry and pointing out the lack of tools to measure if the organic production method leads to a lower level of production diseases. The facilitator prompted the first session asking the participants how they determine whether a farm (or a group of farms) reaches the goal of good animal health. Guided by the facilitator the participants collected indicators. In the second session the status of production diseases in the four countries was presented by the research team, using herd-level indicators similar to the ones presented in this article. Participants were asked to formulate whether they expected the results and whether they found them satisfying, and to comment on the choice of indicators. Next, all participants but the facilitator and the project researchers, were provided with a number of statements on 'How to act in regard to the large variation in health among organic farms?'. They were asked to rate their agreement on a on a five-point Likert scale from 1 ('I do not agree at all') to 5 ('I fully agree') either on a paper response form or by a 'clicker'. After collection, the answers were visualised and discussed with the group. Each focus group closed with a feedback session. For analysis, stakeholder responses were trichotomised into 'disagreement' (1 and 2), 'neutral' (3), and 'agreement' (4 and 5), and summarised across all participant groups. Non-parametric statistics (Kruskal-Wallis test, Mann-Whitney U test) were used to assess differences between countries, with results considered significant if $p < 0.05$.

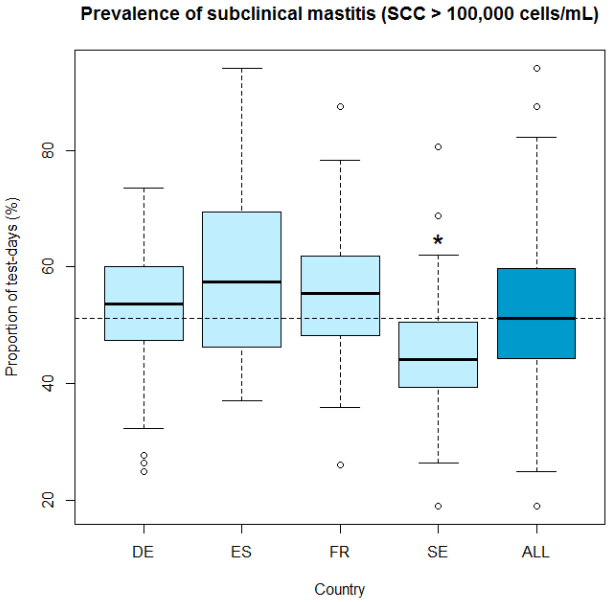
3.3 Results

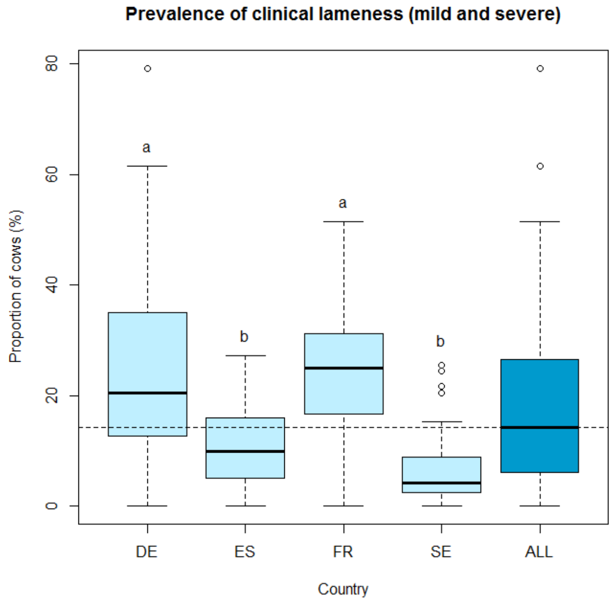
3.3.1 Farm description

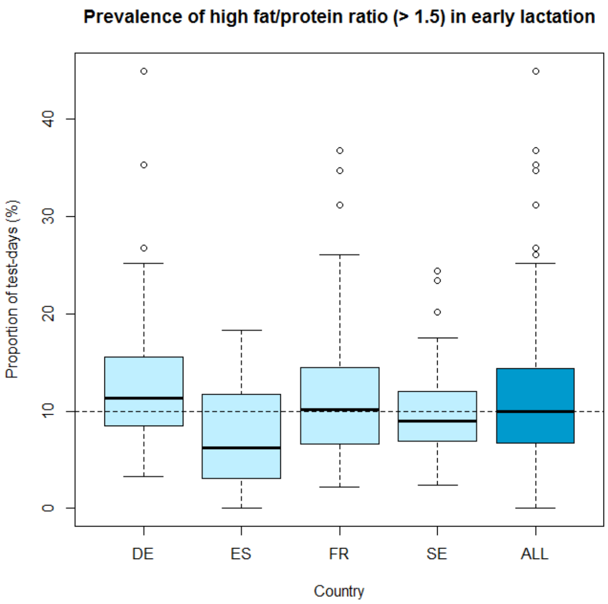
A total of 200 farms were visited. Data from 8 farms were not available from databases or incomplete. Those farms were excluded from analysis resulting in 192 complete datasets, i.e. 60 in DE, 23 in ES, 54 in FR, and 55 in SE. Within the entire group the time since conversion to organic farming ranged from 1 to 29 years with a median (m_{ALL}) of 7. Ninety-seven, 30, 4, and 67 percent of farms in DE, ES, FR, and SE, respectively, were members of an organic farming association. Farms were smallest in ES (m_{ES} 47 ha agricultural area) and largest in SE (m_{SE} 200 ha). In all ES and SE farms the lactating cows had access to pasture during the grazing season, whereas in 23 and 2 percent of farms in DE and FR, respectively, cows did not have the opportunity to graze. Cows were mostly kept in loose housing with cubicles (69.8% of farms). In ES and SE, 13 and 16 percent of farms kept their cows in tie stalls whereas there was no such housing amongst the farms in DE and FR. Thirteen percent of the ES farms had no housing at all and had their cows outside all year round. Automatic milking systems were used by 10 percent of the DE and half of the SE farms, and not at all in FR and ES. Herd size ranged from 7.4 to 376.5 cow-years (m_{DE} 62.8, m_{ES} 29.7, m_{FR} 60.6, m_{SE} 68.1). On animal level, the predominant breeds were Holstein (41%) and Simmental (31%) in DE, Holstein (100% including crosses) in ES, Holstein (53%), Normande (16%) and Montbéliarde (16%) in FR, and Holstein (41%) and Swedish Red and White Cattle (39%) in SE. Milk yield varied between 2,324 and 10,880 kg ECM per cow and year (m_{DE} 6,588 kg, m_{ES} 5,742 kg, m_{FR} 6,378 kg, m_{SE} 8,979 kg). Most concentrate (per cow and year) was fed in SE (m_{SE} 2,373 kg), followed by ES (m_{ES} 1,500 kg), DE (m_{DE} 1,200 kg), and FR (m_{FR} 616 kg). Milk yield and concentrate feeding were highly correlated ($r = 0.65$, $p < 0.001$).

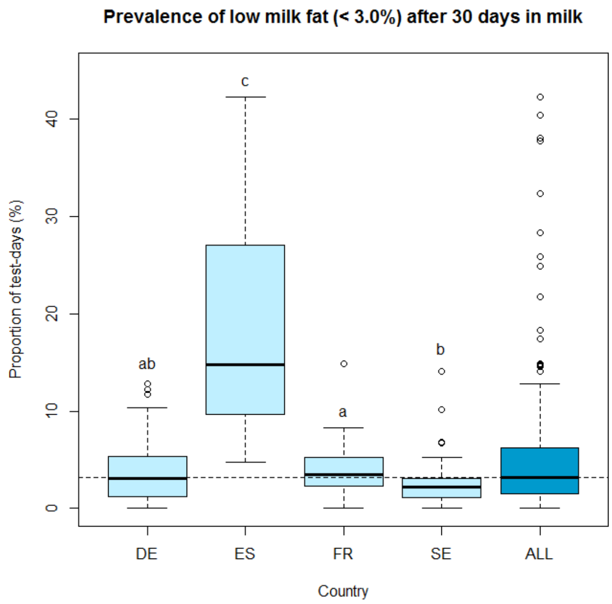
3.3.2 Production diseases

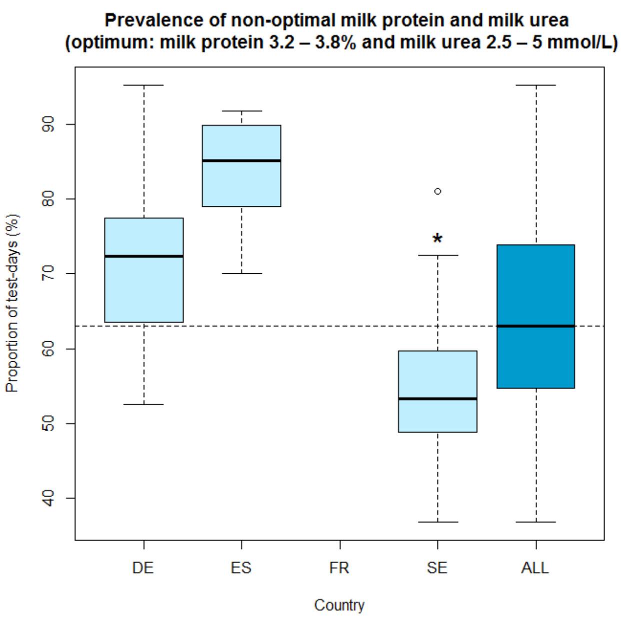
Distributions of production disease related indicators for the four countries and the whole sample are presented in ***Figure 3.1 to 3.10*** (p.27f.). Prevalence was highest for suboptimal protein/energy status and subclinical mastitis (m_{ALL} 62.9% and 51.3%, respectively). Largest variation was found for prolonged calving interval (IQR 20.7) and clinical lameness (IQR 20.4). Milk urea values were available for all farms in DE and SE, and 8 farms in Asturia (ES). Therefore, results on suboptimal nutrient supply exclude the remaining ES farms and all farms in FR. Recording of calf births in the ES animal movement database was substantially incomplete which is why calf mortality was not calculated for ES farms.

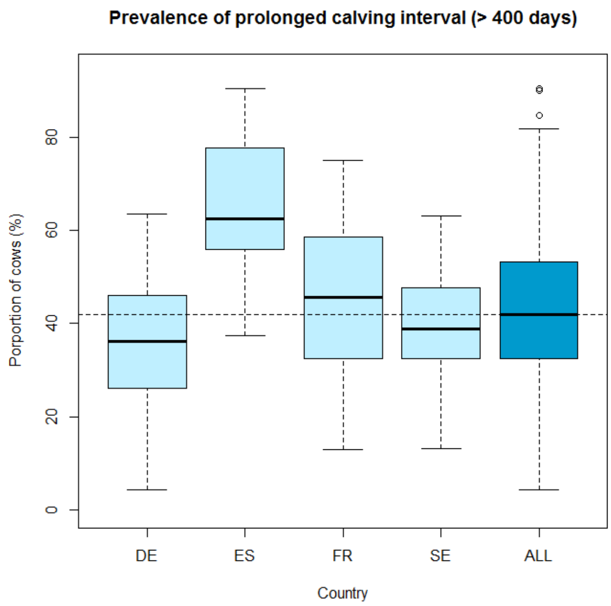

Prevalence of subclinical mastitis (SCC > 100,000 cells/mL)
Proportion of test-days (%)
20
40
60
80
*
DE
ES
FR
SE
ALL
Country


Prevalence of clinical lameness (mild and severe)
Proportion of cows (%)
0
20
40
60
80
a
b
a
b
DE
ES
FR
SE
ALL
Country


Prevalence of high fat/protein ratio (> 1.5) in early lactation
Proportion of test-days (%)
0
10
20
30
40
DE
ES
FR
SE
ALL
Country


Prevalence of low milk fat (< 3.0%) after 30 days in milk
Proportion of test-days (%)
0
10
20
30
40
ab
c
a
b
DE
ES
FR
SE
ALL
Country


Prevalence of non-optimal milk protein and milk urea
(optimum: milk protein 3.2 – 3.8% and milk urea 2.5 – 5 mmol/L)
Proportion of test-days (%)
40
50
60
70
80
90
*
DE
ES
FR
SE
ALL
Country


Prevalence of prolonged calving interval (> 400 days)
Porportion of cows (%)
0
20
40
60
80
DE
ES
FR
SE
ALL
Country

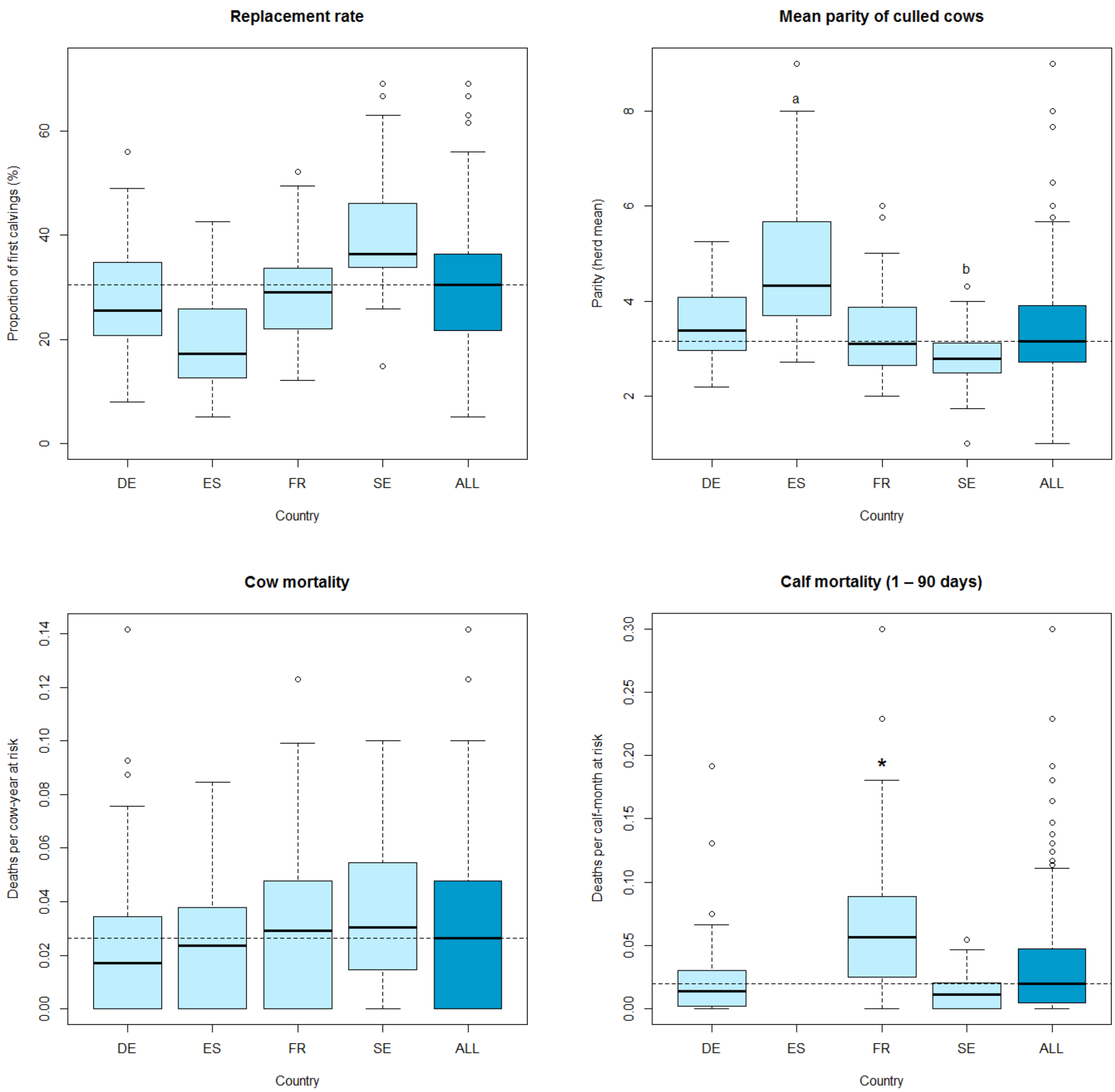


Figure 3.1 to 3.10. *Boxplots showing the prevalences of production diseases and related indicators of study farms in Germany (DE), Spain (ES), France (FR) and Sweden (SE) with the overall distribution (ALL). Median values are represented as thick lines, the lower and upper quartile values as boxes, and the extreme values as whiskers. Outliers are data points outside 1.5 times the interquartile range above the upper quartile and below the lower quartile.*

Mood's Median Test revealed significant differences between countries for the prevalence of subclinical mastitis, clinical lameness, risk of subacute ruminal acidosis, suboptimal nutrient supply, prolonged calving interval, replacement rate, mean parity of culled cows, and calf mortality.

3.3.3 Stakeholder responses

The four focus groups were attended by 9, 11, 10, and 9 stakeholders and 3, 2, 3, and 3 project researchers in DE, ES, FR, and SE, respectively. The German focus group consisted of four advisors specialised in organic dairy farming, one veterinarian (also an organic advisor), one practical claw trimmer, one organic certification inspector, one organic dairy employee (also a farmer) and one researcher from an organic farming institute. In France, one organic dairy farmer (also chairman of the organic committee of a farmer's cooperative), one advisor in organic farming, one advisor from a dairy company, two veterinarians (one working for a technical institute and one for a farmer's organisation) and five researchers (veterinary epidemiology, environmental toxicology, food marketing/consumer perception, and parasitology) participated. In Spain, the attendants were two organic dairy farmers (also retailers), two technicians of the Spanish Milk Recording Scheme, one veterinary advisor specialised in organic farming, five researchers (two veterinarians with experience in organic dairy farming, one biologist dealing with mastitis and milk quality, one environmentalist researching on alternative food systems and one professor in animal production) and one veterinarian of the Agriculture Board of Catalunya. The Swedish group included two farmers (one of which also representing a dairy company), two veterinary advisors, one veterinarian from the Swedish Board of Agriculture, one epidemiologist at an advisory organisation, one representative of an organic certification organisation, one dairy employee, and one veterinarian working for a major food retailer.

When asked what they would look at in order to decide if a farm is meeting the aim of good animal health the focus groups collected a great number of indicators, ranging from very general ('overall appearance of the herd') to quite precise ones ('fat/protein ratio). Three groups of information indicators were identified: a) information available in databases, b) information obtainable from the farm, and c) information requiring on-farm assessment. With respect to evaluating groups of farms the participants in all countries agreed on the necessity of robust indicators based on readily available data. The presented prevalences of production diseases came not as a surprise to stakeholders who stated they expected the figures. Participants expressed the need to improve the farms scoring lowest with regard to animal health, as those pose a threat to the image of the organic label. Responses to the set of statements are presented in ***Table 3.1*** (p.30).

Table 3.1. *Participants' votes on statements presented during focus groups in Germany (DE), Spain (ES), France (FR), and Sweden (SE) dealing with the question 'How to act on the large variation in animal health among organic farms?'.*

Statement	Vote	DE	ES	FR	SE	Total	%
There is no need to do anything about it.	Agree	1	1	1	0	3	8.1
	Neutral	0	1	1	0	2	5.4
	Disagree	8	9	8	7	32	86.5
	N	*9*	*11*	*10*	*7*	*37*	
There should be minimum standards for animal health.	Agree	9	11	9	6	35	92.1
	Neutral	0	0	0	0	0	0.0
	Disagree	0	0	1	2	3	7.9
	N	*9*	*11*	*10*	*8*	*38*	
Organic farms below the standard should be obliged to improve animal health.	Agree	9	6	8	6	29	80.6
	Neutral	0	5	1	0	6	16.7
	Disagree	0	0	1	0	1	2.8
	N	*9*	*11*	*10*	*6*	*36*	
Minimum standards should be based on … **predetermined values**.	Agree	4	5	7	5	21	60.0
	Neutral	4	4	1	1	10	28.6
	Disagree	0	2	2	0	4	11.4
	N	*8*	*11*	*10*	*6*	*35*	
… **the current state.**	Agree	3	8	1	3	15	42.9
	Neutral	1	3	3	1	8	22.9
	Disagree	2	0	6	4	12	34.3
	N	*6*	*11*	*10*	*8*	*35*	
For organic farms with good animal health there should be … **incentives**.	Agree	8	7	7	5	27	77.1
	Neutral	1	2	2	1	6	17.1
	Disagree	0	2	0	0	2	5.7
	N	*9*	*11*	*9*	*6*	*35*	
… **a premium segment** (on top of the organic label).	Agree	6	4	4	4	18	50.0
	Neutral	1	2	4	2	9	25.0
	Disagree	2	4	2	1	9	25.0
	N	*9*	*10*	*10*	*7*	*36*	
For organic farms with poor animal health there should be … **admonishment**.	Agree	9	6	9	6	30	78.9
	Neutral	0	3	1	1	5	13.2
	Disagree	0	2	0	1	3	7.9
	N	*9*	*11*	*10*	*8*	*38*	
… **sanctioning**.	Agree	8	4	2	6	20	52.6
	Neutral	0	3	6	2	11	28.9
	Disagree	1	4	2	0	7	18.4
	N	*9*	*11*	*10*	*8*	*38*	
… **exclusion if no improvement**.	Agree	8	7	9	6	30	83.3
	Neutral	1	3	1	0	5	13.9
	Disagree	0	1	0	0	1	2.8
	N	*9*	*11*	*10*	*6*	*36*	
Organisations should be asked to improve their advisory service.	Agree	8	8	9	5	30	81.1
	Neutral	1	2	1	1	5	13.5
	Disagree	0	1	0	1	2	5.4
	N	*9*	*11*	*10*	*7*	*37*	

There were few significant differences between countries. ES participants were more in favour of minimum standards being based on the current situation than participants in FR (p-value < 0.01). In DE there was significantly more agreement with sanctioning poorly performing farms than in ES and FR (p-values < 0.05). The same accounts for SE compared to FR (p-value < 0.05).

Most of the participants in all countries expressed the need to do something about the large variation between farms, and there was a high agreement that there should be minimum standards in terms of production diseases. The majority of participants agreed that farms below certain levels should be obliged to take action to reduce prevalences of production diseases and advisory organisations should be asked to improve their advisory services targeting such farms. The stakeholders differed on whether thresholds should be based on values that are determined based on knowledge or if they should be based on the current state of production diseases in organic farms. There were mixed opinions with regard to how farms with good or with poor health status should be approached. Incentives were more often preferred over establishing a premium segment for organic production with good animal health. Sanctioning farms with poor animal health was least favoured in most of the countries. The German focus group identified advice obligation for such farms as an additional option to deal with poor animal health. Also mentioned in all countries was that the limited access to data acted as a major constraint in monitoring animal health and comparing farms at herd level in a continuous process.

3.4 Discussion

The first aim of this study was to assess the current prevalence of production diseases in European organic dairy farms. A major achievement of this present study was to provide harmonized methods to calculate a comprehensive set of suitable indicators, which means that they can, for the first time, be compared across countries. By accessing monthly milk recordings, breeding records, and animal identification and registration databases, extensive data from all cows of all herds could be retrieved for analysis. It was thus taken advantage of information that is already available sparing the need to establish new and costly procedures. However, data structures are very variable between countries and most data are not freely available to use for all actors that work with animal health in the field because of ownership constraints. There may therefore be a need for actions to ensure access to harmonized and relevant data to those authorised to have access, e.g. by farmers or by law. All study farms were members of milk recording schemes (an inclusion criterion), but this is not the case for all organic dairy farms. Monitoring of the prevalence of production diseases on farms not enrolled in such schemes may therefore be much more difficult.

Prevalences of production diseases varied immensely between farms. This fact is clearly depicted in the boxplots. High variations between European organic dairy farms in terms of metabolic disorders have also been reported by Ivemeyer et al. (2012), who found a mean prevalence ± standard deviation of 22.3 ± 13.3% for low fat/protein ratio and of 9.5 ± 7.9% for high fat/protein ratio across countries. In agreement with our study they also identified significant differences between countries in terms of subclinical mastitis, subacute ruminal acidosis and calving interval, and none for risk of ketosis, although different countries were studied and sample sizes were relatively low. Prevalences of high fat/protein ratio in our research were lower than those found in a German study on 19 organic dairy farms where the mean prevalence ranged from 10.6 to 21.6 (March et al., 2014). Similar distributions of lameness prevalence as the ones found in this study have been reported for DE where Dippel et al. (2009) found a mean prevalence of 24% (range 2–50%) in organic farms, for ES where Pérez-Cabal and Alenda (2014) identified an average of 13.8% of non-organic Holstein cows suffering from lameness, and for conventional farms in SE where according to Manske et al. (2002) lameness prevalence was 3.7% (median; range 0–33%). Few studies have investigated the prevalence of subclinical mastitis using individual test day records (Dufour et al., 2011). In conventional Danish herds, Dam Rasmussen et al. (2001) found an SCC > 200,000 cells/mL in 34.5% of cows before introduction of automatic milking. A slightly lower prevalence of 31.5% was reported for conventional freestall herds in Wisconsin, USA (Rodrigues et al., 2005). Both studies used a higher threshold than the one used in the current study and did not specify distributions so a direct comparison cannot be made. Even lower values were reported by Madouasse et al. (2010b), who found 25% of SCC records above 200,000 cells/mL and 45% above 100,000 cells/mL in 2,128 UK dairy herds enrolled in National Milk Recording. Härle and Sundrum (2013) also considered different SCC classes. In their study of 83 conventional dairy herds in Bavaria 39.8% of cows had an SCC > 100,000 cells/mL showing a large variation between farms (10–90%) which matches the variation found in our study. The same study identified an average of 61.4% of cows whose nutritional needs (protein and energy) were not met (Härle and Sundrum, 2013), a figure close to the overall median in this study of 63%. However, they published no information on the variation between herds. In our study, Mood’s Median Test revealed significant differences between countries for most of the investigated indicators. Some of them may be related to country-specific strategies in terms of available resources and management, or to the distribution of breeds (e.g. ES data being limited to Holstein cattle). Swedish farms, in comparison with the other countries, were characterised by low levels of subclinical mastitis and lameness which may be connected to the comprehensive information provided by the national cattle database to farmers and advisors for decades (Emanuelson, 1988) or the multi-trait selection of Swedish breeds (Oltenacu and Broom, 2010). However, identifying causal relationships with respect to the between-country variation is not within the scope of this paper. Moreover, it cannot be ruled out that some of the observed between-country differences may also be related to data recording. In terms of lameness there may have occurred inter-rater disagreement despite the joint training. With respect to calf mortality, some of the variation between FR and DE may be due to a different handling of stillbirths, since in France registration is mandatory (Raboisson et al., 2013) whereas in Germany it is not (Pannwitz, 2015).

The choice of indicators in this report was made based on scientific knowledge as far as possible and was limited by data availability. Although the informational value of the used milk parameters has been confirmed in previous studies (Bramley et al., 2008; Heuer et al., 2000; Kirchgessner et al., 1986; Laevens et al., 1997), some of them are also being discussed controversially, e.g. SCC thresholds for the detection of subclinical mastitis (Ruegg and Pantoja, 2013) and fat/protein ratio as a measure of energy balance (Madouasse et al., 2010a). Therefore, the prevalences that are provided cannot be considered as perfect measures of production diseases but are merely useful proxies. Most indicators were expressed as herd percentages so they describe the proportion animals in a herd deviating from a predetermined reference range and whose capability to adapt to conditions in the farm system is overstressed (Sundrum, 2012). The lack of information on locomotion disorders was compensated by lameness scoring performed on all farms by the project scientists. Without this extra effort the information would not have been available although this disease complex is of high relevance. A database with recorded observations done at routine claw trimming, as implemented in e.g. Sweden (Nielsen et al., 2013), could be a basis for such monitoring if established in other countries as well. Also, other national data, for instance on treatments of clinical health disorders, may be available that would be better suited to provide an orientation of the animal health status with respect to some production diseases, e.g. reproductive disorders. However, such data may suffer from differences in definitions and in treatment thresholds that may make them less useful for between farm and across-country comparisons, although harmonization efforts, for instance through ICAR, are ongoing (ICAR, 2013).

The second aim of this study was to explore potential drivers for improvement with stakeholders. Naturally, the focus groups were limited in size and time, and cannot be expected to give a complete picture of the very complex area of animal health in organic dairy production. In order to keep them manageable the topic of animal health was narrowed down to a discussion on production diseases and followed a common roadmap. The participants were nominated and agreed to participate based on availability, so they cannot be viewed as representative of all areas of the organic sector. In all countries advisors, veterinarians, and farmers took part whereas scientists, certification bodies, dairies, food retailers, and farmer organisations were not present in all countries. Some persons also participated in dual roles, e.g. advisors belonging to farmers' associations. Whereas in Germany the largest stakeholder group consisted of agricultural advisors, veterinarians represented the largest group in Sweden. Scientists dominated the focus groups in both France and Spain. Although efforts were taken to harmonize the process followed by the workshops there may have been differences between the countries. Thus, the outcomes merely provide an orientation about the variability in viewpoints across the different stakeholder groups and across countries.

In all countries, stakeholders attending the focus groups anticipated the results on prevalence of production diseases. However, the majority of participants also expressed dissatisfaction with the situation and declared a need for change. The necessity to improve animal health was mainly seen for the proportion of farms not complying with good animal health, whereby the understanding of health may have varied largely between persons (Sundrum, 2012; Vaarst and Alrøe, 2011). This assessment is understandable in the context, that animal welfare as targeted by organic agriculture can only be achieved if the prevalence of disease is below a certain level (Borell and Sørensen, 2004; Cockram and Hughes, 2011). The vast majority of participants agreed that there should be a reference range for production diseases in organic dairy farming and that farms below this range should be obliged to improve. Up to now there are few outcome-oriented health standards for organic animal husbandry in Europe, although some actors of the organic sector have demanded them for a long time (Sundrum, 2001). Organic farming is based on values, and regulations and standards therefore need to develop in accordance with values in order better to approach the aims (Michelsen, 2001). The results of this study may help to stimulate this debate.

Standards or target values can be defined by taking into account relevant literature and expert opinions as done in Germany (Brinkmann and March, 2015; Brinkmann et al., 2014). When asked to position themselves, the great majority of participants agreed with using pre-determined values for defining health standards in organic dairy farming. Expressed concerns were that absolute threshold values could wrongly be used as normative values for good animal health and thus not lead to continuous improvement. An alternative way of establishing standards is via benchmarking, where the performance of a sample group serves as measure for evaluating the individual. Werner et al. (2008), for instance, developed health targets for organic pig production based on the performance of the top quartile of a group of farms. The advantage of standards that are based on the current state (benchmarks) is that they take into account the present situation and meet farms where they stand. They point out what others are able to achieve under similar conditions and are dynamic, meaning they change whenever the group performance changes. This can be used to continuously improve a group towards a common goal: If the weakest farms improve the benchmark subsequently increases creating new targets. Relative values, however, can be interpreted as good animal health even though they are 'poor' on an absolute scale, depending on the prevalence of production diseases in the population. In that case benchmarks remain at an inacceptable level leading to low targets. High benchmarks, in contrast, may demand higher standards although the current levels are already satisfactory. Both implications could be reasons why only two thirds of the stakeholders could imagine using the current state for defining health standards.

Comparable indicators can be used to describe the variation between farms and to distinguish between farms with socially acceptable (good) and unacceptable (poor) animal health. In legislative regulations, minimum standards mark the threshold between poor and acceptable. On top of that, premium standards may differentiate between good and very good. The great majority of stakeholders in the focus groups supported the concept of incentives for farms with good animal health, although 'good' was not defined. It can mean that the majority supports extra payment for meeting minimum standards but it could also mean that rewards should be offered to those performing better than acceptable. Brinkmann et al. (2015) suggest an incentive scheme where subsidies are paid only to the top quartile of farms with respect to welfare indicators. Two thirds of the participants in our study agreed with establishing a premium segment on top of the organic label, but the agreement varied between stakeholders in different segments of the organic food chain. Asking consumers to pay more for good animal health, however, may be problematic as they already expect the delivery of this added value when buying 'normal' organic products (Harper and Makatouni, 2002; McEachern and Willock, 2004).

Besides dealing with good farms, in terms of production diseases, stakeholders were asked how to proceed with poor farms. The large majority of participants agreed with admonishment of farms dropping below the minimum threshold. They were much more hesitant, however, in accepting financial sanctions. This reluctance probably has various motives: the already tight financial situation dairy farms are facing and the uncertainty of who would be in charge of sanctioning and how it would be managed. Penalties are likely to be regarded as means that become necessary when other (preferable) mechanisms have failed. They force action rather than promoting it and restrict the freedom of commerce. Exclusion from the organic label of farms that do not improve (albeit admonishment, sanctions etc.) was widely supported. The German focus group identified advice obligation as an additional option to deal with farms not meeting the set targets. This is consistent with actions taken by the Swedish organic certification organisation (KRAV) that requires farmers with poor status in the 'Signals of Animal Welfare' (*Signaler Djurvälfärd)* to take additional actions in the form of a local variant of CowSignals® which captures health and welfare problems and provides advice on how to alleviate them. It also accounts for the important role of communication and the aim of motivating farmers to look after the welfare of the animals in their care (Anneberg et al., 2014).

3.5 Conclusion

The results of this study imply that by evaluating the prevalence of production diseases in relation to a frame of reference farms at risk of not meeting the organic target of good animal health can be successfully identified. Whereas there may be general agreement to the idea of reference values within the organic sector, divergent views seem to exist between stakeholders and between countries on how to arrive at such values and how they should be used. Access to data and harmonised calculations are prerequisites for establishing the current status and must be guaranteed if the idea of benchmarking farms across Europe is to be pursued. Future research should focus on ways to improve the quality and availability of data, increasing the choice of suitable indicators, and on strategies for using that information most effectively to improve the current situation. Opportunities and risks of different strategies must be elaborated and concerns of stakeholders must be considered.

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3.7 References

Allen, M.S., 1997. Relationship Between Fermentation Acid Production in the Rumen and the Requirement for Physically Effective Fiber. Journal of dairy science 80 (7), 1447–1462.

Anneberg, I., Vaarst, M., Sandøe, P., 2014. To inspect, to motivate or to do both: a dilemma for on-farm inspection of animal welfare, in: Mounier, L., Veissier, I. (Eds.), Proceedings of the 6th International Conference on the Assessment of Animal Welfare at Farm and Group Level, 3-5 September, Clermont-Ferrand, France, p. 73.

Arcuri, A., 2015. The Transformation of organic regulation: The ambiguous effects of publicization. Regulation & Governance 9 (2), 144–159.

Best, H., 2008. Organic agriculture and the conventionalization hypothesis: A case study from West Germany. Agriculture and Human Values 25 (1), 95–106.

Blanco-Penedo, I., Fall, N., Emanuelson, U., 2012. Effects of turning to 100% organic feed on metabolic status of Swedish organic dairy cows. Livestock Science 143 (2-3), 242–248.

Borell, E. von, Sørensen, J.T., 2004. Organic livestock production in Europe: Aims, rules and trends with special emphasis on animal health and welfare. Livestock Production Science 90 (1), 3–9.

Bramley, E., Lean, I.J., Fulkerson, W.J., Stevenson, M.A., Rabiee, A.R., Costa, N.D., 2008. The Definition of Acidosis in Dairy Herds Predominantly Fed on Pasture and Concentrates1. Journal of dairy science 91 (1), 308–321.

Brinkmann, J., March, S., 2015. Tiergesundheit [Animal health], in: KTBL (Ed.), Faustzahlen für den Ökologischen Landbau [Reference values for organic farming], Darmstadt, pp. 472–477.

Brinkmann, J., March, S., Renziehausen, C., Bergschmidt, A., 2014. Indicators for a result-oriented approach for animal welfare policies and organic farming, in: Mounier, L., Veissier, I. (Eds.), Proceedings of the 6th International Conference on the Assessment of Animal Welfare at Farm and Group Level, 3-5 September, Clermont-Ferrand, France, p. 88.

Brinkmann, J., March, S., Wagner, K., Renziehausen, C., Starosta, S., Osterbuhr, M., Bergschmidt, A., 2015. Indikatoren für eine ergebnisorientierte Honorierung von Tierschutzleistungen in der Milchviehhaltung, in: Häring A.M., Hörning B., Hoffmann-Bahnsen R., Luley H., Luthardt V., Pape J., Trei G. (Ed.), Am Mut hängt der Erfolg - Rückblicke und Ausblicke auf die ökologische Landbewirtschaftung. Beiträge zur 13. Wissenschaftstagung Ökologischer Landbau, Eberswalde, 17. - 20. März 2015. Verlag Dr. Köster, Berlin, pp. 451–454.

Buttchereit, N., Stamer, E., Junge, W., Thaller, G., 2010. Evaluation of five lactation curve models fitted for fat:protein ratio of milk and daily energy balance. Journal of dairy science 93 (4), 1702–1712.

Cockram, M.S., Hughes, B.O., 2011. Health and disease, in: Appleby, M.C., Mench, J.A., Olsson, I. A. S., Hughes, B.O. (Eds.), Animal welfare, 2nd ed., Wallingford, Oxfordshire, UK, Cambridge, MA, pp. 120–137.

Dam Rasmussen, M., Yde Blom, J., Arne Hjort Nielsen, L., Justesen, P., 2001. Udder health of cows milked automatically. Livestock Production Science 72 (1-2), 147–156.

Dippel, S., Dolezal, M., Brenninkmeyer, C., Brinkmann, J., March, S., Knierim, U., Winckler, C., 2009. Risk factors for lameness in freestall-housed dairy cows across two breeds, farming systems, and countries. Journal of dairy science 92 (11), 5476–5486.

Dubuc, J., Duffield, T.F., Leslie, K.E., Walton, J.S., LeBlanc, S.J., 2010. Definitions and diagnosis of postpartum endometritis in dairy cows. Journal of dairy science 93 (11), 5225–5233.

Dufour, S., Fréchette, A., Barkema, H.W., Mussell, A., Scholl, D.T., 2011. Invited review: effect of udder health management practices on herd somatic cell count. Journal of dairy science 94 (2), 563–579.

DVG, 2012. Leitlinien: Bekämpfung der Mastitis des Rindes als Bestandsproblem, 5th ed. DVG Service, Gießen, Germany, 226 S.

EC, 2007. Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91.

EC, 2015. European Commission - EU Milk Margin Estimate up to 2014: An overview of estimates of costs of production and gross margins of milk production in the EU. EU Agricultural and Farm Economics Briefs 7.

Emanuelson, U., 1988. The national Swedish animal disease recording system. Acta Vet. Scand. Suppl 84, 262–264.

Enemark, J.M.D., 2009. The monitoring, prevention and treatment of sub-acute ruminal acidosis (SARA): a review. The Veterinary Journal 176, 32–43.

Erb, H.N., Martin, S.W., Ison, N., Swaminathan, S., 1981. Interrelationships Between Production and Reproductive Diseases in Holstein Cows. Conditional Relationships Between Production and Disease. Journal of dairy science 64 (2), 272–281.

Fall, N., Emanuelson, U., 2009. Milk yield, udder health and reproductive performance in Swedish organic and conventional dairy herds. The Journal of dairy research 76 (4), 402–410.

Flaten, O., Lien, G., Ebbesvik, M., Koesling, M., Valle, P.S., 2006. Do the new organic producers differ from the 'old guard'? Empirical results from Norwegian dairy farming. RAF 21 (03), 174–182. 10.1079/RAF2005140.

Garmo, R.T., Waage, S., Sviland, S., Henriksen, B. I. F., Østerås, O., Reksen, O., 2010. Reproductive performance, udder health, and antibiotic resistance in mastitis bacteria isolated from Norwegian Red cows in conventional and organic farming. Acta veterinaria Scandinavica 52, 11. 10.1186/1751-0147-52-11.

Hamann, J., 2005. Diagnosis of mastitis and indicators of milk quality, in: Hogeveen, H. (Ed.), Mastitis in dairy production: Current knowledge and future solutions. Wageningen Academic Publishers, The Netherlands, pp. 82–90.

Härle, C., Sundrum, A., 2013. Animal health on the farm level 2. Communication: Nutrient supply on Bavarian Dairy Farms. Zuechtungskunde 85 (5), 396–412.

Harper, G.C., Makatouni, A., 2002. Consumer perception of organic food production and farm animal welfare. British Food Journal 104 (3/4/5), 287–299.

Heuer, C., Schukken, Y.H., Dobbelaar, P., 1999. Postpartum Body Condition Score and Results from the First Test Day Milk as Predictors of Disease, Fertility, Yield, and Culling in Commercial Dairy Herds. Journal of dairy science 82 (2), 295–304.

Heuer, C., Straalen, W.M. van, Schukken, Y.H., Dirkzwager, A., Noordhuizen, J.P.T.M., 2000. Prediction of energy balance in a high yielding dairy herd in early lactation: model development and precision. Livestock Production Science 65 (1–2), 91–105.

ICAR, 2013. Health Data Conference on “Challenges and benefits of health data recording in the context of food chain quality, management and breeding”, Aarhus, Denmark, 30-31 May.

IDF, 2013. Guidelines for the use and interpretation of bovine milk somatic cell counts (SCC) in the dairy industry, 14 pp.

IFOAM, 2006. The IFOAM Basic Standards for Organic Production and Processing: International Federation of Organic Agriculture Movements, Germany.

Ivemeyer, S., Smolders, G., Brinkmann, J., Gratzer, E., Hansen, B., Henriksen, B.I.F., Huber, J., Leeb, C., March, S., Mejdell, C., 2012. Impact of animal health and welfare planning on medicine use, herd health and production in European organic dairy farms. Livestock Science 145 (1), 63–72.

Jeroch, H., Drochner, W., Simon, O., Dänicke, S., 2008. Ernährung landwirtschaftlicher Nutztiere, 2nd ed. Ulmer, Stuttgart.

Kiefer, L., Menzel, F., Bahrs, E., 2014. The effect of feed demand on greenhouse gas emissions and farm profitability for organic and conventional dairy farms. Journal of dairy science 97 (12), 7564–7574.

Kirchgessner, M., Kreuzer, M., Roth-Maier, D.A., 1986. Milk Urea and Protein Content to Diagnose Energy and Protein Malnutrition of Dairy Cows. Archiv fuer Tierernaehrung 36 (2-3), 192–197.

Knaus, W., 2009. Dairy cows trapped between performance demands and adaptability. Journal of the Science of Food and Agriculture 89 (7), 1107–1114.

Laevens, H., Deluyker, H., Schukken, Y.H., Meulemeester, L. de, Vandermeersch, R., Muêlenaere, E. de, Kruif, A. de, 1997. Influence of Parity and Stage of Lactation on the Somatic Cell Count in Bacteriologically Negative Dairy Cows. Journal of dairy science 80 (12), 3219–3226.

LeBlanc, S.J., Duffield, T.F., Leslie, K.E., Bateman, K.G., Keefe, G.P., Walton, J.S., Johnson, W.H., 2002. Defining and Diagnosing Postpartum Clinical Endometritis and its Impact on Reproductive Performance in Dairy Cows. Journal of dairy science 85 (9), 2223–2236.

Madouasse, A., Huxley, J.N., Browne, W.J., Bradley, A.J., Dryden, I.L., Green, M.J., 2010a. Use of individual cow milk recording data at the start of lactation to predict the calving to conception interval. Journal of dairy science 93 (10), 4677–4690.

Madouasse, A., Huxley, J.N., Browne, W.J., Bradley, A.J., Green, M.J., 2010b. Somatic cell count dynamics in a large sample of dairy herds in England and Wales. Preventive Veterinary Medicine 96 (1-2), 56–64.

MAGRAMA, 2014. Agricultura Ecológica. Estadísticas 2013: Ministerio de Agricultura, Alimentación y Medio Ambiente, Madrid.

Manske, T., Hultgren, J., Bergsten, C., 2002. Prevalence and interrelationships of hoof lesions and lameness in Swedish dairy cows. Preventive Veterinary Medicine 54 (3), 247–263.

March, S., Brinkmann, J., Winckler, C., 2014. Improvement of animal health in organic dairy farms through 'stable schools': selected results of a pilot study in Germany. Organic Agriculture 4 (4), 319–323.

McEachern, M.G., Willock, J., 2004. Producers and consumers of organic meat. British Food Journal 106 (7), 534–552.

Michelsen, J., 2001. Organic Farming in a Regulatory Perspective. The Danish Case. Sociologia Ruralis 41 (1), 62–84.

Müller, U., Sauerwein, H., 2010. A comparison of somatic cell count between organic and conventional dairy cow herds in West Germany stressing dry period related changes. Livestock Science 127 (1), 30–37.

Nielsen, C., Stengärde, L., Bergsten, C., Emanuelson, U., 2013. Relationship between herd-level incidence rate of energy-related postpartum diseases, general risk factors and claw lesions in individual dairy cows recorded at maintenance claw trimming. Acta Veterinaria Scandinavica 55 (1), 55.

Oltenacu, P.A., Broom, D.M., 2010. The impact of genetic selection for increased milk yield on the welfare of dairy cows. Animal welfare 19 (1), 39–49.

Padel, S., Röcklinsberg, H., Schmid, O., 2009. The implementation of organic principles and values in the European Regulation for organic food. Food Policy 34 (3), 245–251.

Pannwitz, G., 2015. Standardized analysis of German cattle mortality using national register data. Preventive Veterinary Medicine 118 (4), 260–270.

Patel, M., Wredle, E., Spörndly, E., Bertilsson, J., Kumm, K.-I., 2013. Profitability of organic and conventional dairy production with different dietary proportions of high-quality grass silage. Organic Agriculture 3 (1), 31–39.

Pérez-Cabal, M.A., Alenda, R., 2014. Clinical lameness and risk factors in a Spanish Holstein population. Livestock Science 164, 168–174.

Pryce, J.E., Royal, M.D., Garnsworthy, P.C., Mao, I.L., 2004. Fertility in the high-producing dairy cow. Livestock Production Science 86, 125–135.

Raboisson, D., Delor, F., Cahuzac, E., Gendre, C., Sans, P., Allaire, G., 2013. Perinatal, neonatal, and rearing period mortality of dairy calves and replacement heifers in France. Journal of dairy science 96 (5), 2913–2924.

Rodrigues, A., Caraviello, D.Z., Ruegg, P.L., 2005. Management of Wisconsin Dairy Herds Enrolled in Milk Quality Teams. Journal of dairy science 88 (7), 2660–2671.

Ruegg, P.L., Pantoja, J.C.F., 2013. Understanding and using somatic cell counts to improve milk quality. Irish Journal of Agricultural and Food Research 52 (2), 101–117.

Rutherford, K.M.D., Langford, F.M., Jack, M.C., Lawrence, A.B., Sherwood, L., Haskell, M.J., 2009. Lameness prevalence and risk factors in organic and non-organic dairy herds in the United Kingdom. Veterinary journal (London, England : 1997) 180 (1), 95–105.

Schwarz, D., Diesterbeck, U.S., Failing, K., König, S., Brügemann, K., Zschöck, M., Wolter, W., Czerny, C.-P., 2010. Somatic cell counts and bacteriological status in quarter foremilk samples of cows in Hesse, Germany - A longitudinal study. Journal of dairy science 93 (12), 5716–5728.

Sjaunja, L.O., Baevre, L., Junkkarinen, L., Pedersen, J., Setälä, J., 1990. A Nordic proposal for an energy corrected milk (ECM) formula. 27th session of the International Commission for Breeding and Productivity of Milk Animals, Paris, France, 156–157.

Sundberg, T., Berglund, B., Rydhmer, L., Strandberg, E., 2009. Fertility, somatic cell count and milk production in Swedish organic and conventional dairy herds. Livestock Science 126 (1-3), 176–182.

Sundrum, A., 2001. Organic livestock farming: A critical review. Livestock Production Science 67 (3), 207–215.

Sundrum, A., 2012. "Healthy food" from healthy cows, in: Konvalina, P. (Ed.), Organic Farming and Food Production. InTech Book, Rijeka, pp. 95–120.

Sundrum, A., 2014. Organic Livestock Production, in: Alfen, N. K. van (Ed.), Encyclopedia of Agriculture and Food Systems. Academic Press, Oxford, pp. 287–303.

Thamsborg, S.M., Roderick, S., Sundrum, A., 2004. Animal health and diseases in organic farming: an overview, in: Vaarst, M., Roderick, S., Lund, V., Lockeretz, W. (Eds.), Animal health and welfare in organic agriculture. CABI, Wallingford, pp. 227–252.

Vaarst, M., Alrøe, H.F., 2011. Concepts of Animal Health and Welfare in Organic Livestock Systems. Journal of Agricultural and Environmental Ethics 25 (3), 333–347.

Welfare Quality®, 2009. Welfare Quality® assessment protocol for cattle. Welfare Quality® Consortium, Lelystad, Netherlands.

Werner, C., Löser, R., Kempkens, K., Sundrum, A., 2008. Leitlinien zur Sicherung der Tiergesundheit in der ökologischen Schweineerzeugung [Guidelines to secure animal health in organic pig production]. Landbauforschung Völkenrode Sonderheft 320, 99–108.

Willer, H., Schaack, D., Schlatter, B., Lernoud, J., 2014. Europe: Current Statistics, in: Willer, H., Lernoud, J. (Eds.), The World of Organic Agriculture. Statistics and Emerging Trends 2014. FiBL-IFOAM Report, 24th ed. Research Institute of Organic Agriculture (FiBL), Frick, and International Federation of Organic Agriculture Movements (IFOAM), Bonn, pp. 200–207.

Winckler, C., Brinkmann, J., 2004. Animal health in organic dairy farming – results from a survey in Germany, in: Hovi, M., Sundrum, Albert und Padel, Susanne (Eds.), Organic livestock farming: potential and limitations of husbandry practice to secure animal health and welfare and food quality. Proceedings of the 2nd SAFO Workshop, 25-27 March 2004, Witzenhausen, Germany, pp. 43–47.

4 Capturing systemic interrelationships by an impact analysis to improve animal health in dairy farms

Margret Krieger[1,*], Susanne Hoischen-Taubner[1], Ulf Emanuelson[2], Isabel Blanco-Penedo[3], Manon de Joybert[4], Julie E. Duval[4], Karin Sjöström[2], Albert Sundrum[1]

* Corresponding author. E-mail address: margret.krieger@uni-kassel.de (M. Krieger)
[1] University of Kassel, Department of Animal Nutrition and Animal Health, Nordbahnhofstrasse 1a, D-37213 Witzenhausen, Germany
[2] Swedish University of Agricultural Sciences, Department of Clinical Sciences, SE-750 07 Uppsala, Sweden
[3] IRTA, Animal Welfare Subprogram, ES-17121 Monells, Girona, Spain
[4] BIOEPAR, INRA, Oniris, 44307, Nantes, France

Abstract

Production diseases such as metabolic and reproductive disorders, mastitis, and lameness, emerge from complex interactions between numerous risk factors and can be controlled by the right management decisions. Since animal husbandry systems in practice are very diverse, it is difficult to identify the most influential components in the individual farm context. This, however, is necessary to prevent disease, since farmers are severely limited in their access to resources, and need to invest in management measures most likely to have an effect.

In this study, systemic impact analyses were conducted in European organic dairy farms in the context of reducing the prevalence of production diseases. The overall objective was to evaluate the systemic interrelationships between farm factors and determine the systemic roles of variables. In particular, the aim was to identify the most influential variables in each farm. A stepwise procedure was developed and implemented: (i) in a participatory process 13 relevant system variables affecting the emergence of production diseases in organic dairy farms were defined, (ii) interrelationships between those variables were evaluated on 192 organic dairy farms in France, Germany, Spain, and Sweden by means of an impact matrix, involving the perspectives of farmer, advisor and veterinarian, and (iii) the results were used to identify general system behaviour and the systemic roles of variables to support decision-making.

Variables were classified by their level of influence on other system variables and their susceptibility to influence. An overall active tendency was found for feeding, housing conditions, herd health monitoring, and knowledge and skills. Active variables exercise a lot

of influence on other system variables without being much affected by them. Milk performance and financial resources tended to be reactive, i.e. strongly influenced by other system variables while not being very influential. Production diseases and labour capacity had a tendency for being critical, having a large impact as well as being strongly impacted themselves. Reproduction management, dry cow management, calf and heifer management, hygiene and treatment tended to have a buffering capacity, which means they were comparatively less influential and less influenced than other variables. Besides these general tendencies, the specific role of variables within each system varied widely between farms. The capacity of the tested approach is the ability to point out the deviation from general expectations, which becomes explicit by filling the matrix and discussing the output, specifically to the advisor and veterinarian, thereby supporting a farm specific selection of strategies and measures.

Keywords: organic farming; complexity; participatory approach; decision support; impact matrix

"Every good regulator of a system must be a model of that system."
(Conant and Ashby, 1970)

4.1 Introduction

Multifactorial diseases, such as metabolic and reproductive disorders, mastitis, and lameness, by causing economic losses and impairing the health and welfare of animals, represent serious problems in both conventional and organic dairy farming (Thamsborg et al., 2004). They have in common that all of them arise from complex interactions between large numbers of risk factors, where each, in itself, would not necessarily lead to disease. Risk factors for the emergence of these diseases are mainly related to deficits in the farm management preventing animals from being able to cope with the given living conditions. This is why they are called production diseases (Nir, 2003). It means they are caused or promoted by the farm management but can, in turn, also be controlled by the right management decisions. The presence of (production) disease is thus an emergent property of the farm that arises from the functioning of the component parts of the system (Sundrum, 2012). Animal husbandry systems in practice are so diverse, that it is difficult to identify the most influential component in the individual farm context. This, however, is necessary to prevent disease, since farmers are severely limited in their access to resources, and need to invest in management measures most likely to have a large effect (Sundrum, 2014).

In agriculture, the common attempt to solve problems has been to tackle the various issues individually as they arise and do so in a reductionist way (Bawden, 1991; Darnhofer et al., 2010). Even though this still is the predominant approach in agricultural science, it has been shown that many of the problems agriculture faces are essentially systemic in nature (Bawden, 1997). They are linked to each other and to the performance of the system as a whole and getting rid of one problem might have the effect of creating other problems instead. In the 1970s, there was recognition that it is not sufficient to optimise individual crops or animal production systems but that the farm needs to be understood as a whole (Bawden, 1995; Norman, 2002). A large number of (farming) systems approaches emerged based on the idea that it is necessary to identify and describe the system one wishes to understand in order to improve it (Sands, 1986; Spedding, 1979). They have in common that a system is defined as group of interacting components, operating together for a common purpose and capable of reacting as a whole to external stimuli (Bawden, 1995).

Knowledge on the functional relationships is the basis for understanding the behaviour and attributes of systems and is necessary to achieve significant achievements in the performance of systems (Conway, 1985). In order to assess and analyse the interrelationships at work in systems, Vester and Hesler (1980) developed the Sensitivity Model, a method which uses cybernetic principles for system analysis and which is based on fuzzy logic (Zadeh, 1997), i.e. it uses imprecise knowledge of real experience. Within their ‘network thinking method’, representation of reality is achieved by correctly selecting the system components, understanding how they inter-relate and joining up the pattern in an ‘impact matrix’. Impact matrices were initially developed and used for forecasting purposes (Godet, 1979; Gordon and Hayward, 1968) and have since been applied in a diversity of research contexts, e.g. identification of sustainability values (Cole et al., 2007), optimisation of management processes (Fried, 2010; Gausemeier, 1998; Schianetz and Kavanagh, 2008), cost benefit analysis (Wenzel and Igenbergs, 2001); improvement of slash and burn cultivation systems (Messerli, 2000), management of ecological reserves (Iron Curtain Consortium, 2004) and city regions (Wiek and Binder, 2005) as well as transport (OECD Environment Directorate, 2000), traffic (Vester, 2007), and settlement planning (Coplak and Raksanyi, 2003). Hoischen-Taubner and Sundrum (2012) were the first to use an impact matrix in the context of improving animal health in organic pig farms.

With issues such as impacts on landscape and ecosystems, pollution, health risks, and animal welfare, livestock farming is hard-pressed to change in order to meet societal demands

(Gibon et al., 1999). Organic farming has the stated aim of good animal health and welfare. Stricter production rules and extensive advisory services, however, have not led to outstanding results in a considerable proportion of organic farms, e.g. with regard to production diseases (Hovi et al., 2003; Krieger et al., 2016). Thus, there is the particular need of approaches identifying potentially effective management measures that help to achieve that aim. Due to the high complexity (non-linear dynamic relationships) in (organic) livestock systems, investigating individual issues under *ceteris paribus* assumptions is insufficient for improving animal health. Systemic approaches are needed that take into account the whole farm system, i.e. farmers' decision making scope (Öhlmér et al., 1998) and simplify complexity without reducing it to simple cause-effect relationships. In this study, systemic impact analyses were conducted in European organic dairy farms in the context of reducing the prevalence of production diseases. The overall objective was to evaluate the systemic interrelationships between farm factors and determine the systemic roles of variables. In particular, the aim was to identify the most influential variables in each farm, since they represent levers for driving change into a desired direction.

4.2 Material and methods

4.2.1 System variables

Identification of relevant system variables was performed before the farm visits to filter out vital key factors that play a role in the way the system behaves. This step involves the definition of system boundaries and goal-setting. The system in focus was the 'organic dairy farm' and the goal was defined as 'improving the animal health status' which also determined who should be involved in the subsequent process, namely those affected by and affecting future decisions on the farm.

For the identification of variables at work in the system 'organic dairy farm' with respect to animal health in a European context, five regional workshops were conducted in France (2), Germany (1), Spain (1), and Sweden (1). The workshops were held within a multidisciplinary framework and attended by a total of 80 experts in animal health on organic dairy farms: farmers, advisors, veterinarians, researchers, and members of dairy associations and the organic dairy industry. Variables were collected in a participatory process, structured, and reduced to a set of essential components. Four national variable lists were created containing a total of 81 variables. Based on these, a multinational team of researchers established a pan-European set of 20 variables applicable to a wider range of farms (Duval et al., 2013). Variables were screened to essential bio-cybernetic criteria, provided by the

Sensitivity Model of Vester (2007). Following pilot visits on two organic dairy farms, the number of variables was further aggregated to a final set of 13 variables (***Table 4.1***), comprising all relevant influencing factors in relation to animal health on the farm level on an operational level.

Table 4.1. *List of system variables related to animal health in the organic dairy farm.*

	Variable	Definition
1	Milk performance	Level of milk production (considering quality and quantity).
2	Production diseases	Health status of the herd related to enzootic (production) diseases including udder diseases, lameness, and reproductive and metabolic disorders.
3	Financial resources	Economical results, financial resources of the farm to modify and improve suboptimal conditions.
4	Labour capacity	Ratio between available labour time and work to do.
5	Feeding	Degree of meeting the feeding requirement of individual animals in their actual life stage (energy nutrients, structure, water etc.); influenced by feeding management and the availability of feed.
6	Housing conditions	Attributes of the cow environment (housing and pastures) that have a potential effect on animal health and welfare.
7	Reproduction management	Ensuring fertility in heifers and dairy cows meets the objectives of the farmer.
8	Dry cow management	Ensuring optimal conditions (regarding nutrition, housing, hygiene, and welfare) for dry cows to be able to start healthy into the next lactation.
9	Calf and heifer management	Ensuring optimal conditions (regarding nutrition, housing, hygiene, and welfare) for the development of calves and heifers.
10	Herd health monitoring	Quality of the perception and documentation of herd health and production at individual cow and herd level.
11	Hygiene	To what extent are hygiene standards met/hygienic measures taken with respect to housing, milking, and the risk of transmitting infectious diseases through internal or external contact.
12	Treatment	Degree of meeting the need of an individual (sick) animal by using remedies and palliative measures; needs-related = appropriate (made to measure therapy) and in time (early/timely treatment).
13	Knowledge and skills on the farm	Knowledge and skills that can be accessed for the benefit of the farm. This includes knowledge and skills of external persons which can be involved if necessary.

4.2.2 Impact analysis

An impact analysis was used to examine and visualise how single variables are estimated in their impact on other listed variables. To apply the method the farmer, an advisor, the local veterinarian and a researcher visited each farm together, the latter taking up the role of the facilitator. Prior to the visits, all researchers had been trained in the moderation of group discussions and had tested the procedure on two pilot farms. Each assessment was preceded by a short farm walk and a presentation of general farm characteristics and health-related figures by the researcher. During the assessment an impact matrix was filled in by quantifying the relationships between each two variables in a pair-wise comparison. By definition, variables could have no impact on themselves, which is why the diagonal in each matrix was crossed out (***Figure 4.1***). The underlying question for each pair was: "If variable A changes, how will variable B change on this farm?" Only changes as a result of direct influence were taken into account, irrespective of the direction of anticipated shift. The strength of influence was scored with 0 (no obvious influence), 1 (weak change), 2 (proportional change), or 3 (strong change). Each score was immediately discussed between the participants and the consensual score inserted by the researcher into a software tool specifically designed for the purpose called 'dsp-Impro'. Once all interrelationships were scored, this resulted in a consensual impact matrix and an output graph relevant for the farm in question.

Impact of ↓ on →	1	2	3	4	5	6	7	8	9	10	11	12	13	absolute Active Sum	relative Active Sum	Sector	Activity Index	Criticality Index
1 Milk performance		1	1	0	1	0	0	1	0	0	0	0	0	4	0.18	G	-0.07	-0.25
2 Production diseases	3		3	3	0	0	3	1	1	3	1	2	2	22	1.00	C	0.14	0.36
3 Financial resources	0	0		0	0	0	0	0	0	0	0	0	0	0	0.00	H	-0.27	-0.23
4 Labour capacity	0	1	1		0	1	1	2	1	1	1	0	0	9	0.41	E	-0.09	0.00
5 Feeding	2	2	1	1		0	0	0	0	1	0	0	1	8	0.36	D	0.07	-0.20
6 Housing conditions	0	1	1	1	1		0	2	0	1	1	0	0	8	0.36	D	0.09	-0.23
7 Reproduction management	0	0	0	1	0	0		0	0	1	0	0	0	2	0.09	G	-0.05	-0.36
8 Dry cow management	1	3	1	2	1	2	0		0	2	1	2	1	16	0.73	B	0.11	0.11
9 Calf and heifer management	0	2	2	2	0	0	0	0		0	1	1	1	9	0.41	D	0.14	-0.23
10 Herd health monitoring	0	1	1	1	1	0	0	2	0		0	1	1	8	0.36	E	-0.05	-0.09
11 Hygiene	1	2	0	2	0	1	0	1	0	0		0	0	7	0.32	G	0.02	-0.20
12 Treatment	0	2	1	0	0	0	0	1	0	0	0		1	5	0.23	G	-0.05	-0.23
13 Knowledge and skills	0	1	0	0	1	0	0	1	1	1	1	1		7	0.32	G	0.00	-0.18
absolute Passive Sum	7	16	12	13	5	4	4	11	3	10	6	7	7					
relative Passive Sum	0.32	0.73	0.55	0.59	0.23	0.18	0.18	0.50	0.14	0.45	0.27	0.32	0.32					

Figure 4.1. *Impact matrix (farm A) with display of sums, sectors and indices.*

Within the impact matrix the row sum is a measure of a variable's exerted influence (AS = Active Sum) whereas the column sum of a variable is a measure of its received influence (PS = Passive Sum). The output graph (***Figure 4.2***, p.53) represents the numerically aggregated impact strengths for each variable and classifies the indicators depending on their type of system impact as active, reactive, critical or buffering using a grid of nine sectors developed by Schianetz and Kavanagh (2008). The systemic roles associated with the sectors and their implications for system control are presented in ***Table 4.2*** (p.50).

Table 4.2. *Systemic roles of variables according to Vester (2007) and Schianetz and Kavanagh (2008).*

Sector	Systemic role	Active Sum	Passive Sum	Use for System control
A	Active	High	Low	Effective control levers that will re-stabilise the system once change has occurred.
B	Active-Critical	High	Medium	High leverage, but outcomes are less stable, more difficult to control than Sector A indicators.
C	Critical	High	High	Accelerators and catalysts that are suitable as change starters, but outcomes are very difficult to control and can put the systems resilience at risk.
D	Buffering-Active	Medium	Low	Medium leverage points with minimal side effects.
E	Neutral	Medium	Medium	It will be difficult to steer the system with components in this area, but they are useful for self-regulation.
F	Critical-Reactive	Medium	High	Changes in this area do not achieve expected results.
G	Buffering	Low	Low	Low leverage for system control, interventions serve no purpose.
H	Buffering-Reactive	Low	Medium	Sluggish system reaction with indicator change, but they may be suitable for experimentation.
I	Reactive	Low	High	Intervening here to steer the system is (only) treating symptoms; these components make excellent indicators.

Information on the systemic roles of a system's variables was considered in the further course of the farm visit, when action plans were established to improve the level of production diseases on the farm. Results of the health planning, however, are not part of this report.

4.2.3 Farms

The impact matrix assessment was performed on organic dairy farms in France, Germany, Spain and Sweden. Farms were invited directly by phone or mail in Spain and Sweden, and indirectly through advisers involved in the project in Germany and France (for more details see Krieger et al., 2016). Once farms were recruited, advisors and veterinarians usually working with the farm were invited to join the meeting. In some cases a project veterinarian stepped in if the farm veterinarian could not attend ensuring a veterinarian's perspective to be present.

4.2.4 Data analysis

Impact matrix data assessed with the software tool 'dsp-Impro' were further analysed using the statistical software package R. For between-farm comparison, relative values were determined by dividing Active Sum (AS) and Passive Sum (PS) by the maximum value of both AS and PS per farm which led to values between 0 and 1.

Inspired by the works of Linss and Fried (2010), two indices were obtained for each variable:

$$\mathrm{AI} = \frac{relative\ AS - relative\ PS}{2}$$

$$\mathrm{CI} = \frac{relative\ AS + relative\ PS - 1}{2}$$

Where
AI = Activity Index
CI = Criticality Index
AS = Active Sum
PS = Passive Sum

Variables with a high AI are active. They exercise a lot of influence on other system variables without being much affected by them, whereas variables with a low AI are reactive, i.e. strongly influenced by other system variables while not being very influential. Variables scoring a high CI are critical in a farm system, i.e. having a large impact as well as being strongly impacted themselves, whilst variables with a low CI tend to be buffering, which means they are neither influential nor much influenced by others. ***Figure 4.3*** (p.55) shows the contour lines for the AI and CI functions. Variables were ranked according to their AI and CI on farm level. The resulting activity and criticality ranks were used to identify the most active/reactive and most critical/buffering variables in each farm system.

4.2.5 Statistics

Medians (rather than means) were used to report data because they are much less sensitive to outlying values. Since variances were not equal, an approximate method of Welch (1951) was used for continuous data, which generalizes the two-sample Welch test to the case of arbitrarily many samples. The Dunnett-Tukey-Kramer test adjusted for unequal variances (Dunnett, 1980) was used for post-hoc analysis. Pearson's Chi-squared test was applied to ordinal data using the Holm–Bonferroni method for control of the familywise error rate. Results were considered significant if $p < 0.05$.

4.3 Results

During a period of 6 months (from November 2013 until April 2014) 51, 60, 28, and 53 organic dairy farms were visited in France, Germany, Spain, and Sweden, respectively. In total, 6 different researchers (2 in France, 2 in Germany, 1 in Spain, and 1 in Sweden), 58 agricultural advisors and 143 veterinarians (some of them also advisors) participated in the farm visits. Farms had been organic from 1 to 29 years and were smallest in Spain (median 47 ha agricultural area) and largest in Sweden (median 200 ha). Herd size ranged from 7.4 to 376.5 cow-years with the median being lowest in Spain (29.7) and highest in Sweden (68.1).On all farms joint meetings with farmer, veterinarian and/or advisor were held resulting in 192 complete impact matrices. In each matrix 156 interactions between variable-pairs were scored, which took between 1 and 2 hours. The median number of impacts (influences per system disregarding strength) was 84 with a range of 25 – 155. There was a significant difference between Germany (median 73) and Sweden (median 98; $p < 0.001$). The cumulated impact strength per matrix (sum of all cell values) ranged from 28 to 312 (median 119.5) and varied significantly between countries ($p < 0.001$). The German median was lowest (94.5) whilst the French and Swedish were highest (133 and 130).

In the output graphs, the variables were spread out across 6 sectors per farm on average (range 3 – 9). Across all farms, sector E was frequented most (24.3%) and sectors A and I contained the least variables (3.5% and 5.4%). Twenty-six percent of farms tended to be particularly inert with more than 9 out of 13 variables located in sector G and neighbouring sectors. An almost similar proportion (25%) was characterised as generally critical with more than 9 variables located in sector C and neighbouring sectors. Forty-six percent of farm systems could not be associated with one role area by the distribution of their variables and 3% were generally reactive. ***Figure 4.2*** (p.53) shows the distribution of variables on the grid of systemic roles for two farms (A and B). Whereas most variables of farm A are located in the buffering region, farm B is characterised by its variables tending to be critical. Levers for change are 'dry cow management' (8), calf and heifer management' (9), 'housing conditions' (6) and 'feeding' (5) in farm A, and 'knowledge and skills on the farm' (13), 'herd health monitoring' (10), 'treatment' (12), 'housing conditions' (6) and possibly 'feeding' (5) in farm B.

With regard to the four systemic key roles some general tendencies could be observed (see ***Table 4.3***, p.54): Both variables 'milk performance' and 'financial resources' were characterised by low median CI of − 0.2 and − 0.25, respectively, which indicate a strongly reactive tendency. The variable ‘production diseases’, with a median CI of 0.28, was the most critical of all variables (see also ***Figure 4.3***, p.55). ‘Labour capacity’ was rather critical as well, with a median CI of 0.09. Quite active were both variables ‘feeding’ and ‘housing conditions’ with median AI of 0.07 and 0.09, whereby the latter had also a tendency for being buffering (median CI − 0.11). Similarly characterised by low median CI and thus a buffering tendency were the variables ‘reproduction management’ (− 0.12), ‘dry cow management’ (− 0.11), ‘calf and heifer management’ (− 0.13), ‘hygiene’ (− 0.08), and treatment’ (− 0.09). ‘Herd health monitoring’ generally had an active tendency with a median AI of 0.07. The variable ‘knowledge and skills on the farm’ was the most active of all variables with a median AI of 0.11 but at the same time was quite critical with a median CI of 0.08. All variables were characterised by a large spread of AI and CI values (see the interquartile range in ***Table 4.3***, p.54), which indicates a great variation between farms. Significant country effects were found for all variables.

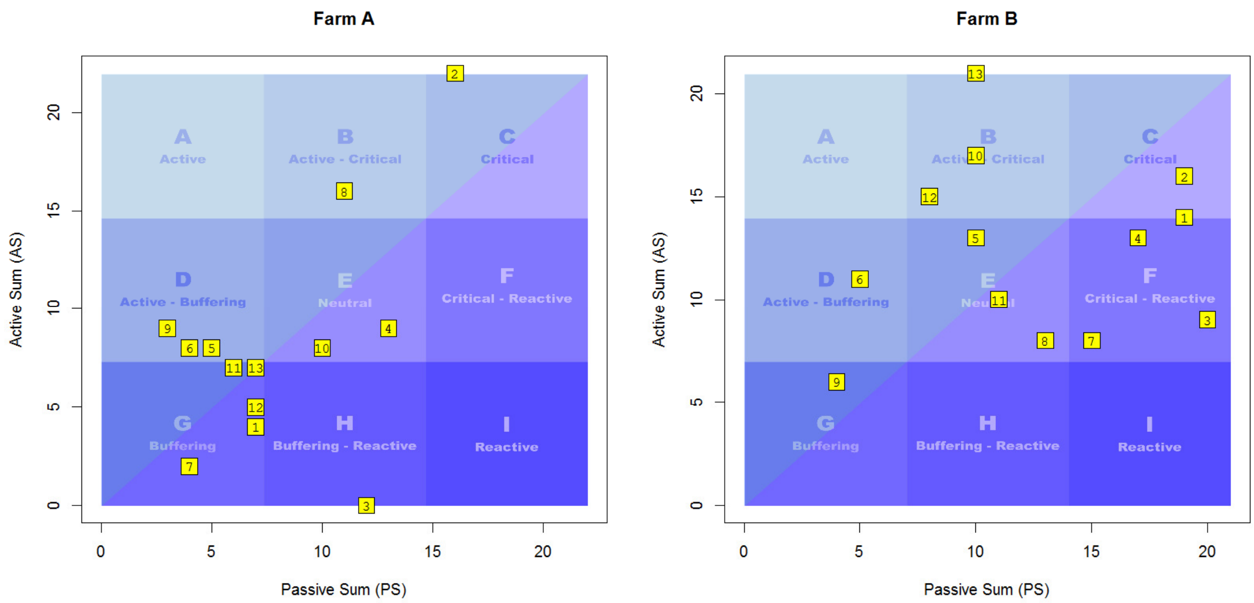

Figure 4.2. *Output graphs of two farms showing the spatial distribution of 13 variables (definitions in* ***Table 4.1****, p.48) on the grid of systemic roles determined by their absolute Active Sum (AS) and Passive Sum (PS). Axes ends are the maximum value of both AS and PS. The diagonal y = x was added to distinguish between variables where AS > PS (rather active) and variables where AS < PS (rather reactive).*

Figure 4.4 (p.55) depicts the distribution of activity and criticality ranks of all variables. The most active variable was ‘knowledge and skills on the farm’ (first rank in 27.6% of farms) and ‘production diseases’ was by far the most critical variable (first rank in 56.8% of farms). It is also shown, that each of the 13 variables, except ‘milk performance’, reached the top activity rank at least once and all variables appeared as the most critical variable in at least one farm.

Table 4.3. *Median activity and criticality indices and interquartile range (IQR) of all system variables across countries (ALL) and within France (FR), Germany (DE), Spain (ES) and Sweden (SE) with significance between countries marked as *** p < 0.001; ** p < 0.01; * p < 0.05; n.s. = not significant.*

			Activity index						Criticality index					
No	Variable		ALL	FR	DE	ES	SE		ALL	FR	DE	ES	SE	
1	Milk performance	median	-0.20	-0.16	-0.21	-0.26	-0.20	**	0.08	0.06	0.03	0.18	0.12	***
		IQR	*0.15*	*0.16*	*0.14*	*0.14*	*0.13*		*0.18*	*0.13*	*0.21*	*0.17*	*0.15*	
2	Production diseases	median	0.03	-0.04	0.10	0.03	0.04	***	0.28	0.32	0.32	0.22	0.22	***
		IQR	*0.17*	*0.12*	*0.17*	*0.12*	*0.20*		*0.17*	*0.16*	*0.13*	*0.17*	*0.15*	
3	Financial resources	median	-0.25	-0.25	-0.25	-0.24	-0.25	n.s.	0.05	0.00	-0.03	0.06	0.18	***
		IQR	*0.16*	*0.16*	*0.20*	*0.11*	*0.15*		*0.22*	*0.21*	*0.17*	*0.15*	*0.18*	
4	Labour capacity	median	-0.04	-0.03	-0.07	-0.01	-0.04	n.s.	0.09	-0.02	0.14	0.06	0.16	**
		IQR	*0.17*	*0.21*	*0.14*	*0.21*	*0.12*		*0.25*	*0.24*	*0.23*	*0.17*	*0.21*	
5	Feeding	median	0.07	0.09	0.05	0.07	0.06	*	-0.04	-0.04	-0.08	0.00	0.00	**
		IQR	*0.15*	*0.14*	*0.11*	*0.18*	*0.13*		*0.18*	*0.14*	*0.18*	*0.12*	*0.19*	
6	Housing conditions	median	0.09	0.09	0.04	0.14	0.10	**	-0.11	-0.18	-0.18	0.07	-0.04	***
		IQR	*0.14*	*0.10*	*0.11*	*0.07*	*0.14*		*0.26*	*0.24*	*0.19*	*0.20*	*0.26*	
7	Reproduction management	median	-0.03	-0.04	0.00	-0.01	-0.06	***	-0.12	-0.09	-0.24	-0.07	-0.04	***
		IQR	*0.13*	*0.14*	*0.10*	*0.16*	*0.14*		*0.27*	*0.25*	*0.23*	*0.20*	*0.25*	
8	Dry cow management	median	0.04	0.00	0.09	0.09	0.04	***	-0.11	-0.11	-0.13	-0.17	-0.06	n.s.
		IQR	*0.13*	*0.12*	*0.14*	*0.16*	*0.12*		*0.28*	*0.22*	*0.27*	*0.21*	*0.34*	
9	Calf and heifer management	median	0.04	0.03	0.05	0.04	0.03	n.s.	-0.13	-0.03	-0.25	-0.11	0.03	***
		IQR	*0.12*	*0.15*	*0.08*	*0.11*	*0.11*		*0.29*	*0.22*	*0.11*	*0.22*	*0.38*	
10	Herd health monitoring	median	0.07	0.12	0.03	0.06	0.06	*	-0.05	0.07	-0.07	-0.17	-0.04	***
		IQR	*0.14*	*0.13*	*0.17*	*0.16*	*0.13*		*0.26*	*0.22*	*0.24*	*0.22*	*0.26*	
11	Hygiene	median	0.02	0.06	0.00	0.03	0.00	**	-0.08	-0.02	-0.16	-0.12	-0.02	***
		IQR	*0.13*	*0.17*	*0.09*	*0.10*	*0.15*		*0.26*	*0.24*	*0.21*	*0.24*	*0.28*	
12	Treatment	median	0.00	0.03	-0.01	-0.01	0.03	*	-0.09	-0.02	-0.11	-0.14	-0.14	***
		IQR	*0.14*	*0.16*	*0.13*	*0.10*	*0.12*		*0.26*	*0.23*	*0.26*	*0.18*	*0.26*	
13	Knowledge and skills on the farm	median	0.11	0.07	0.13	0.11	0.09	n.s.	0.08	0.21	0.00	0.11	0.07	***
		IQR	*0.19*	*0.27*	*0.18*	*0.12*	*0.13*		*0.27*	*0.24*	*0.24*	*0.21*	*0.24*	

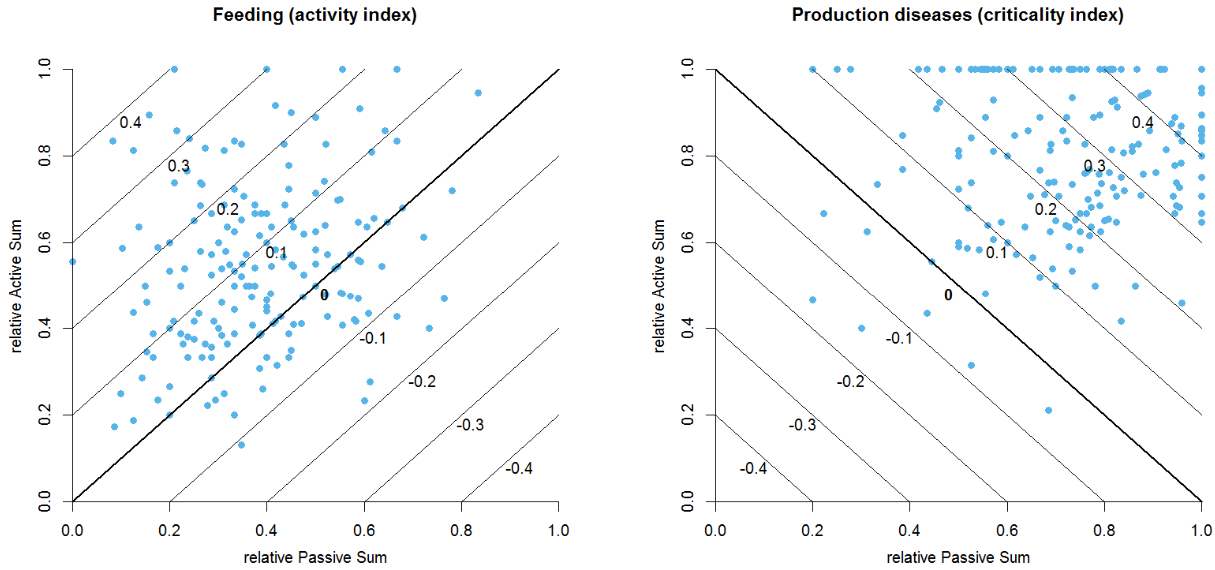

Figure 4.3. *Position of the variables 'feeding' and 'production diseases' in all farms (n = 192) determined by their relative Active and Passive Sums with contour lines of the activity and criticality indices.*

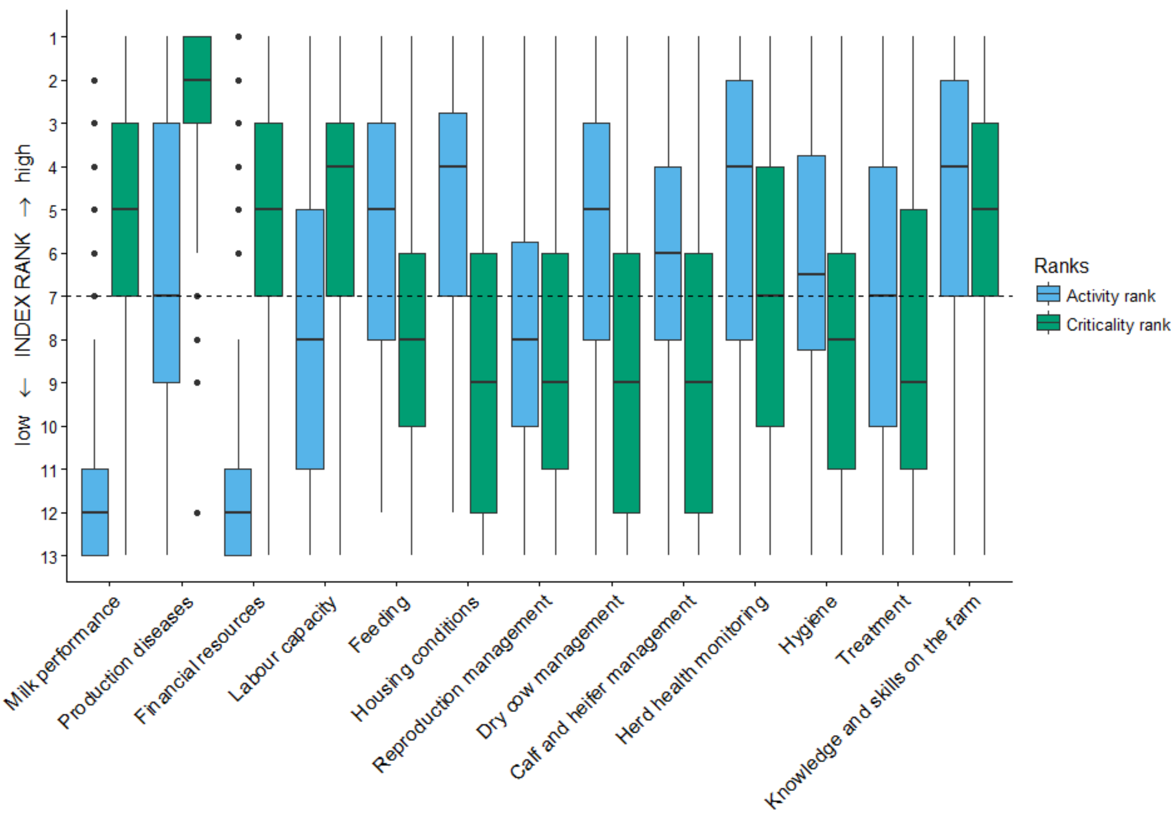

Figure 4.4. *Distribution of activity ranks (1 = most active, 13 = most reactive) and criticality ranks (1 = most critical, 13 = most buffering) for all system variables across all farms (n = 192); variables could be assigned the same rank in one farm if activity and criticality indices were equal; the dotted line divides top and bottom ranks.*

4.4 Discussion

4.4.1 System variables

As far as we are aware of, this was the first time an impact assessment was applied to a large number of different systems using the same variables. Although the individual participants on a given farm would probably have identified slightly different, e.g. less aggregated and more farm specific, variables to describe individual systems, the common set proved to be usable in all farms. This broad applicability was achieved by the participatory framework where all participants, farmers, advisors, veterinarians, and other stakeholders, were involved as knowing subjects who brought their perspectives into the knowledge-production process (Bergold and Thomas, 2012). The impact assessment focused on the dairy farm, this being the main field of action for farmers and advisors in terms of dairy cattle health. Variables were thus located within the farm system boundaries and excluding other business branches, e.g. crop production, other livestock, and processing. The total number of variables was smaller than the recommended range of 20 – 40 (Vester, 2007). This, however, was deliberately achieved through an intensive reduction process for practical reasons: Scoring all interrelationships between thirteen variables already required a reasonable amount of time and endurance from the participants. Due to the reduction, variables became rather highly aggregated. The variable 'housing conditions', for example, could include anything from cubicle measures to air temperature and 'hygiene' could be related to different areas, such as bedding, milking, or feed. Only in accepting this fuzziness, it became feasible to apply the method in a consistent manner on 192 farms during a farm visit with the given time constraints.

4.4.2 Impacts

Impact numbers and strengths varied between systems and countries. System effects and possibly also some of the differences between countries can be explained by the fact that dairy farms in general, and organic dairy farms in particular, vary in many aspects, such as overall organisation and availability of resources (Häring, 2003; Sundrum et al., 2006). National conditions and regulations may have had additional effects. It cannot be ruled out that some of the between-country variation is also due to different researchers applying the method. The distinction between direct and indirect impacts, for example, can be quite difficult and may have been handled differently in spite of previous training. Those differences, however, do not diminish the insights gained by the impact assessment, because its aim was not to identify general laws between variables but to supply a first description of the variables at work within each system.

The square matrix is an essential component of the assessment since it forces the scoring of all bilateral relationships between all impact factors. This procedure is time consuming for those doing the assessment but at the same time crucial since it sheds light not only on those relationships well known to the assessors, but on those that are normally hidden or latent at the time of the assessment. Filling the matrix enables a comprehensive reflection of the most important variables and their interrelationships. By identifying the most influential variables, the procedure clears the ground for further in-depth analysis, pointing to the most relevant areas in the farm specific situation. Impact strengths were estimated by the participants. Thereby subjective perception is validated through intersubjectivity (Velmans, 1999) based on the idea that if different observers agree about a percept or concept, then this phenomenon may be considered 'real' by consensus (Heylighen and Joslyn, 2001). Involving the 'steersman' (the farmer) in the process allowed acknowledging the systems own steering potential, its latent risks and opportunities. By including external perspectives (of advisor and veterinarian) to form a frame of reference, complement existing knowledge and break through established routines (Hall and Wapenaar, 2012), this study clearly extended the approach applied to organic pig farms (Hoischen-Taubner and Sundrum, 2012).

4.4.3 Output

The output graph made it possible to immediately learn the position of each variable between the four key roles in each farm. This position can be regarded as relational information (Maruyama, 1972), as it does only come about as a result of all other variables being involved. By means of the graph the system can be characterised as a whole and its critical points can promptly be pointed out as well as its levers for change and its sensory variables (that are better left alone). The output graph can thus be regarded as a revelation of a system's inherent potentials where the distinctive features of its variables become explicit (e.g. being more active or buffering), especially to those not being a part of the system (e.g. veterinarian and advisor). Comparison of different outputs revealed that the variables' systemic behaviour in the different farm systems was quite different.

Despite this, some variables were found to have a general tendency of influencing the system, namely 'feeding', 'herd health monitoring' and 'knowledge and skills on the farm'. These variables can easily be imagined as levers for change: Metabolic health and feeding strategies were the most common topics selected by farmers during stable school interventions on organic farms in Germany (March et al., 2014). Monitoring, in terms of regular planned observations and documentation, identifies health areas not under control and is likely to trigger changes in management (Brand et al., 1996). Farmers monitor health indicators to analyse whether their objectives are being reached and to support their decision-making (Duval et al., 2016). In a Dutch study 30% of randomly chosen farmers stated they lacked sufficient knowledge to prevent mastitis problems which could mean that they saw potential in increasing their knowledge (Kuiper et al., 2005).

Variables that were generally sensitive to changes and thus reactive in nature were ‘milk performance’ and ‘financial resources’. Milk yield has been shown to be affected by numerous farm factors such as feeding, housing, management, and prevalence of disease (Roesch et al., 2005) and is thus a typical performance indicator in dairy farms. Due to limited selection criteria, milk performance has also been associated with an increase in production diseases in dairy cattle (Ingvartsen et al., 2003; Simianer et al., 1991; van Dorp et al., 1998). Perhaps one reason for the small impact, expected from a change in milk performance in our study farms, is that performance levels are generally lower in organic compared to conventional farms (Fall and Emanuelson, 2009). Financial resources, in this study, were merely seen as a result than a means for change by farmers and their advisors. One reason for this may be that although farmers are aware about losses caused by disease, they do not necessarily value economic information in the context of decision-making (van Asseldonk et al., 2010). Our results indicate that, despite decisions being made within financial constraints, non-financial factors may be more crucial within the farm system (Edwards-Jones, 2006).

All three management variables as well as ‘hygiene’, ‘treatment’ and ‘housing conditions’ were found to have a buffering tendency in most farms. Their impact on the whole system may be low because they act upon specific areas and have little direct effects on variables outside these areas. Besides being buffering, ‘housing conditions’ had an active tendency too. This was probably the case in systems where the assessors saw room for improvement that would have a direct effect on other variables. Most critical were ‘production diseases’ and ‘labour capacity’. Production diseases are caused by an interplay of many factors (Nir, 2003). At the same time their prevalence affects production levels, financial resources, and forces management decisions. Labour capacity, as well, determines what can be achieved on a farm and may act as a constraint or catalyst for change (Mugera and Bitsch, 2005). Reversely, labour may also be consumed or released by changes on the farm. Labour management, for instance, has been reported as a major challenge after modernisation and expansion (Bewley et al., 2001).

In this study, the impact assessment was used to serve as a supportive tool for decision-making to improve animal health in organic dairy farms. The aim was to identify the most active variables for each farm, since changes in these variables can be expected to have large effects on the system. The fact, that almost all variables were identified as the most active and simultaneously as the least active variable in different farms, emphasises the heterogeneity between systems. On the farm level some variables were found to comply with the general tendency regarding their systemic role, which is likely to be in line with expectations. The capacity of this approach, however, is the ability to point out the deviation from such expectations, which becomes explicit by filling the matrix and discussing the output, specifically to the advisor and veterinarian, thereby supporting a farm specific selection of strategies and measures.

The impact analysis is a means of arriving at hypotheses about the most effective (and efficient) strategies in the farm specific context for the purpose intended. In our study, due to high variable aggregation, the hypotheses remained rather imprecise, e.g. a change in feeding can imply very different aspects depending on the farm, making it difficult to derive precise instructions. Despite this vagueness, the method has the capacity to achieve system-understanding and to draw the attention to crucial areas. In order to identify concrete measures, it will be necessary to take into focus the identified areas and study them in more detail relying on sound diagnosis and in-depth knowledge. One approach may also be to apply the impact assessment defining specific (health) goals and using specific variable sets related to these goals.

4.5 Conclusion

Variables affecting the emergence of production diseases in organic dairy farming systems have been shown to be very different between farms. This emphasises that also very different measures may be most effective in improving the animal health status and stresses the need to apply farm-centric approaches that evaluate the relationships at work in those systems. The impact analysis, by involving stakeholder perception and expertise, can help to identify potential levers for change within the farm system by explaining the context. Thus, it supports the formulation of hypotheses on possible strategies for improvement. Whether these hypotheses turn out to be true and the results of the exercise prove effective in fostering improvement must be tested in future applications of the method.

4.6 Acknowledgements

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4.7 References

Bawden, R., 1995. On the systems dimension in FSR. Journal of Farming Systems Research-Extension 5 (2), 1–18.

Bawden, R., 1997. Learning to Persist, in: Stowell, F.A., Ison, R.L., Armson, R., Holloway, J., Jackson, S., McRobb, S. (Eds.), Systems for Sustainability: People, Organizations, and Environments. Springer US, Boston, MA, pp. 1–5.

Bawden, R.J., 1991. Systems Thinking and Practice in Agriculture. Journal of Dairy Science 74 (7), 2362–2373.

Bergold, J., Thomas, S., 2012. Participatory Research Methods: A Methodological Approach in Motion. Forum Qualitative Sozialforschung / Forum: Qualitative Social Research 13 (1).

Bewley, J., Palmer, R.W., Jackson-Smith, D.B., 2001. An Overview of Experiences of Wisconsin Dairy Farmers who Modernized Their Operations. Journal of Dairy Science 84 (3), 717–729.

Brand, A., Noordhuizen, Josephus Pieter Thérèse Maria, Schukken, Y.H., 1996. Herd health and production management in dairy practice. Wageningen Pers, Wageningen.

Cole, A., Allen, W., Kilvington, M., Fenemor, A., 2007. Participatory modelling with an influence matrix and the calculation of whole-of-system sustainability values. International Journal of Sustainable Development 10 (4), 382–401.

Conant, R.C., Ashby, R.W., 1970. Every good regulator of a system must be a model of that system. International Journal of Systems Science 1 (2), 89–97.

Conway, G.R., 1985. Agroecosystem analysis. Agricultural Administration 20 (1), 31–55.

Coplak, J., Raksanyi, P., 2003. Planning sustainable settlements: Rep. No. EC Project Ecocity- EBVK4-CT-2001-00056. Slovak University of Technology, Bratislava.

Darnhofer, I., Bellon, S., Dedieu, B., Milestad, R., 2010. Adaptiveness to enhance the sustainability of farming systems. A review. Agron. Sustain. Dev. 30 (3), 545–555.

Dunnett, C.W., 1980. Pairwise Multiple Comparisons in the Unequal Variance Case. Journal of the American Statistical Association 75 (372), 796.

Duval, J.E., Blanco-Penedo, I., Jonasson, K., Hoischen-Taubner, S., Selle, M., Sundrum, A., 2013. Identification of variables affecting animal health in European organic dairy farms, in: Book of Abstracts: 15th International Conference on Production Diseases in Farm Animals. ICPD, Uppsala, Sweden. 24-28 June 2013, p. 215.

Duval, J.E., Fourichon, C., Madouasse, A., Sjöström, K., Emanuelson, U., Bareille, N., 2016. A participatory approach to design monitoring indicators of production diseases in organic dairy farms. Preventive Veterinary Medicine 128, 12–22.

Edwards-Jones, G., 2006. Modelling farmer decision-making: Concepts, progress and challenges. Animal Science 82 (6), 783–790.

Fall, N., Emanuelson, U., 2009. Milk yield, udder health and reproductive performance in Swedish organic and conventional dairy herds. The Journal of dairy research 76 (4), 402–410.

Fried, A., 2010. Performance measurement systems and their relation to strategic learning: A case study in a software-developing organization. Critical Perspectives on Accounting 21 (2), 118–133.

Gausemeier, J., 1998. Scenario Management: An Approach to Develop Future Potentials. Technological Forecasting and Social Change, 111–130.

Gibon, A., Sibbald, A.R., Flamant, J.C., Lhoste, P., Revilla, R., Rubino, R., Sørensen, J.T., 1999. Livestock farming systems research in Europe and its potential contribution for managing towards sustainability in livestock farming. Livestock Production Science 61 (2-3), 121–137.

Godet, M., 1979. The crisis in forecasting and the emergence of the “prospective” approach: With case studies in energy and air transport. Pergamon Press, New York, xi, 134.

Gordon, T.J., Hayward, H., 1968. Initial experiments with the cross impact matrix method of forecasting. Futures 1 (2), 100–116.

Hall, J., Wapenaar, W., 2012. Opinions and practices of veterinarians and dairy farmers towards herd health management in the UK. The Veterinary record 170 (17), 441.

Häring, A.M., 2003. Organic dairy farms in the EU: Production systems, economics and future development. Livestock Production Science 80 (1-2), 89–97.

Heylighen, F., Joslyn, C., 2001. Cybernetics and Second-Order Cybernetics, in: Meyers, R.A. (Ed.), Encyclopedia of Physical Science & Technology, 3rd ed. Academic Press, New York, pp. 155–170.

Hoischen-Taubner, S., Sundrum, A., 2012. Impact matrix: a tool to improve animal health by a systemic approach, in: Rahmann, G. (Ed.), Tackling the future challenges of organic animal husbandry. 2nd Organic Animal Husbandry Conference, Hamburg, Trenthorst, 12 - 14 September 2012. vTI, Braunschweig, pp. 139–142.

Hovi, M., Sundrum, A., Thamsborg, S., 2003. Animal health and welfare in organic livestock production in Europe: Current state and future challenges. Livestock Production Science 80 (1-2), 41–53.

Ingvartsen, K., Dewhurst, R., Friggens, N., 2003. On the relationship between lactational performance and health: Is it yield or metabolic imbalance that cause production diseases in dairy cattle? A position paper. Livestock Production Science 83 (2-3), 277–308.

Iron Curtain Consortium, 2004. Integrated multilayer database for the reference areas andinterpreted maps and time series: Rep. No. QLK5-2001-01401. Institute for Geography – Geoinformatics, Friedrich-Schiller-Universität Jena, Germany.

Krieger, M., Sjöström, K., Blanco-Penedo, I., Madouasse, A., Duval, J.E., Bareille, N., Fourichon, C., Sundrum, A., Emanuelson, U., 2016. Prevalences of production diseases in European organic dairy herds and potential drivers for improvement as identified by stakeholders. Manuscript submitted to Livestock Science.

Kuiper, D., Jansen, J., Renes, R.J., Leeuwis, C., van der Zwaag, H., 2005. Social factors related to mastitis control practices: the role of dairy farmers' knowledge, attitude, values, behaviour and networks, in: Hogeveen, H. (Ed.), Mastitis in dairy production. Wageningen Academic Publishers, The Netherlands, pp. 576–582.

Linss, V., Fried, A., 2010. The ADVIAN® classification - A new classification approach for the rating of impact factors. Technological Forecasting and Social Change 77 (1), 110–119.

March, S., Brinkmann, J., Winckler, C., 2014. Improvement of animal health in organic dairy farms through 'stable schools': selected results of a pilot study in Germany. Organic Agriculture 4 (4), 319–323.

Maruyama, M., 1972. Non-Classificational Information and Non-Informational Communication. Dialectica 26 (1), 51–59.

Messerli, P., 2000. Use of Sensitivity Analysis to Evaluate Key Factors for Improving Slash-and-Burn Cultivation Systems on the Eastern Escarpment of Madagascar. Mountain Research and Development 20 (1), 32–41.

Mugera, A., Bitsch, V., 2005. Managing Labor on Dairy Farms: A Resource-Based Perspective with Evidence from Case Studies. International Food and Agribusiness Management Review 8 (3), 79–98.

Nir, O., 2003. What are Production Diseases, and How do We Manage Them? Acta vet. scand. (Suppl. 98), 21–32.

Norman, D.W., 2002. The farming systems approach: A historical perspective. Invited paper at the 17th Symposium of the International Farming Systems Association in Lake Buena Vista, Florida, USA, 17-20 November.

OECD Environment Directorate, 2000. Project on environmentally sustainable transport – the economic and social implications of sustainable transportation. OECD Working group on Transport, Paris, France, 153 pp.

Öhlmér, B., Olson, K., Brehmer, B., 1998. Understanding farmers' decision making processes and improving managerial assistance. Agricultural Economics 18 (3), 273–290.

Roesch, M., Doherr, M.G., Blum, J.W., 2005. Performance of Dairy Cows on Swiss Farms with Organic and Integrated Production. Journal of Dairy Science 88 (7), 2462–2475.

Sands, D.M., 1986. Farming Systems Research: Clarification of Terms and Concepts. Experimental Agriculture 22 (2), 87–104.

Schianetz, K., Kavanagh, L., 2008. Sustainability Indicators for Tourism Destinations: A Complex Adaptive Systems Approach Using Systemic Indicator Systems. Journal of Sustainable Tourism 16 (6), 601.

Simianer, H., Solbu, H., Schaeffer, L.R., 1991. Estimated Genetic Correlations Between Disease and Yield Traits in Dairy Cattle. Journal of Dairy Science 74 (12), 4358–4365.

Spedding, C.R.W., 1979. An introduction to agricultural systems. Applied Science Publishers, London, 169 pp.

Sundrum, A., 2012. Health and Welfare of Organic Livestock and Its Challenges, in: Ricke, S.C. (Ed.), Organic meat production and processing. John Wiley and Sons, Hoboken, NJ, pp. 87–112.

Sundrum, A., 2014. Organic Livestock Production, in: Alfen, N.K. van (Ed.), Encyclopedia of Agriculture and Food Systems. Academic Press, Oxford, pp. 287–303.

Sundrum, A., Padel, S., Arsenos, G., Kuzniar, A., Henriksen, B.I.F., Walkenhorst, M., Vaarst, M., 2006. Current and proposed EU legislation on organic livestock production, with a focus on animal health, welfare and food safety: a review, in: Future perspectives for animal health on organic farms: main findings, conclusions and recommendations from the SAFO network. 5th SAFO-Workshop, Odense, Denmark.

Thamsborg, S.M., Roderick, S., Sundrum, A., 2004. Animal health and diseases in organic farming: an overview, in: Vaarst, M., Roderick, S., Lund, V., Lockeretz, W. (Eds.), Animal health and welfare in organic agriculture. CABI, Wallingford, pp. 227–252.

van Asseldonk, M.A.P.M., Renes, R.J., Lam, T. J. G. M., Hogeveen, H., 2010. Awareness and perceived value of economic information in controlling somatic cell count. Veterinary Record 166 (9), 263–267.

van Dorp, T.E., Dekkers, J., Martin, S.W., Noordhuizen, J., 1998. Genetic Parameters of Health Disorders, and Relationships with 305-Day Milk Yield and Conformation Traits of Registered Holstein Cows. Journal of Dairy Science 81 (8), 2264–2270.

Velmans, M., 1999. Intersubjective science. Journal of Consciousness Studies 6 (2-3), 299–306.

Vester, F., 2007. The art of interconnected thinking: Tools and concepts for a new approach to tackling complexity. MCB Verlag, Munich, 364 pp.

Vester, F., Hesler, A.v., 1980. Sensitivity model UNESCO Man and the biosphere project 11. Umweltforschungsplan des Bundesministers des Innern : UNESCO Man and the Biosphere Projekt 11.

Welch, B.L., 1951. On the Comparison of Several Mean Values: An Alternative Approach. Biometrika 38 (3/4), 330.

Wenzel, S., Igenbergs, E., 2001. Agent Systems Architectures for Complex and distributed Product Development Systems. INCOSE International Symposium 11 (1), 65–75.

Wiek, A., Binder, C., 2005. Solution spaces for decision-making - a sustainability assessment tool for city-regions. Environmental Impact Assessment Review 25 (6), 589–608.

Zadeh, L.A., 1997. Toward a theory of fuzzy information granulation and its centrality in human reasoning and fuzzy logic. Fuzzy Sets and Systems 90 (2), 111–127.

5 Farm factors related to the prevalence of production diseases in organic dairy cows – Results of graph-based impact analysis involving farmers, advisors and veterinarians

Margret Krieger[1,*], Eva-Marie Schwabenbauer[1], Susanne Hoischen-Taubner[1], Ulf Emanuelson[2], Albert Sundrum[1]

[1] University of Kassel, Department of Animal Nutrition and Animal Health, Nordbahnhofstrasse 1a, D-37213 Witzenhausen, Germany
[2] Swedish University of Agricultural Sciences, Department of Clinical Sciences, SE-750 07 Uppsala, Sweden
Corresponding author: Margret Krieger. E-mail: margret.krieger@uni-kassel.de.

Abstract

Graph-based impact analysis was performed on 192 European organic dairy farms to identify factors related to the prevalence of production diseases. In a joint meeting with farmer, veterinarian and advisor, direct influences between predefined system variables were estimated for the farm specific context. Indirect impacts were elaborated through graph analysis taking into account impact strengths. Across farms, factors supposedly exerting the most influence on the prevalence of production diseases were feeding, hygiene and treatment (direct impacts), as well as knowledge and skills and herd health monitoring (indirect impacts). Factors strongly influenced by the prevalence of production diseases were milk performance, financial resources and labour capacity (directly and indirectly). The findings underline the general importance of production diseases for economic performance and point out levers that can help to improve animal health. The ranking of variables on the farm level, however, revealed considerable differences between farms in terms of their most influential and most influenced farm factors. In case of knowledge and skills the results imply no general relationship, but merely illustrate that, in a distinct number of farms, the participants saw a potential benefit for animal health deriving from a change in that variable. Their assessment considers the knowledge and skills actually present on the farm and the current level of disease. Both the required input (in terms of knowledge) for unfolding this potential and the expected output (improvement) is highly farm-specific. In a considerable proportion of farms the variables with a strong general impact contributed much less to the prevalence of disease than others. One capacity of the approach is the ability to point out such deviations from general expectations. Even more important, it can help to clarify which potentials are available in the different areas of each individual farm and, based on goals, support the

formulation of farm-specific strategies to improve animal health. In future, the method should be tested using more specific problem-oriented variable sets than applied in the current study and following up the resulting changes in order to evaluate the effectiveness of the approach.

Keywords: animal health, management, system analysis, participatory approach, impact matrix

Implications

The results of our study show that the relationships between farm factors and production diseases are very complex and highly farm-specific. Farmers and advisors need a profound understanding of the system properties to translate their knowledge into on-farm application and support decision-making with respect to animal health. Suitable tools, such as graph-based impact analysis, can support this understanding by considering direct and indirect relationships and identifying the most important levers in a farm. Using the method, farm advisors could improve their advice by suggesting those management measures that are most likely to have the desired effect in the farm context.

5.1 Introduction

Production diseases, such as mastitis, lameness and metabolic disease, are major problems in conventional and organic dairy farms alike (Hovi *et al.*, 2003; LeBlanc *et al.*, 2006). They are a risk for organic dairy farms in particular by posing a threat to their image. Enhanced animal health is one declared aim of organic livestock farming (IFOAM, 2006) and as a consequence consumers expect a higher health status in organic farms (Hughner *et al.*, 2007). Improvements are crucial and, since production diseases are primarily caused or enhanced by nutritional or management factors (Nir, 2003), must be achieved by targeted management actions.

Actions taken and decisions made by farmers, are *inter alia* based on their understanding of the farm system, in particular on their understanding of the underlying impact mechanisms between farm factors. Those mechanisms are not easily understood since a farm is a complex system consisting of numerous factors and a vast number of interrelationships between them (Dillon, 1992). Identification of potentially most effective measures to improve the prevalence of production diseases requires this understanding. Animal health management being not just a farmers' prerogative, but often a cooperation between farmers and their veterinarians and advisors (Vaarst *et al.*, 2011), all of them need a profound understanding of the dairy farm as an integrated system to be able to translate their knowledge into on-farm application (Kristensen and Jakobsen, 2011).

Thus, there is a need for approaches that take into account the systemic nature of animal production systems and that involve all relevant actors. The overall aim of such an approach is to gain understanding by linking technical and biological information with knowledge of farmers' decisions and practices (Béranger and Vissac, 1994). A relational approach allows an integration of social and ecological aspects by acknowledging the interdependency of farm, farmer and context (Darnhofer *et al.*, 2016). By considering system interrelationships in animal health planning, improvement measures are selected based on full knowledge of the existing farming system and not solely in terms of their technical fitting, but in terms of their conformity to the behaviour, goals, needs and socio-economic circumstances of the targeted farm system as well (Sands, 1986).

Although a number of livestock farming systems approaches have been described in the literature (Gibon *et al.*, 1999), only a few of them focus on the complex relationships between farm factors incorporating a stakeholder perspective. Hoischen-Taubner and Sundrum (2012), to our knowledge, were the first to apply a relational approach in the context of animal health studying interdependencies between factors in organic pig farms by means of an impact matrix. Impact (or cross-impact) analysis is mainly based on two techniques that were developed for the assessment of impacts within a system, namely the MICMAC method and the Network Thinking method. Both methods use an impact matrix that is evaluated mathematically to arrive at graphical representations, and are characterised by different qualities: whereas the Network Thinking method considers impact strengths (Vester and Hesler, 1980), MICMAC determines indirect impacts through matrix multiplication (Godet, 1979). Linss and Fried (2009) attempted to integrate both qualities by developing the ADVIAN method which multiplies matrices containing impact strengths. Their method, however, has several drawbacks such as not differentiating between paths and loops, and thus counting short impact chains several times (Götze, 1993), as well as overestimating the total strength of indirect impacts. Overcoming these shortcomings would substantially improve the method's capability to map complex interactions and identify the most influential components of a system, e.g. with respect to animal health.

The aims of our study were therefore (i) to develop the impact analysis further in order to consider both impact strengths and indirect relationships between farm factors, and (ii) to identify farm factors related to the prevalence of production diseases, considering indirect relationships and impact strengths, and incorporating the knowledge of farmers, veterinarians and advisors.

5.2 Material and methods

In this study, impact mechanisms between farm factors and production diseases were studied using impact analysis and extending it by graph analysis. Impact matrices were used for scoring the mutual interrelationships between 13 system variables in organic dairy farms in France, Germany, Spain and Sweden. For details concerning farm recruitment see Krieger *et al.* (Paper I). The definition of variables and the on-farm application of the impact matrix have also been described by Krieger *et al.* (Paper II). Briefly, a set of system variables related to animal health on the farm level was developed within a multidisciplinary framework, involving stakeholder workshops in all participating countries, and tested in two pilot farm visits before the actual assessments (the final set is shown in ***Table 5.1***, p.69). The relationships between all pairs of system variables in each farm were assessed during round-table discussions between farmer, veterinarian and advisor that were facilitated by a trained researcher. Impacts were scored with 0 (no obvious influence), 1 (weak influence), 2 (medium influence), or 3 (strong influence), and inserted in a matrix, whereby variables, by definition, could have no impact on themselves. The filled matrices were used for graph analysis.

Graph theory is a well-established and developed area in mathematics and theoretical computer science, although many of the recent developments have taken place in other fields such as sociology, biology and physics (Costa *et al.*, 2008). Graphs can be used for representation, characterization, classification and modelling of complex networks, whereby complex networks are defined by the following characteristics: (i) they consist of a great number of interacting agents, (ii) they are characterised by self-organising behaviour, which cannot be deduced from the behaviour of its individual parts (emergence), and (iii) their behaviour is not determined by a central controller (Boccara, 2010). Analysis of complex networks requires suitable software that can handle large datasets.

Mathematica (Wolfram Research, 2015) has been suggested as a computer algebra system for modeling complex systems by Brand (2013) because it allows for both accuracy and flexibility. In his book 'Komplexe Systeme' (engl. 'Complex systems'), he describes a procedure, where graphs are built from impact matrices and individual paths, including their strengths, can be analysed. A similar procedure was used within this study. A weighted, directed graph was created for each farm system based on its impact matrix using the function `WeightedAdjacencyGraph`. Thereby variables were regarded as nodes and cell values as links (***Figure 5.1***, p.70). By using the command `weighted` it was made sure that in case of an existing impact between two variables (cell value > 0) its strength (1-3) was considered.

Table 5.1. *Set of system variables related to animal health in the organic dairy farm.*

	Variable	Definition
1	Milk performance	Level of milk production (considering quality and quantity).
2	Production diseases	Health status of the herd related to enzootic (production) diseases including udder diseases, lameness, and reproductive and metabolic disorders.
3	Financial resources	Economical results, financial resources of the farm to modify and improve suboptimal conditions.
4	Labour capacity	Ratio between available labour time and work to do.
5	Feeding	Degree of meeting the feeding requirement of individual animals in their actual life stage (energy nutrients, structure, water etc.); influenced by feeding management and the availability of feed.
6	Housing conditions	Attributes of the cow environment (housing and pastures) that have a potential effect on animal health and welfare.
7	Reproduction management	Ensuring fertility in heifers and dairy cows meets the objectives of the farmer.
8	Dry cow management	Ensuring optimal conditions (regarding nutrition, housing, hygiene, and welfare) for dry cows to be able to start healthy into the next lactation.
9	Calf and heifer management	Ensuring optimal conditions (regarding nutrition, housing, hygiene, and welfare) for the development of calves and heifers.
10	Herd health monitoring	Quality of the perception and documentation of herd health and production at individual cow and herd level.
11	Hygiene	To what extent are hygiene standards met/hygienic measures taken with respect to housing, milking, and the risk of transmitting infectious diseases through internal or external contact.
12	Treatment	Degree of meeting the need of an individual (sick) animal by using remedies and palliative measures; needs-related = appropriate (made to measure therapy) and in time (early/timely treatment).
13	Knowledge and skills on the farm	Knowledge and skills that can be accessed for the benefit of the farm. This includes knowledge and skills of external persons which can be involved if necessary.

OUT \ IN	V1	V2	V3
V1	X	2	0
V2	1	X	3
V3	0	0	X

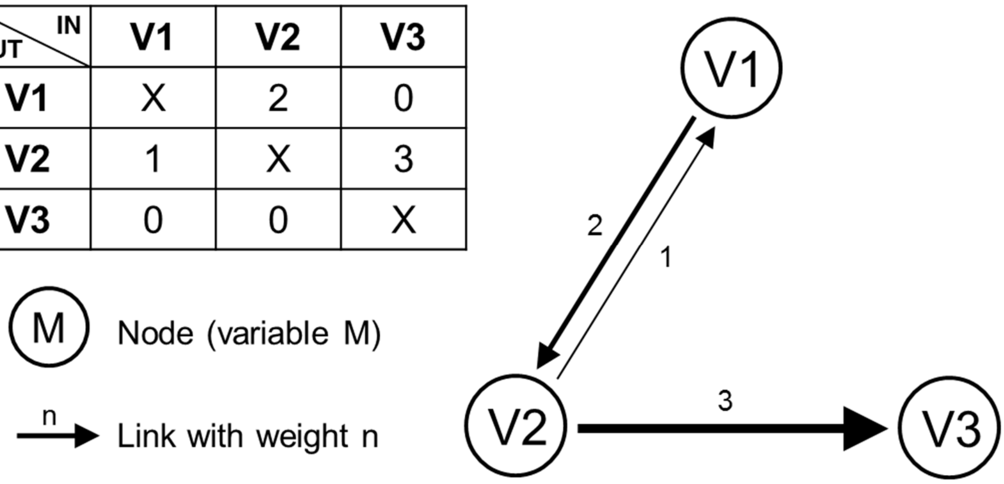
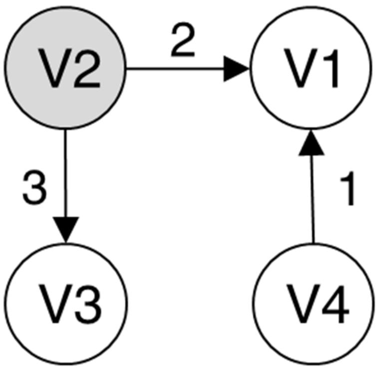


Figure 5.1. *Example of an impact matrix and the according graph; variables V1, V2, and V3 are displayed as nodes and impacts as arrows (directed links).*

Graphs produced with the `WeightedAdjacencyGraph`-function form the basis for quantitative analyses but can also be used for qualitative assessment of systems. Nodes are positioned automatically depending on the number of outgoing (out-degree) and incoming links (in-degree), disregarding strength, and according to aesthetic criteria (minimal edge crossing and even spacing between vertices). Thus, the most integrated variables inherit central positions, whereas variables with few links, i.e. a low total degree, are placed in the periphery. Additional functions exist for emphasising specific interactions by highlighting selected nodes and links.

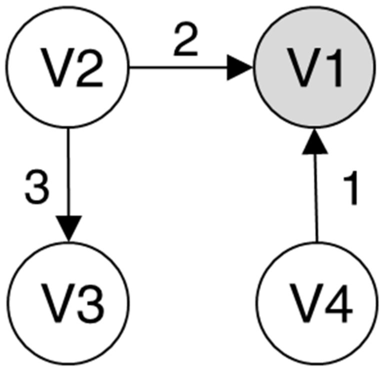
In graph theory, a path is defined as the connection between two nodes, where all the nodes (and thus necessarily all links) are distinct (Harary, 1969). By this definition paths are never loops and do not contain loops. Paths between pairs of variables were evaluated on system level by means of the function `FindPath.` This function, after specifying start and end nodes as well as the length(s) of the paths under investigation, returns the number of specified paths in each system. Path length in this study was restricted to a maximum of 7 nodes (equals 6 links) due to restricted computing capacity. Path weight (or impact strength) was defined as the geometric mean of the individual weights (or strengths) of all links involved (Onnela *et al.*, 2005). In order to assess the overall impact of variables within a system the sum of the impact strengths of all their outgoing/incoming paths was computed. Relative values for comparing variables' overall impact across different path lengths and across farms were obtained by assigning ranks and by computing the proportional impact of/on one variable using R (r-project.org). Variables were ranked on farm level whereby the most influential or most influenced variable was assigned rank 1. Ties (equal values) were treated with the `min` function, i.e. they were replaced by their minimum.

The proportional outgoing impact (PO) of one variable on another variable was computed by dividing its impact on that variable by its total outgoing impact (***Figure 5.2***). In contrast, the proportional incoming impact (PI) is the share of one variable in all incoming impact of another variable (***Figure 5.3***). PO and PI were determined on farm level. In order to compare the most influencing and most influenced variables across farms, the median of all farms was used.



$$\text{PO (V2} \rightarrow \text{V1)} = \frac{2}{5} = 0.4$$

Figure 5.2. *Proportional outgoing impact (PO) of V2 on V1.*



$$\text{PI (V1} \leftarrow \text{V2)} = \frac{2}{3} = 0.67$$

Figure 5.3. *Proportional incoming impact (PI) of V1 from V2.*

5.3 Results

5.3.1 Graphs

Graphs were created for 192 farm systems based on the pre-defined 13 variables and impact matrix cell values. Two examples are displayed in ***Figure 5.4*** (p.72). Farm A is characterised by few links and thus a lightly branched network, with reproduction management (RE) being completely disconnected. The variable production diseases (PD) has a central position and is most interlinked with a total degree of 13. Cross-linking density, in comparison, is much higher in farm B. PD is also strongly integrated (total degree: 20), but central positions are inherited by the variables herd health monitoring (HM) and labour capacity (LC).

The study farms varied widely in the number of identified interactions (see ***Table 5.2***, p.72). With increasing path length the number of paths in a system increases. Whereas, until a length of 6, the increase in farm A is almost linear it is rather exponential in farm B.

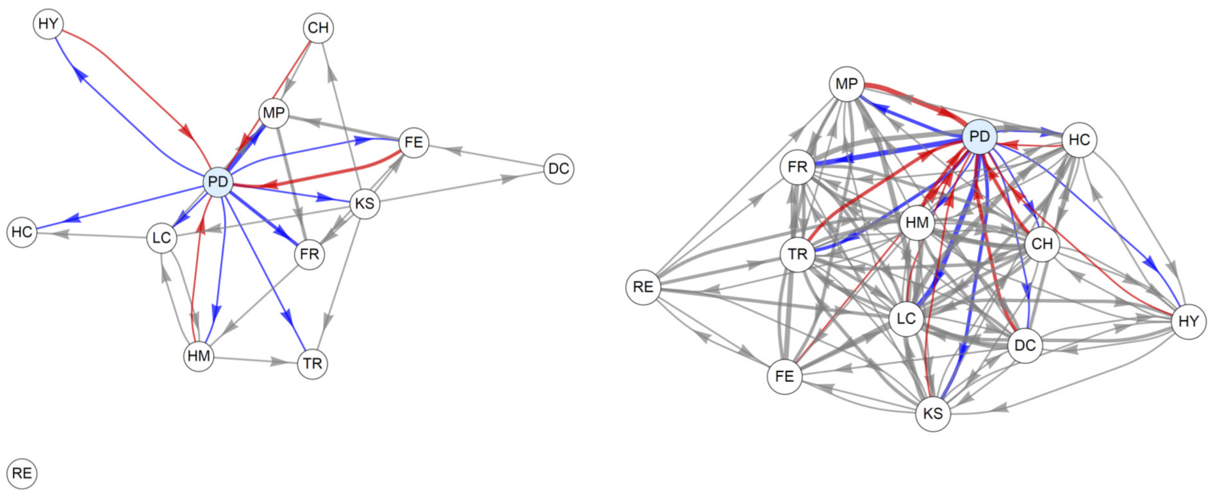


Figure 5.4. *Directed graphs of farms A (left) and B (right) with arrow thickness indicating link weight; highlighted is variable production diseases (PD) with outgoing links (blue) and incoming links (red); other variables are milk performance (MP), financial resources (FR), labour capacity (LC), feeding (FE), housing conditions (HC), reproduction management (RE), dry cow management (DC), calf and heifer management (CH), herd health monitoring (HM), hygiene (HY), treatment (TR), and knowledge and skills (KS).*

Table 5.2. *Numbers of paths of different length in farms A and B with median and range (min – max) of all farms (n=192).*

		Number of paths			
		Farm A	Farm B	Median all	Range all
Direct paths	2 variables (1 link)	30	104	84	25 – 155
Indirect paths	3 variables (2 links)	73	761	504	38 – 1,694
	4 variables (3 links)	132	5,017	2,679	45 – 16,830
	5 variables (4 links)	170	29,082	12,384	42 – 150,480
	6 variables (5 links)	177	145,940	47,601	31 – 1,195,920
	7 variables (6 links)	143	622,376	154,319	13 – 8,316,000

5.3.2 Outgoing and incoming impacts

Figure 5.5 and ***5.6*** (p.73f.) present the rank distribution for the system variables in terms of their outgoing and incoming impacts with increasing path length. Considering only direct impacts (path length 1) production diseases was the most influential variable across all farms, reaching a median rank of 2, followed by knowledge and skills with a median rank of 3.5. The directly most influenced variables across farms were financial resources and milk performance, both with a median rank of 2, followed by production diseases and labour capacity. With increasing path length, the relative importance of production diseases as influencing variable declined, whereas other variables gained influence, e.g. herd health monitoring and housing conditions. A similar reduction in rank for production diseases was observed with regard to ingoing impacts. With increasing path length, feeding and reproduction management became more susceptible to influence. Milk production and financial resources remained the most highly ranked variables until length 6.

On the farm level, rank changes with respect to both outgoing and incoming impacts occurred up until a length of 6, irrespective of the system being weakly interconnected or very dense. The extent to which variables' ranks changed was highest between length 1 and 2 (median = 1) and less when path length increased above 2 (median = 0).

The PO of the four most influencing variables and the PI of the four most influenced variables across farms was calculated until a path length of 6. Between 1 and 2 links values varied considerably, whereas consideration of paths longer than 2 links did not result in substantial changes. This is why ***Table 5.3*** (p.75) only displays proportional impacts until length 2.

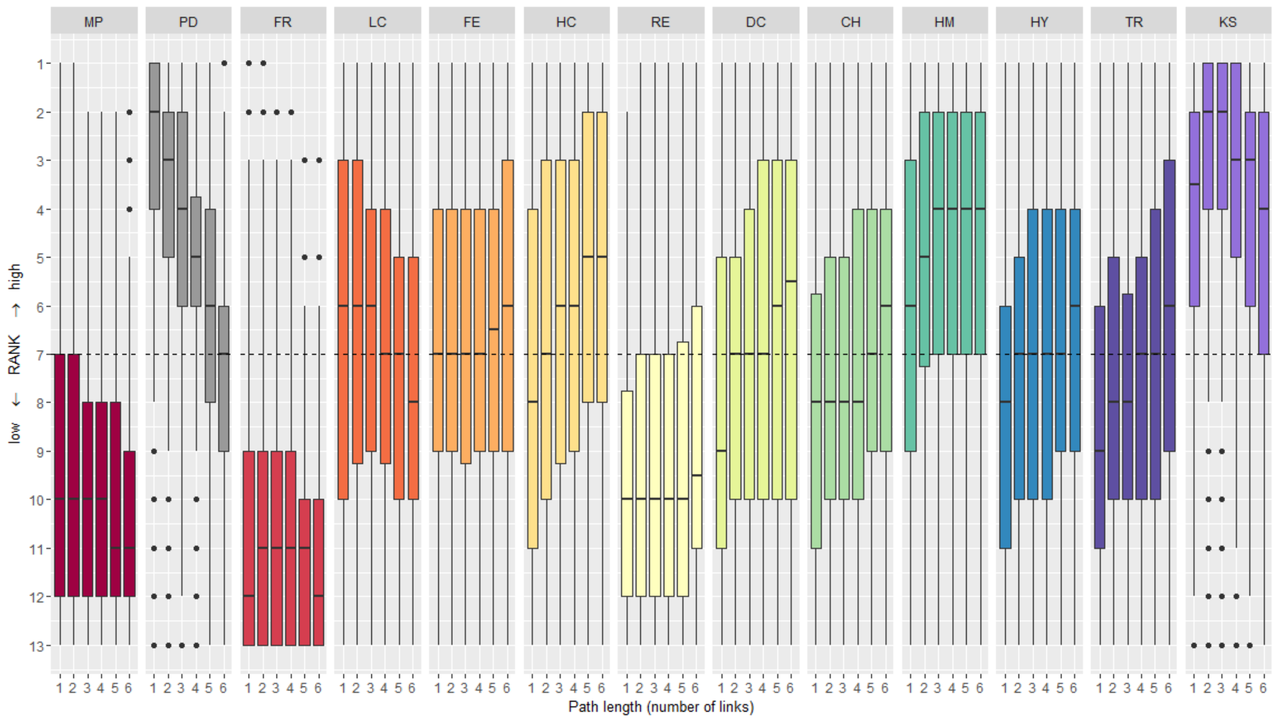


Figure 5.5. *Rank development with increasing path length of system variables in terms of their* <u>*outgoing*</u> *impacts across farms (n = 192); variables are milk performance (MP), production diseases (PD), financial resources (FR), labour capacity (LC), feeding (FE), housing conditions (HC), reproduction management (RE), dry cow management (DC), calf and heifer management (CH), herd health monitoring (HM), hygiene (HY), treatment (TR), and knowledge and skills (KS).*

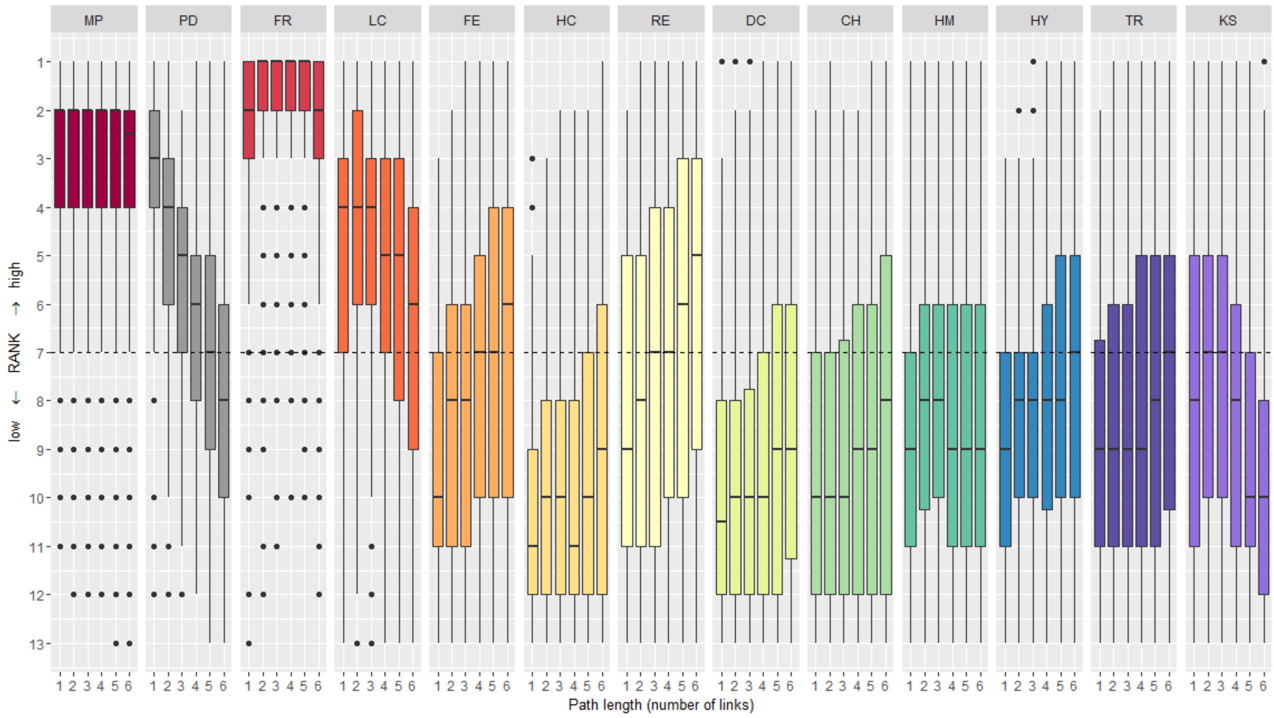


Figure 5.6. *Rank development with increasing path length of system variables in terms of their* <u>*incoming*</u> *impacts across farms (n = 192); variables are milk performance (MP), production diseases (PD), financial resources (FR), labour capacity (LC), feeding (FE), housing conditions (HC), reproduction management (RE), dry cow management (DC), calf and heifer management (CH), herd health monitoring (HM), hygiene (HY), treatment (TR), and knowledge and skills (KS).*

Table 5.3. *Proportional outgoing impact (PO) of the most influencing variables and proportional incoming impact (PI) of the most influenced variables expressed as median across farms (n = 192) at different path lengths (1-2 links).*

		Median PO								Median PI							
		PD		KS		HM		HC		PD		FR		MP		LC	
	Variable	1*	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1	Milk performance (MP)	.143	.108	.077	.126	.077	.118	.125	.109	.049	.068	.143	.055	---	---	.045	.070
2	Production diseases (PD)	---	---	.091	.119	.119	.107	.143	.095	---	---	.125	.113	.143	.106	.158	.109
3	Financial resources (FR)	.125	.131	.091	.130	.077	.127	.100	.125	.000	.071	---	---	.000	.058	.092	.052
4	Labour capacity (LC)	.125	.103	.077	.111	.093	.099	.111	.098	.065	.103	.071	.090	.050	.099	---	---
5	Feeding (FE)	.000	.079	.091	.059	.059	.069	.000	.068	.125	.072	.105	.084	.154	.073	.063	.085
6	Housing conditions (HC)	.000	.063	.071	.053	.000	.060	---	---	.100	.079	.064	.083	.079	.081	.096	.083
7	Reproduction management	.067	.078	.077	.072	.077	.074	.000	.075	.019	.061	.077	.057	.083	.054	.063	.066
8	Dry cow management	.067	.065	.077	.061	.077	.062	.000	.062	.100	.073	.056	.077	.083	.076	.057	.080
9	Calf and heifer management	.000	.070	.083	.057	.061	.061	.000	.062	.091	.065	.077	.076	.111	.062	.082	.077
10	Herd health monitoring (HM)	.083	.077	.083	.071	---	---	.000	.080	.091	.107	.058	.098	.059	.102	.080	.098
11	Hygiene	.083	.072	.077	.067	.071	.075	.100	.072	.111	.072	.059	.078	.059	.076	.096	.080
12	Treatment	.083	.074	.095	.062	.096	.071	.000	.071	.111	.067	.071	.073	.073	.069	.081	.078
13	Knowledge and skills (KS)	.095	.083	---	---	.108	.083	.000	.088	.091	.137	.077	.115	.062	.131	.086	.122

* path length

5.3.3 Most influencing variables

The four most influencing variables were production diseases, knowledge and skills, herd health monitoring and housing conditions. Most of the total direct impact exerted by production diseases went into milk performance, financial resources and labour capacity (see ***Figure 5.7***, p.77). Together they had an impact share of 39.3% (sum of medians). This proportional impact decreased slightly when only paths of length 2 were taken into account (34.2%). Feeding, housing conditions and calf and heifer management were least directly influenced by production diseases (median 0%). With increasing path length their impact shares became less distinguished from the other variables reaching 7.9, 6.3, and 7 percent, respectively.

Considering direct impacts, knowledge and skills affected treatment, production diseases, financial resources and feeding most. This changed considerably when indirect impacts were taken into account. Feeding and treatment were then replaced by milk performance and labour capacity. Herd health monitoring showed the greatest direct impact on production diseases, knowledge and skills, treatment and labour capacity. At length 2, however, its main influence was on financial resources (12.7%) and milk performance (11.8%). The largest impact share of housing conditions was exerted on milk performance, production diseases, financial resources and labour capacity, both directly and indirectly. Via direct paths, hygiene was also influenced by housing conditions (10%). The impact share, however, decreased significantly when indirect paths were considered (7.2%).

5.3.4 Most influenced variables

The four most influenced variables were production diseases, financial recourses, milk performance and labour capacity. Besides being very influential, the variable production diseases was also highly influenced by other variables. Variables with the highest direct impact share on production diseases were feeding (12.5%), hygiene and treatment (both 11.1%). Considering indirect impacts, however, knowledge and skills (13.7%), herd health monitoring (10.7%) and labour capacity (10.3%) had the highest proportional impact (displayed in ***Figure 5.7***, p.77).

Direct impacts on financial resources originated from three variables in particular, i.e. milk performance, production diseases and feeding (together 37.3%). Indirectly most affecting were knowledge and skills, production diseases and herd health monitoring. Milk performance was directly most influenced by feeding, production diseases and calf and heifer management. In terms of indirect influences knowledge and skills dominated (13.1%) followed by production diseases, herd health monitoring, and labour capacity.

Labour capacity was strongly influenced by production diseases, both directly and indirectly (15.8 and 10.9%, respectively). Whereas housing conditions and hygiene affected labour capacity directly as well, a higher percentage of indirect impacts came from knowledge and skills as well as herd health monitoring.

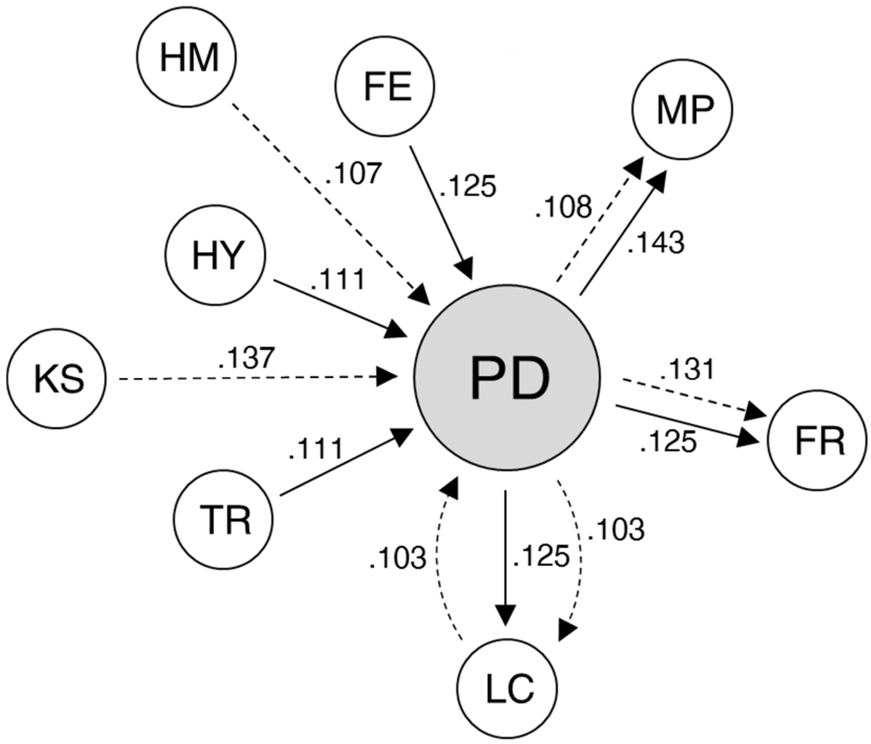


Figure 5.7. *Proportional incoming and outgoing impact of the variable production diseases (PD) expressed as median across farms (n = 192) at path length 1 (solid line) and 2 (dashed line); only variables with an impact share > 10% are displayed; influencing variables: feeding (FE), herd health monitoring (HM), hygiene (HY), knowledge and skills (KS), treatment (TR), and labour capacity (LC); influenced variables: milk performance (MP), financial resources (FR), and LC.*

Changing PI of production diseases with increasing path length in farms A and B is depicted in ***Figure 5.8*** (p.78). In farm A four variables exerted direct influence on production diseases, namely feeding, calf and heifer management, herd health monitoring and hygiene. Entirely different variables affected production diseases via 2 links, i.e. financial resources, labour capacity, reproduction management and knowledge and skills. In farm B, the variable production diseases was directly influenced by all variables, except financial resources and reproduction management, and indirectly by all variables, whereby impact shares varied significantly. Knowledge and skills represented the most radiating variable in farm A and could be expected to have a large effect on production diseases. In farm B the picture was somewhat more heterogeneous. At path length 6 the largest impact could be expected from a combination of knowledge and skills, herd health monitoring, dry cow management and reproduction management. All four variables together made up 44.6% of the influence working on production diseases in that farm system.

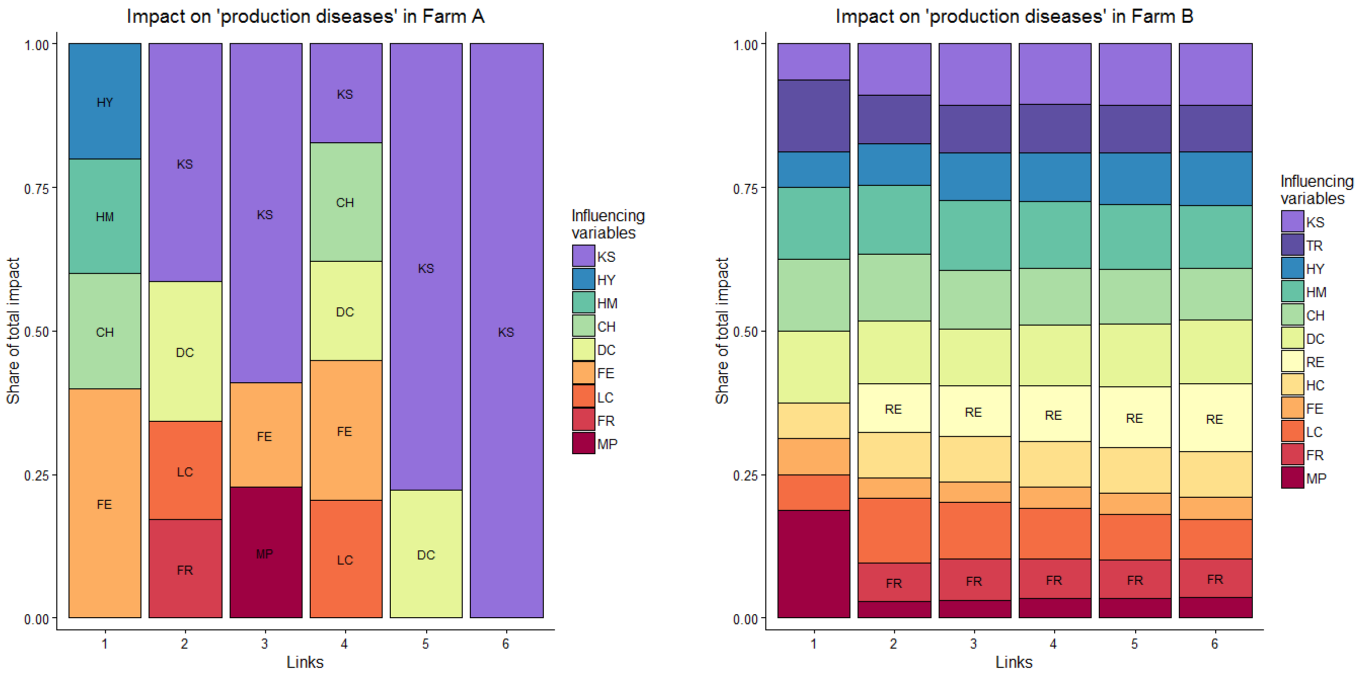


Figure 5.8. *Proportional incoming impact of production diseases in farm A and B; variables are milk performance (MP), financial resources (FR), labour capacity (LC), feeding (FE), housing conditions (HC), reproduction management (RE), dry cow management (DC), calf and heifer management (CH), herd health monitoring (HM), hygiene (HY), treatment (TR), and knowledge and skills (KS).*

5.4 Discussion

Advancements of the method used for this study are (i) the definition of paths as connections crossing a node not more than once and (ii) the follow-up of actual paths in a system by means of graph analysis. Matrix multiplication is basically a multiplication of links between two variables. Within the MICMAC method multiplication is reasonable, since links are assigned the value 1 (no link = 0). The product thus indicates whether there is (1) or is not (0) a longer path between two variables. ADVIAN, by multiplying strengths ≥ 1, is overestimating the indirect impact of one variable on another. A path of length 2 with strengths 2 and 3 would have a total strength of 6 in ADVIAN. In our study, the total strength of the same path is 2.4. By computing the geometric mean of the impact strengths involved in one path, path strength may be low because one of the links is very weak, or it may result from all of the links being weak, which resembles impact behaviour in reality (Onnela *et al.*, 2005). Thus, the graph-based analysis of indirect effects used in this study can be regarded as superior to previous methods.

Effects between system variables were scored on the farm level by individuals familiar with the farm system and knowledgeable in general mechanisms in organic dairy farming, i.e. farmers, veterinarians and advisors. This has two implications. On the one hand estimation of potential impacts is not purely subjective but intersubjective, based on the knowledge of the participants and their agreement, and thus validated (Velmans, 1999). On the other hand, the farm-specific context is taken into account. This means that interrelationships are not scored based solely on general knowledge ('feeding has an impact on milk performance') but also considering the relevance of such knowledge for the observed system ('on this farm, a change in feeding would cause a change in milk performance'). The latter involves information on the farm conditions (current feeding management, current milk performance, potential for change, potential effects of change) which has a great effect on the estimated impacts and thus on the graphs produced by the impact matrix. The variability of impacts (caused by different farm conditions) is reflected in the graphs of different farms and is also seen in the variability of their variable ranking. Although the variable knowledge and skills was highly influential in many farms, this being its general tendency, it also occupied the lower ranks in a distinct number of farms. This re-ranking of variables according to the farm context can be compared to the re-ranking of breeding traits because of genotype-environment interactions (Ismael *et al.*, 2016).

MICMAC and ADVIAN method both investigate indirect impacts with increasing length until a stabilisation in ranks occurs. Graph-based impact analysis does not lead to rank stabilisation (at least not until path length 7, which was the longest that was computed in this study). Although rank change on the farm level decreased with increasing path length, it did not cease altogether. An explanation for the continuous re-ranking in our study may be that feedback loops were not considered and impact strengths were not multiplied. A weakness of ranking in general, is that the actual distance between ranks is not known. Re-ranking did thus occur with very little changes in the absolute values of two variables. So besides ranks being very useful for comparing variable behaviour between farms and for identifying a system's most influencing and most influenced variables they may imply differences where there may barely be any.

Evaluating variables based on their behaviour within a system can be done based entirely on direct impacts (Krieger *et al.*, submitted, b). Our research has shown that the systemic role of variables may change substantially when indirect interactions are taken into account. Indirect influences are important characteristics of complex networks (Hub, 1994). Thus, they should be considered in impact analysis. Computing-capacity, in our study, limited the maximum path length that could be investigated. Thus, no statement can be made with regard to rank changes beyond a path length of 7. Computing a length of up to 12 would have been preferable to find out which is an optimal maximum path length to be considered. We found changes to be highest between direct impacts and paths of length 2, so considering the latter is already an advancement to former approaches and can be done with a normal computer. Longer paths, however, can increase a variables impact by their sheer number, which is why they should not be ignored.

Production diseases was found to be a highly influencing variable across farms. Most of its impact was exerted on milk performance, financial resources and labour capacity (directly and indirectly). Thus, improving the prevalence of production diseases, in many farms, is expected to have an effect on factors that are closely related to economic success, i.e. production, income and labour (Huirne *et al.*, 1997). It follows that even if improving production diseases is not the primary farm goal, it may be a way of reaching other farm objectives. One specific characteristic of production diseases is that they emerge from the complex interactions between other farm factors (Sundrum, 2014), which means they can only be changed indirectly via other variables. It is therefore no surprise that production diseases also was one of the most influenced variables. Variables affecting production diseases most in the studied farms were feeding, hygiene and treatment (directly) as well as knowledge and skills, herd health monitoring and labour capacity (indirectly).

Feeding having a direct effect on production diseases has been shown by numerous studies. Metabolic status is a direct result of feeding. Deficient nutrient supply and poor rumen health in dairy cattle are related to metabolic disease but also reproductive disorders, lameness and udder infections (Oetzel, 2014; van Saun and Sniffen, 2014). In many of the studied farms, a change in feeding management was seen to have the potential of improving the prevalence of production diseases. Nutrition is one aspect of the animal-environment interaction that does or does not lead to disease, depending on the adaptation of the animal to its living conditions (Sundrum, 2015). Another such aspect is hygiene, which also was one of the variables most affecting production diseases. Hygiene measures control the introduction and spread of infectious agents and thus determine to which extent the animal is exposed to (potential) pathogens (Noordhuizen and da Silva, 2009). In many study farms it was estimated that a change in hygiene could help to control the emergence of production diseases, hence the high mean PI. Treatment also reached high PI values in lots of farms with regard to production diseases. Sick and injured animals are treated to reduce suffering, promote healing and prevent the spread of disease. Early and effective treatment is an important component of disease control (LeBlanc *et al.*, 2006). The high PI indicates that the farm assessors saw potential effects from changing the treatment strategy in many farms with benefits for the prevalence of production diseases.

In terms of indirect effects, knowledge and skills, herd health monitoring and labour capacity had the highest proportional impact on production diseases. This rating acknowledges the fact that preventive and curative measures can only be applied if problems are recognised as such. Identification of health areas not under control requires good monitoring in terms of regular planned observations and documentation (Brand *et al.*, 1996). Implementation of (health-related) improvement measures is likely to be higher if the person in charge knows what to do and why, feels capable and has sufficient labour capacity at his/her disposal (Lam *et al.*, 2011). These interdependencies were recognised and considered by the persons doing the impact assessments, therewith increasing the degree by which the farm specific situation is reflected.

Via production diseases and other variables, knowledge and skills and herd health monitoring were shown to indirectly affect financial resources and milk performance to a large extent. Thus, their changing was expected to have far-reaching implications in many farms. Again, the identified relationships do not imply that more knowledge will generally lead to low disease prevalence, high milk yields and good income. It illustrates that a lot of farmers, veterinarians and advisors saw a potential benefit deriving from increasing the knowledge and skills on the farm. This assessment considers the knowledge and skills actually present on the farm and the current level of disease, yield and income. Both the required input (in terms of knowledge) for unfolding this potential and the expected output (improvement) is highly farm-specific. In a considerable proportion of farms, the variables with a strong general impact contribute much less to the prevalence of disease than others. Thus, the capacity of the approach is the ability to point out the deviation from general expectations and thereby enabling a farm specific selection of strategies, or as Bawden (1991) puts it: “Improvements come about as a result of all the participants exploring unanticipated patterns in unanticipated ways, but all from a framework that respects interconnectedness and the sense of wholeness”. The presented method can hekp to uncover which potentials are hidden in the different areas of each individual farm. For farms diagnosing knowledge and skills to be a lever for desired change, it may be an option to seek special advice or to consider educational training. Others may identify completely different tasks.

Future research should focus on different aspects: The variable set used for the graph-based impact analysis is characterised by a high aggregation level in order to ensure applicability in different farms and countries. In the future, the method could be tested on specific questions, e.g. the solving a single health issue, and follow up identified (direct and indirect) effects in reality. Besides evaluating impacts and their strengths, future studies could also assess the quantitative dimension of impacts, e.g. if a measure frees or ties up labour capacity. If positive (strengthening) and negative (weakening) impacts can be distinguished it may also be an option to study feedback loops since they provide some indication where there may be mechanisms of self-regulation in a system (Vester, 2007).

5.5 Conclusion

Farm factors most strongly influencing the prevalence of production diseases and thus with the potential to improve animal health can be identified on farm level by studying direct as well as indirect impacts. Graph-based impact analysis has been shown to be a suitable tool to assess the forces at work in a farm system. The presented method can help to clarify which potentials are hidden in the different areas of each individual farm and, based on goals, support the formulation of farm-specific strategies to improve animal health. In future, the method should be tested using more specific problem-oriented variable sets than applied in the current study and following up the resulting changes in order to evaluate the effectiveness of the approach.

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5.7 References

Bawden RJ 1991. Systems Thinking and Practice in Agriculture. Journal of Dairy Science 74, 2362–2373.

Béranger C and Vissac B 1994. An holistic approach to livestock farming systems: theoretical and methodological aspects. Proceedings of the 2nd International Symposium on Livestock Farming Systems, EAAP Publication 63, 5–17.

Boccara N 2010. Modeling complex systems, 2nd ed. Springer, New York.

Brand A, Noordhuizen, Josephus Pieter Thérèse Maria and Schukken YH 1996. Herd health and production management in dairy practice. Wageningen Pers, Wageningen.

Brand F 2013. Komplexe Systeme. Neue Ansätze und zahlreiche Beispiele. Oldenbourg Verlag, München.

Costa LdF, Rodrigues FA, Travieso G and Villas Boas PR 2008. Characterisation of complex Networks: A survey of measurements. Advances in Physics 56, 167–242.

Darnhofer I, Lamine C, Strauss A and Navarrete M 2016. The resilience of family farms. Towards a relational approach. Journal of Rural Studies 44, 111–122.

Dillon JL 1992. The farm as a purposeful system, Rev. ed. University of New England, Armidale, N.S.W.

Gibon A, Sibbald AR, Flamant JC, Lhoste P, Revilla R, Rubino R and Sørensen JT 1999. Livestock farming systems research in Europe and its potential contribution for managing towards sustainability in livestock farming. Livestock Production Science 61, 121–137.

Godet M 1979. The crisis in forecasting and the emergence of the „prospective“ approach. With case studies in energy and air transport. Pergamon Press, New York.

Götze U 1993. Szenario-Technik in der strategischen Unternehmensplanung [Scenario analysis in strategic corporate planning], 2nd ed. Springer Fachmedien, Wiesbaden.

Harary F 1969. Graph Theory. Addison-Wesley Publishing Company, Philippines.

Hoischen-Taubner S and Sundrum A 2012. Impact matrix: a tool to improve animal health by a systemic approach. In Tackling the future challenges of organic animal husbandry. 2nd Organic Animal Husbandry Conference, Hamburg, Trenthorst, 12 - 14 September 2012 (ed G Rahmann), pp. 139–142. vTI, Braunschweig.

Hovi M, Sundrum A and Thamsborg S 2003. Animal health and welfare in organic livestock production in Europe. Current state and future challenges. Livestock Production Science 80, 41–53.

Hub H 1994. Ganzheitliches Denken im Management. Komplexe Aufgaben PC-gestützt lösen. Gabler, Wiesbaden.

Hughner RS, McDonagh P, Prothero A, Shultz CJ and Stanton J 2007. Who are organic food consumers? A compilation and review of why people purchase organic food. Journal of Consumer Behaviour 6, 94–110.

Huirne RB, Harsh SB and Dijkhuizen AA 1997. Critical success factors and information needs on dairy farms. The farmer‘s opinion. Livestock Production Science 48, 229–238.

IFOAM 2006. The IFOAM Basic Standards for Organic Production and Processing. International Federation of Organic Agriculture Movements, Corrected Version, 2007, Germany.

Ismael A, Strandberg E, Berglund B, Kargo M, Fogh A and Lovendahl P 2016. Genotype by environment interaction for the interval from calving to first insemination with regard to calving month and geographic location in Holstein cows in Denmark and Sweden. Journal of Dairy Science.

Kristensen E and Jakobsen EB 2011. Challenging the myth of the irrational dairy farmer; understanding decision-making related to herd health. New Zealand Veterinary Journal 59, 1–7.

Lam TJGM, Jansen J, van den Borne, B H P, Renes RJ and Hogeveen H 2011. What veterinarians need to know about communication to optimise their role as advisors on udder health in dairy herds. New Zealand Veterinary Journal 59, 8–15.

LeBlanc SJ, Lissemore KD, Kelton DF, Duffield TF and Leslie KE 2006. Major Advances in Disease Prevention in Dairy Cattle. Journal of Dairy Science 89, 1267–1279.

Linss, V and Fried, A 2009. Advanced Impact Analysis:. The ADVIAN® method - an enhanced approach for the analysis of impact strengths with the consideration of indirect relations. Papers and Preprints of the Department of Innovation Research and Sustainable Resource Management (BWL IX) 1/2009: Chemnitz University of Technology.

Nir O 2003. What are Production Diseases, and How do We Manage Them? Acta vet. scand., 21–32.

Noordhuizen JP and da Silva JC 2009. Animal Hygiene and Animal Health in Dairy Cattle Operations. The Open Veterinary Science Journal 3, 17–21.

Oetzel GR 2014. Undertaking nutritional diagnostic investigations. The Veterinary clinics of North America. Food animal practice 30, 765–788.

Onnela J-P, Saramäki J, Kertész J and Kaski K 2005. Intensity and coherence of motifs in weighted complex networks. Physical review. E, Statistical, nonlinear, and soft matter physics 71, 65103.

Sands DM 1986. Farming Systems Research. Clarification of Terms and Concepts. Experimental Agriculture 22, 87–104.

Sundrum A 2014. Organic Livestock Production. In Encyclopedia of Agriculture and Food Systems (ed NK van Alfen), pp. 287–303. Academic Press, Oxford.

Sundrum A 2015. Metabolic Disorders in the Transition Period Indicate that the Dairy Cows' Ability to Adapt is Overstressed. Animals 5, 978–1020.

Vaarst M, Winckler C, Roderick S, Smolders G, Ivemeyer S, Brinkman J, Mejdell CM, Whistance LK, Nicholar P, Walkenhorst M, Leeb C, March S, Henriksen BIF, Stöger E, Gratzer E, Hansen B and Hubner J 2011. Animal Health and Welfare Planning in Organic Dairy Cattle Farms. The Open Veterinary Science Journal 5, 19–25.

van Saun RJ and Sniffen CJ 2014. Transition cow nutrition and feeding management for disease prevention. The Veterinary clinics of North America. Food animal practice 30, 689–719.

Velmans M 1999. Intersubjective science. Journal of Consciousness Studies 6, 299–306.

Vester F 2007. The art of interconnected thinking. Tools and concepts for a new approach to tackling complexity. MCB Verlag, Munich.

Vester, F and Hesler, A von 1980. Sensitivitätsmodell. Forschungsbericht 80-101 040 34, Bonn: Bundesminister. d. Innern.

Wolfram Research 2015. Mathematica, Version 10.1. Wolfram Research, Inc., Champaign, Illinois.

Supplementary material

Table S 5.1. *Outgoing and incoming impacts (quartiles and median) at different path length (1-6 links) for the 13 system variables*

			Path length (number of links)																	
			1			2			3			4			5			6		
		Variable	Q1	Med	Q3	Q1	Med	Q3	Q1	Med	Q3	Q1	Med	Q3	Q1	Med	Q3	Q1	Med	Q3
Outgoing	1	Milk performance	5	7	10	22	38	71	90	184	464	300	916	2,696	873	3,567	13,758	1,916	11,608	61,906
	2	Production diseases	12	15	18	46	75	107	166	357	642	506	1,451	3,418	1,298	5,329	16,356	2,742	15,722	65,326
	3	Financial resources	3	5	9	15	29	56	59	165	358	213	733	2,013	584	2,913	9,001	1,231	9,334	37,595
	4	Labour capacity	6	10	14	33	60	96	138	298	557	452	1,359	3,200	1,205	5,061	15,396	2,645	16,460	63,340
	5	Feeding	7	10	13	29	54	83	114	279	538	412	1,293	3,159	1,101	5,240	16,218	2,526	17,014	72,625
	6	Housing conditions	5	9	13	27	57	90	109	297	570	397	1,388	3,259	1,227	5,188	17,224	2,882	17,262	77,301
	7	Reproduction management	4	7	10	18	40	70	79	209	439	283	946	2,606	888	4,049	13,687	1,886	14,007	61,444
	8	Dry cow management	4	8	13	24	46	93	106	225	583	403	1,068	3,224	1,172	4,379	15,965	2,902	14,668	70,478
	9	Calf and heifer management	5	8	12	26	48	82	107	254	529	382	1,205	2,959	1,081	4,859	15,063	2,747	15,923	66,587
	10	Herd health monitoring	6	10	14	34	62	104	157	337	661	503	1,494	3,659	1,545	5,937	17,931	3,403	19,253	82,632
	11	Hygiene	5	8	13	26	52	91	115	268	576	406	1,186	3,264	1,208	4,666	15,928	2,680	15,068	68,116
	12	Treatment	5	8	12	30	50	83	124	267	528	433	1,274	3,233	1,203	5,254	16,169	2,812	17,338	67,591
	13	Knowledge and skills	10	13	18	52	76	113	202	397	688	661	1,773	3,926	1,784	6,748	19,596	3,904	22,095	78,078
Incoming	1	Milk performance	11	15	19	50	75	116	197	385	665	725	1,787	3,823	2,098	6,862	19,551	4,608	22,483	81,289
	2	Production diseases	10	14	18	40	65	104	144	306	609	454	1,305	3,485	1,126	4,781	16,905	2,286	14,206	64,303
	3	Financial resources	12	15	19	56	85	120	245	449	768	836	2,073	4,474	2,464	8,140	21,798	5,210	27,498	91,023
	4	Labour capacity	8	12	16	38	66	102	149	341	628	472	1,414	3,471	1,224	5,092	15,387	2,493	15,796	62,689
	5	Feeding	5	7	10	24	45	74	98	247	471	361	1,126	2,678	1,143	4,851	14,327	2,708	17,190	67,573
	6	Housing conditions	3	5	9	17	40	66	72	210	425	270	965	2,512	828	3,684	13,662	1,941	13,309	57,625
	7	Reproduction management	4	7	12	25	49	84	105	264	550	374	1,192	3,143	1,154	4,949	17,123	2,874	16,120	72,898
	8	Dry cow management	3	7	10	18	40	73	66	211	474	243	1,052	2,646	820	4,367	12,879	2,091	14,550	56,351
	9	Calf and heifer management	3	6	11	16	38	68	71	214	452	269	1,026	2,560	742	4,123	12,836	1,889	13,725	55,914
	10	Herd health monitoring	5	7	11	25	43	82	100	226	513	325	1,027	2,822	940	3,894	13,684	2,173	12,579	57,173
	11	Hygiene	4	7	11	24	43	81	98	217	521	351	978	3,115	1,076	3,745	15,171	2,436	13,025	64,097
	12	Treatment	4	7	11	23	43	75	99	216	480	369	1,104	2,586	1,054	4,330	13,053	2,333	13,881	60,998
	13	Knowledge and skills	5	9	13	29	51	89	103	258	553	345	1,107	2,978	858	4,139	13,609	1,822	12,859	55,813

* Q – quartile, Med – median

Table S 5.2. *Outgoing and incoming impacts and according ranks at different path length (1-6 links) of the 13 system variables in two farms A and B.*

			Farm A												Farm B											
			Impacts						Ranks						Impacts						Ranks					
		Variable	1*	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Outgoing	1	Milk performance	2	1	4	8	7	2	6	10	10	9	8	8	9	50	310	1,788	9,146	40,293	9	12	12	13	13	13
	2	Production diseases	12	17	19	21	17	12	1	1	3	4	6	6	17	109	671	3,648	17,109	67,758	2	3	4	5	7	7
	3	Financial resources	1	3	9	8	5	1	8	9	8	10	10	10	9	56	363	2,076	10,400	44,308	9	11	11	11	11	11
	4	Labour capacity	3	3	9	11	11	9	4	8	9	7	7	7	14	96	598	3,202	14,714	57,111	5	6	6	9	10	10
	5	Feeding	5	16	21	28	29	17	3	2	2	2	2	4	8	46	299	1,793	9,434	42,654	12	13	13	12	12	12
	6	Housing conditions	0	0	0	0	0	0	11	11	11	11	11	11	9	76	528	3,087	15,454	65,285	9	9	10	10	9	9
	7	Reproduction management	0	0	0	0	0	0	11	11	11	11	11	11	10	75	535	3,383	18,815	90,184	8	10	9	6	4	2
	8	Dry cow management	1	4	14	18	27	27	8	7	6	6	4	2	15	107	710	4,166	21,112	90,562	4	4	2	2	1	1
	9	Calf and heifer management	2	12	17	21	27	21	6	3	4	3	3	3	18	112	689	3,815	18,336	74,735	1	2	3	4	5	6
	10	Herd health monitoring	3	11	13	9	6	1	4	4	7	8	9	9	17	123	774	4,348	21,061	86,372	2	1	1	1	2	3
	11	Hygiene	1	9	16	19	21	17	8	6	5	5	5	5	8	80	562	3,383	17,496	76,362	12	8	8	7	6	5
	12	Treatment	0	0	0	0	0	0	11	11	11	11	11	11	11	92	583	3,302	16,207	67,260	7	7	7	8	8	8
	13	Knowledge and skills	6	11	32	52	56	59	2	5	1	1	1	1	13	97	660	3,876	19,512	82,929	6	5	5	3	3	4
Incoming	1	Milk performance	7	16	23	32	30	19	1	2	2	2	3	4	11	88	626	3,903	21,039	96,360	7	7	6	3	2	2
	2	Production diseases	5	6	6	6	6	1	3	7	8	8	7	11	16	107	660	3,614	17,052	68,170	2	3	4	6	6	6
	3	Financial resources	6	18	32	33	32	16	2	1	1	1	2	6	16	116	782	4,709	24,559	108,400	2	2	2	1	1	1
	4	Labour capacity	3	7	17	22	28	25	4	5	5	5	4	3	28	147	807	4,139	18,707	72,444	1	1	1	2	3	5
	5	Feeding	3	5	7	8	5	6	4	8	7	7	9	8	8	52	389	2,533	14,218	68,006	10	12	12	12	10	7
	6	Housing conditions	2	7	13	22	27	33	8	5	6	6	5	2	14	105	667	3,742	18,339	76,452	5	4	3	4	4	3
	7	Reproduction management	0	0	0	0	0	0	13	13	13	13	13	13	2	16	130	856	4,785	22,660	13	13	13	13	13	13
	8	Dry cow management	1	1	4	2	2	4	9	11	10	12	11	9	7	64	432	2,543	12,798	54,186	12	11	11	11	12	12
	9	Calf and heifer management	1	1	3	3	2	3	9	11	11	10	11	10	10	89	586	3,321	16,142	66,177	8	6	7	7	7	8
	10	Herd health monitoring	3	10	22	32	25	18	4	3	3	3	6	5	13	79	520	2,876	13,611	54,375	6	9	8	10	11	11
	11	Hygiene	1	3	6	5	6	6	9	10	8	9	8	7	8	75	516	3,029	15,316	65,667	10	10	10	8	8	9
	12	Treatment	3	8	20	29	38	34	4	4	4	4	1	1	15	101	648	3,656	17,866	73,981	4	5	5	5	5	4
	13	Knowledge and skills	1	4	3	2	5	1	9	9	11	11	10	11	10	80	520	2,946	14,366	58,935	8	8	9	9	9	10

* path length (number of links)

6 General Discussion

One aim this thesis was to assess the prevalences of production diseases in organic dairy farms in Europe and to identify potential drivers on the sector level by means of stakeholder consultation. The study countries were selected to represent a variety of environmental and structural conditions, as well as different experiences in organic farming, i.e. Sweden, Germany and France with a substantial number of organic dairy cows, and Spain with a comparably small but increasing organic dairy sector (EC, 2013). Health-related herd-level indicators were determined in a harmonised way using the same R scripts in all countries, which proved to be feasible but also challenging due to a high variability in national data structures and data quality. By using the uniform procedure, results were obtained that are highly comparable between countries, which is a major achievement. It shows, that routinely collected herd data can be used for the purpose of determining robust herd-health indicators, which is a precondition for regular monitoring.

The determined prevalences are in line with the results from previous studies that have shown that animal health in organic dairy systems is comparable with that in conventional systems. Achieving similar results with fewer treatments (von Borell and Sørensen, 2004) one could argue that organic dairy farms manage to fare better than their conventional colleagues. However, there are also studies reporting similar treatment frequencies (Fall and Emanuelson, 2009), and no information on treatments was available for the farms in this study. The high variation between farms indicates that some farms may indeed achieve high levels of animal health. Others, however, certainly do not, despite following the EU regulation on organic farming, which is mandatory for all study farms. This situation poses a threat to consumer confidence in the organic label (Nieberg and Offermann, 2003), and is probably also one reason, why stakeholders in the focus groups formulated the need to regularly monitor animal health in organic farms to identify those farms that do not achieve good levels of animal health, e.g. to allocate advisory services or other actions to those in dire need to change.

Differences between countries indicate that national conditions or practices may have a significant effect on disease prevalence. Swedish herds, for instance, were characterised by comparably low levels of subclinical mastitis and low lameness prevalence, which may be due to widely used animal welfare tools (Hallén-Sandgren et al., 2011) and a comprehensive monitoring system, i.e. the national cattle database in Sweden (Löf, 2012). Identifying factors contributing to these good national results is beyond the scope of this work, but may be worthwile in future studies, since it may identify strategies that could be transferred from a national to a European level. Besides regular monitoring, stakeholders generally agreed that there should be a frame of reference that helps to distinguish between farms achieving good animal health and those that do not and are thus in need of improvement. Although stakeholders varied in their preferred consequences for well performing farms (e.g. incentives, premium segment) and poorly performing farms (e.g. admonishment, sanctions, exclusion from the scheme), the majority agreed with the monitoring of each farms health performance in addition to the regular inspection of the compliance with the organic production rules.

The results, in showing that stakeholders see the need to inspect not only the conditions in which organic animals are kept but also the outcome in order to make sure the organic principle of health is put into practice, have important practical implications. The idea of using outcome-oriented criteria is not new. Performance criteria related to health have been demanded for some time (Blokhuis et al., 2003; Sundrum, 2001) and there have also been initiatives developing indicator sets specifically suited for organic dairy farming, at least in Germany (Brinkmann and March, 2015). Implementation on a European level, however, is still not within sight. One reason for this is certainly the fact, that although there is agreement about the organic principles, they represent very unspecific conepts. The IFOAM principle of health, for instance, covers the health of animals as well as the health of soil, plants, and humans (IFOAM, 2006), which led Padel (2005) to propose to establish a principle of animal health and welfare in the EU Regulation to specify the objective and thus “encourage more active engagement of all stakeholders with these issues” (p.5). The gap between the ethical values of organic agriculture and the organic practice, which van Huik and Bock (2006) refer to as ‘blurring ethics’, may be the reason for a mismatch between the expectations of consumers and producers, where consumers expect animals to be healthy and well, while farmers merely promise to follow rules (which do not necessarily result in meeting these expectations). A way out of this dilemma may be a new agreement between consumers and producers, which is based on measureable aims (Sundrum, 2014) and which is supported by politics and policies (Guthman, 2004). The definition of a common objective ‘good animal health’ would naturally demand regular monitoring of disease prevalences, and would justify consequences for poorly performing farms and thus lead to a convergence of expectations. Reliable herd-level indicators, like the ones applied in this thesis, could be used to verify if the aim of good animal health is being reached or to attest an improvement towards that common goal.

Another objective of this work was to evaluate the systemic interrelationships between farm factors in each specific farm and, in particular, to identify drivers for improving animal health on the farm level. For that purpose, impact analyses, slightly modified but comparable to the

Sensitivity Model (Vester, 2007), were applied during farm visits and the evaluation of the direct impacts between farm variables was used to support decision-making with regard to animal health management. The impact analysis offers a framework for structural assessment and knowledge exchange and, most of all, provides a tool that relates the individual knowledge of different experts to the system in question and its specific necessities. By that, the tested approach can be regarded as an alternative to common health planning where (veterinary) advisors apply general knowledge to the farm context and expect uniform outcomes with little consideration of the individual situation, preferences and perceptions of the farmer and farm-individual effect mechanisms (Sundrum, 2012). The approach facilitates mutual learning, supports system understanding and draws the attention to those areas that are crucial for optimising the farm, e.g. in terms of animal health. External persons are encouraged to address farmers' aims and expectations, support the formulation of goals and control their achievement taking into account the individual situation of farms, all of which are crucial aspects of animal health planning (Kleen et al., 2015).

Shortcomings of the applied method were the amount of time that was needed for the scoring of impacts and the sole focus on direct effects between variables. The variable list was designed to study the whole organic dairy farm as a system of interlinked components and accounting for the diverse production conditions across Europe. Since the scoring of interactions between more than 13 variables would not have been feasible in the given time frame, variables were highly aggregated. In future applications of the method, sets of variables could be developed suitable for specific goals or specific situations. Depending on the efficacy of the measures identified by means of such an approach, the benefits may be well worth the effort, even if larger variable sets were to be used.

The limitation to studying direct effects was overcome by enhancement of the impact matrix evaluation. By means of graph-based analysis, indirect relationships between farm factors were determined and evaluated both qualitatively, by studying the graphs, as well as quantitatively, by computing the actual impact paths, including their strengths. The method was shown to add valuable information to the results obtained by ordinary impact analysis and was successfully used to evaluate the relationships between farm factors and production diseases and to identify drivers to improve animal health in the farm context. To have a tool available that can capture complex networks consisting of many components and their mutual interactions and that can marginalise this complexity to an operational level, can be regarded as a milestone in dealing with the multifactorial processes leading to disease. Beyond that, there are endless possibilities for using the method, e.g. for different research questions in the fields of animal health and agriculture or for questions arising in other disciplines.

By computing individual paths, the method allows an investigation of specific connections between selected variables. This was crucial for determining variables related to production diseases within this work and may be useful also in other research contexts. With regard to future applications in practice it must be noted that the calculation of paths requires a lot of computing capacity. Due to this, the length of paths that could be studied within this thesis was limited, with calculations still taking several hours. By definition, paths in a system of 13 variables have a maximum length of 12 links. In order to comprehensively study all existing indirect effects, it would have been preferable to include all those paths in the analysis. Increasing the computing capacity in future studies may allow the study of all possible impact paths and thus contribute to a better understanding of system behaviour.

All results derived from the impact matrices, by ordinary or graph-based impact analysis, have in common, that they assign attributes to variables based on their relationships with other variables in the system. Thus, both methods use relational information to determine the systemic roles of individual variables. Within this study, production diseases was shown to be a highly influencing variable across farms. This is probably due to the fact that all 13 variables in the list were, by definition, supposed to be related to animal health in the organic dairy farm. The participants estimating strong links between production diseases and the other variables in the real farm situation, suggests that the variable set was well chosen. Most of the estimated impact of production diseases was exerted on milk performance, financial resources and labour capacity (directly and indirectly), whereas variables strongly affecting production diseases in the studied farms were feeding, hygiene and treatment (directly) as well as knowledge and skills, herd health monitoring and labour capacity (indirectly). The important aspect of these findings is not that they confirm general relationships that have been described in the literature. Unique about the approach is that each farm's highly individual situation was assessed, considering the present status of each variable, the potential change in each variable as well as current levels of disease. The strength of the approach is thus that it takes into account each system's (a.k.a. farm's) specific needs and constraints, and that it can point out the deviations from general tendencies.

A lot of farmers, veterinarians and advisors saw, for instance, a potential benefit deriving from increasing the knowledge and skills on the farm which means, in those cases, training and advisory may be suitable options to pursue the aims. However, in a lot of farms increasing the knowledge and skills cannot be expected to have the desired effect which was revealed by the impact analysis approach. By indicating the degree of influence exerted by the different farm areas, the method can prevent farmers, veterinarians and advisors from planning measures not likely to be effective (or not likely to be implemented) and instead promote changes that will potentially have an effect in the farm-specific situation. The approach is not a black box that when fed with information produces a list of promising measures, but it provides a structure that offers comprehensive insights from different perspectives and gives an orientation as to what the crucial areas in a farm are, and where changes will thus have a large impact. The approach does not replace proper diagnostics, but coupled with a thorough health assessment and cost-benefit-analysis, the impact analysis has the potential to greatly improve the animal health planning currently practised. In addition to its ability to capture complex farm interlinkages, the approach acknowledges the mindset of the farmer, which can inhibit the impact of a 'theoretically effective' measure, e.g. by leading to poor implementation (Lam et al., 2011). Enabling active participation of the involved actors and mediating between them as well as allowing mutual learning, the method may even move the farmer's mindset and thereby result in a better implementation of measures. Future research might give an answer to the question, if the presented approach can have an actual effect on the animal health status in (organic) dairy farms.

7 General Conclusions

This work has shown that the common production rules of organic dairy farming in Europe do not result in consistently low level of production diseases. Furthermore, a connection was drawn between the current health situation in organic dairy farms and the lack of a joint objective with respect to animal health. If the organic principle of health is taken seriously, there is the need to formulate a common aim and to install instruments to ensure and prove that the aim is followed by all dairy farmers in Europe who sell their products under the organic label. The basis of such instruments must be regular monitoring of the animal health outcome and an evaluation based on reference values, in order to identify farms not reaching the target and to direct interventions to where they are most needed. Access to harmonised data and standardised procedures are prerequisites for establishing the status quo and would have to be guaranteed if the idea of benchmarking farms across Europe was to be pursued.

It was also shown, that graph-based impact analysis represents a suitable method for modeling and evaluating the complex interactions between farm factors and for identifying the most influential components on the farm level taking into account direct and indirect impacts as well as impact strengths. Variables likely to affect the prevalence of production diseases were shown to vary largely between farms despite some general tendencies. This finding reflects the diversity of farm systems and underlines the importance of applying systemic approaches in health management. Knowledge on the behaviour of variables provided by the impact analysis can make an important contribution to the development of farm-specific strategies to improve animal health. The method does neither replace proper health diagnostics nor does it provide a recipe, in terms of a list of measures, for a successful intervention. Reducing the complexity of farm systems and indicating farm-specific drivers of animal health, however, it has the potential to complement and enrich current advisory practice and farmers' decision-making. The efficacy of measures identified with the help of an impact analysis has not been examined within this study and needs to be tested in prospective applications of the method, before it can be recommended for animal health planning.

8 References

Bawden, R., 1997. Learning to Persist, in: Stowell, F.A., Ison, R.L., Armson, R., Holloway, J., Jackson, S., McRobb, S. (Eds.), Systems for Sustainability: People, Organizations, and Environments. Springer US, Boston, MA, pp. 1–5.

Blanco-Penedo, I., Fall, N., Emanuelson, U., 2012. Effects of turning to 100% organic feed on metabolic status of Swedish organic dairy cows. Livestock Science 143 (2-3), 242–248.

Blokhuis, H.J., Jones, R.B., Geers, R., Miele, M., Veissier, I., 2003. Measuring and monitoring animal welfare: transparency in the food product quality chain. Animal welfare 12, 445–455.

Brinkmann, J., March, S., 2010. Tiergesundheit in der ökologischen Milchviehhaltung - Status quo sowie (Weiter-) Entwicklung , Anwendung und Beurteilung eines präventiven Konzeptes zur Herdengesundheitsplanung, Dissertation, Georg-August-Universität Göttingen, 279 pp.

Brinkmann, J., March, S., 2015. Tiergesundheit [Animal health], in: KTBL (Ed.), Faustzahlen für den Ökologischen Landbau [Reference values for organic farming], Darmstadt, pp. 472–477.

Cole, A., Allen, W., Kilvington, M., Fenemor, A., 2007. Participatory modelling with an influence matrix and the calculation of whole-of-system sustainability values. International Journal of Sustainable Development 10 (4), 382–401.

Conway, G.R., 1986. Agroecosystem analysis for research and development. Winrock International Institute for Agricultural Development, Bangkok, IX, 111 S.

Darnhofer, I., Bellon, S., Dedieu, B., Milestad, R., 2010. Adaptiveness to enhance the sustainability of farming systems. A review. Agronomy for Sustainable Development 30 (3), 545–555.

Dufour, S., Frechette, A., Barkema, H.W., Mussell, A., Scholl, D.T., 2011. Invited review: effect of udder health management practices on herd somatic cell count. Journal of dairy science 94 (2), 563–579.

EC, 2007. Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91.

EC, 2013. Facts and figures on organic agriculture in the European Union. DG Agriculture and Rural Development, European Union. http://ec.europa.eu/agriculture/markets-and-prices/more-reports/pdf/organic-2013_en.pdf.

Fall, N., Emanuelson, U., 2009. Milk yield, udder health and reproductive performance in Swedish organic and conventional dairy herds. The Journal of dairy research 76 (4), 402–410.

Garmo, R.T., Waage, S., Sviland, S., Henriksen, B. I. F., Østerås, O., Reksen, O., 2010. Reproductive performance, udder health, and antibiotic resistance in mastitis bacteria isolated from Norwegian Red cows in conventional and organic farming. Acta veterinaria Scandinavica 52, 11.

Godet, M., 1979. The crisis in forecasting and the emergence of the "prospective" approach: With case studies in energy and air transport. Pergamon Press, New York, xi, 134.

Green, M.J., Leach, K.A., Breen, J.E., Green, L.E., Bradley, A.J., 2007. National intervention study of mastitis control in dairy herds in England and Wales. The Veterinary record 160 (9), 287–293.

Guthman, J., 2004. The Trouble with 'Organic Lite' in California: A Rejoinder to the 'Conventionalisation' Debate. Sociologia Ruralis 44 (3), 301–316.

Hall, J., Wapenaar, W., 2012. Opinions and practices of veterinarians and dairy farmers towards herd health management in the UK. The Veterinary record 170 (17), 441.

Hallén-Sandgren, C., Winblad von Walter, L., Carlsson, J., 2011. Tools for improved animal welfare in Swedish dairy production, in: Widowski, T., Lawlis, P., Sheppard, K. (Eds.), Proceedings of the 5th International Conference on the Assessment of Animal Welfare at Farm and Group Level, 8-11 August, Guelph, Canada, p. 36.

Harper, G.C., Makatouni, A., 2002. Consumer perception of organic food production and farm animal welfare. British Food Journal 104 (3/4/5), 287–299.

Hoischen-Taubner, S., Sundrum, A., 2012. Impact matrix: a tool to improve animal health by a systemic approach, in: Rahmann, G. (Ed.), Tackling the future challenges of organic animal husbandry. 2nd Organic Animal Husbandry Conference, Hamburg, Trenthorst, 12 - 14 September 2012. vTI, Braunschweig, pp. 139–142.

IFOAM, 2006. The IFOAM Basic Standards for Organic Production and Processing: Version 2005, Germany.

Ivemeyer, S., Smolders, G., Brinkmann, J., Gratzer, E., Hansen, B., Henriksen, B.I.F., Huber, J., Leeb, C., March, S., Mejdell, C., 2012. Impact of animal health and welfare planning on medicine use, herd health and production in European organic dairy farms. Livestock Science 145 (1), 63–72.

Kleen, J.L., Beening, J., Detterer, J., 2015. Ergebnisse eines Workshops von Tierärzten und Landwirten zur Zusammenarbeit in der Betreuung von Milchviehherden. Tierärztl. Umschau 70 (3), 83–86.

Lam, T.J.G.M., Jansen, J., van den Borne, B H P, Renes, R.J., Hogeveen, H., 2011. What veterinarians need to know about communication to optimise their role as advisors on udder health in dairy herds. New Zealand Veterinary Journal 59 (1), 8–15.

LeBlanc, S.J., Lissemore, K.D., Kelton, D.F., Duffield, T.F., Leslie, K.E., 2006. Major Advances in Disease Prevention in Dairy Cattle. Journal of dairy science 89 (4), 1267–1279.

Linss, V., Fried, A., 2009. Advanced Impact Analysis: The ADVIAN® method - an enhanced approach for the analysis of impact strengths with the consideration of indirect relations. Papers and Preprints of the Department of Innovation Research and Sustainable Resource Management (BWL IX) 1/2009. Chemnitz University of Technology.

Löf, E., 2012. Epidemiological Studies of Reproductive Performance Indicators in Swedish Dairy Cows. Doctoral Thesis, Uppsala.

McEachern, M.G., Willock, J., 2004. Producers and consumers of organic meat. British Food Journal 106 (7), 534–552.

Messerli, P., 2000. Use of Sensitivity Analysis to Evaluate Key Factors for Improving Slash-and-Burn Cultivation Systems on the Eastern Escarpment of Madagascar. Mountain Research and Development 20 (1), 32–41.

Müller, U., Sauerwein, H., 2010. A comparison of somatic cell count between organic and conventional dairy cow herds in West Germany stressing dry period related changes. Livestock Science 127 (1), 30–37.

Nieberg, H., Offermann, F., 2003. The profitability of organic farming in Europe, in: OECD (Ed.), Organic Agriculture: Sustainability, Markets and Policies. OECD Publishing, Paris, pp. 141–151.

Padel, S., 2005. Focus groups of value concepts of organic producers and other stakeholders: EEC 2092/91 (Organic Revision Project Reports) Nr. D 2.1. University of Wales, Aberystwyth, Institute of Rural Sciences.

Rutherford, K.M.D., Langford, F.M., Jack, M.C., Lawrence, A.B., Sherwood, L., Haskell, M.J., 2009. Lameness prevalence and risk factors in organic and non-organic dairy herds in the United Kingdom. The Veterinary Journal 180 (1), 95–105.

Sundberg, T., Berglund, B., Rydhmer, L., Strandberg, E., 2009. Fertility, somatic cell count and milk production in Swedish organic and conventional dairy herds. Livestock Science 126 (1-3), 176–182.

Sundrum, A., 2001. Organic livestock farming: A critical review. Livestock Production Science 67 (3), 207–215.

Sundrum, A., 2012. Health and Welfare of Organic Livestock and Its Challenges, in: Ricke, S.C. (Ed.), Organic meat production and processing. John Wiley and Sons, Hoboken, NJ, pp. 87–112.

Sundrum, A., 2014. Organic Livestock Production, in: Alfen, N.K. van (Ed.), Encyclopedia of Agriculture and Food Systems. Academic Press, Oxford, pp. 287–303.

Thamsborg, S.M., Roderick, S., Sundrum, A., 2004. Animal health and diseases in organic farming: an overview, in: Vaarst, M., Roderick, S., Lund, V., Lockeretz, W. (Eds.), Animal health and welfare in organic agriculture. CABI, Wallingford, pp. 227–252.

van Huik, M.M., Bock, B.B., 2006. Attitudes of organic pig farmers towards animal welfare, in: Kaiser, M., Lien, M.E. (Eds.), Ethics and the politics of food. Preprints of the 6th Congress of the European Society for Agricultural and Food Ethics, EurSAFE 2006, Oslo, Norway, June 22-24, 2006. Wageningen Academic Publishers, Wageningen, pp. 550–555.

Vester, F., 2007. The art of interconnected thinking: Tools and concepts for a new approach to tackling complexity. MCB Verlag, Munich, 364 pp.

Vester, F., Hesler, A.v., 1980. Sensitivity model UNESCO Man and the biosphere project 11. Umweltforschungsplan des Bundesministers des Innern: UNESCO Man and the Biosphere Projekt 11.

von Borell, E., Sørensen, J.T., 2004. Organic livestock production in Europe: Aims, rules and trends with special emphasis on animal health and welfare. Livestock Production Science 90 (1), 3–9.

Wenzel, S., Igenbergs, E., 2001. Agent Systems Architectures for Complex and distributed Product Development Systems. INCOSE International Symposium 11 (1), 65–75.

Wessels, R., Lam, T.J.G.M., Jansen, J., 2014. Communication in Practice: The vet's manual on clienthusiasm. Nijmegen, the Netherlands.

Wiek, A., Binder, C., 2005. Solution spaces for decision-making - a sustainability assessment tool for city-regions. Environmental Impact Assessment Review 25 (6), 589–608.

Winckler, C., Brinkmann, J., 2004. Animal health in organic dairy farming – results from a survey in Germany, in: Hovi, M., Sundrum, Albert und Padel, Susanne (Eds.), Organic livestock farming: potential and limitations of husbandry practice to secure animal health and welfare and food quality. Proceedings of the 2nd SAFO Workshop, 25-27 March 2004, Witzenhausen, Germany, pp. 43–47.

Affidavit

I herewith give assurance that I completed this dissertation independently without prohibited assistance of third parties or aids other than those declared in this dissertation. All passages that are drawn from published or unpublished writings, either word-for-word or in paraphrase, have been clearly identified as such. Third parties were not involved in the drafting of the material content of this dissertation; most specifically I did not employ the assistance of a dissertation advisor. No part of this thesis has been used in another doctoral or tenure process.

Eidesstattliche Erklärung

Hiermit versichere ich, dass ich die vorliegende Dissertation selbstständig, ohne unerlaubte Hilfe Dritter angefertigt und andere als die in der Dissertation angegebenen Hilfsmittel nicht benutzt habe. Alle Stellen, die wörtlich oder sinngemäß aus veröffentlichten oder unveröffentlichten Schriften entnommen sind, habe ich als solche kenntlich gemacht. Dritte waren an der inhaltlich-materiellen Erstellung der Dissertation nicht beteiligt; insbesondere habe ich hierfür nicht die Hilfe eines Promotionsberaters in Anspruch genommen. Kein Teil dieser Arbeit ist in einem anderen Promotions- oder Habilitationsverfahren verwendet worden.

Witzenhausen, August 2016

Margret Krieger