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Animal health and welfare planning in dairy cattle

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Effects on animals and farm efficiency

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Für Reto und Simon, sie wissen warum

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Summary

Animal health and welfare planning (AHWP) is considered an important tool for herd management which is based on the assessment of the health and welfare state followed by the implementation of changes in management and housing. Participation of all involved persons, farm-specific measures regarding management and housing, high levels of compliance with those measures, continuous review, and prompt adaptation are considered to be decisive. (Partial) improvements in health and welfare following the use of AHWP have been shown by several on-farm studies, especially in the context of mastitis and lameness. However, studies on health and welfare planning that consider a more comprehensive view of welfare are scarce and the limited evidence available indicates that improvements may less likely be achieved. The first aim of this study was to review animal health and welfare planning approaches. Therefore, a review paper entitled "*Effectiveness of animal health and welfare planning in dairy herds: a review*" was published in 2015 in *Animal Welfare*. It includes a discussion on current knowledge for the evaluation of the success of health and welfare planning studies with respect to changes in health and welfare, farm economics and non-monetary benefits for the farmer. The main aim of this study was to conduct animal health and welfare planning on 34 Austrian dairy farms and to evaluate changes in health and welfare after one year. After an initial assessment using the Welfare Quality® protocol, health and welfare area(s) were discussed, for which both the farmer and the researcher regarded improvement as important. Management practices and husbandry measures were chosen according to the respective farm situation. One year after interventions had been initiated, the average implementation rate of the measures was 57% and thus relatively high when compared with other studies. With 77% and 63%, high degrees of implementation were achieved related to cleanliness and udder health respectively. Intervention measures addressing udder health were mostly easy to incorporate in the daily routine and led to a reduced somatic cell score while this score increased in herds without implementation of measures. Also the decrease of cows with dirty teats was more pronounced when measures were implemented compared to control farms. The implementation rate regarding leg health (46%) was comparably low in the present study, and even when measures were implemented, leg health did not improve. Lying comfort, social behaviour and human animal relationship did not require interventions in most farms and were therefore seldom chosen as part of the health and welfare plans. Based on the same sample of farms, the relationship between health and welfare state and technical efficiency was evaluated. Technical efficiency describes how inputs (e.g. land, feed) are used for producing output (e.g. milk). In the present study it was

investigated using data envelopment analysis. Farms with higher levels of animal health according to the WQ principle “Good health” were also technically more efficient. Furthermore, the effects of changes in health and welfare states on changes in technical efficiency were analysed using Malmquist index models. However, improvement or deterioration of the health and welfare state did not affect the Malmquist index (i.e. technical efficiency change). In conclusion, the structured, participatory process of animal health and welfare planning appears to be a promising way to improve at least some animal health and welfare issues. It is called for further investigations to clarify how changes in animal health and welfare states might also be reflected in farm economics.

Zusammenfassung

Tiergesundheits- und Wohlergehensplanung ist ein vielversprechendes Instrument für das Herdenmanagement, das auf der Implementierung von Maßnahmen in Management und Haltungsumwelt der Tiere beruht. Diese Maßnahmen entstehen in Zusammenarbeit mit allen beteiligten Personen und basieren auf einer Erhebung von Tiergesundheit und Wohlergehen. Betriebsspezifität, eine hohe Implementierungsrate der gewählten Maßnahmen sowie kontinuierliche Überprüfung und Anpassung an geänderte Gegebenheiten sind für den Erfolg entscheidend. Eine Verbesserung von Tiergesundheit und Wohlergehen, vor allem von Mastitis und Lahmheit, auf Basis dieses Planungsansatzes wurde bereits in mehreren Studien nachgewiesen. Wissenschaftliche Studien, die Wohlergehen in einem breiteren Sinne betrachten, wurden bisher jedoch selten durchgeführt. Als erstes Ziel dieser Arbeit wurden verschiedene Ansätze zur Tiergesundheits- und Wohlergehensplanung untersucht und die Ergebnisse in einem Review-Artikel *"Effectiveness of animal health and welfare planning in dairy herds: a review*" 2015 in der Zeitschrift *Animal Welfare* veröffentlicht. Dieser Artikel beinhaltet derzeitige Herangehensweisen zur Beurteilung der Effektivität von Tiergesundheits- und Wohlergehensplanung sowohl in Bezug auf Veränderungen in Tiergesundheit und Wohlergehen als auch betriebswirtschaftliche Auswirkungen und nicht-monetäre Nutzen für Milchviehbäuerinnen und –Bauern. Das primäre Ziel dieser Studie war es, auf 34 österreichischen Milchviehbetrieben Tiergesundheits- und Wohlergehensplanung einzuführen und mögliche Veränderungen von Tiergesundheit und Wohlergehen zu erfassen. Ausgehend von einer Erhebung von Tiergesundheit und Wohlergehen basierend auf dem Welfare Quality® (WQ)-Erhebungsprotokoll für Milchvieh wurden auf jedem Betrieb Bereiche besprochen, für die Bauern gemeinsam mit dem Forscher eine Verbesserung als notwendig erachteten. Unter Berücksichtigung der betrieblichen Gegebenheiten wurden Maßnahmen in Tiermanagement und Haltungsbedingungen ausgewählt. Ein Jahr nach Beginn der Interventionen waren im Mittel 57% der im Plan festgehaltenen Maßnahmen umgesetzt worden. Verglichen mit anderen Studien zeigte sich eine relativ hohe Umsetzungsrate, vor allem für die Bereiche Sauberkeit und Eutergesundheit (77% und 63% der Maßnahmen umgesetzt). Die Maßnahmen im Bereich Eutergesundheit ließen sich einfach in die tägliche Arbeitsroutine integrieren und führten zu einer Reduktion des Zellzahlgehalts während sich die Eutergesundheitssituation in Kontrollbetrieben (d.h. Betriebe ohne Intervention bezüglich Eutergesundheit) verschlechterte. Die Verbesserung hinsichtlich Sauberkeit der Zitzen war ausgeprägter, wenn entsprechende Maßnahmen umgesetzt wurden, als ohne Intervention. Die Umsetzungsrate bezüglich Lahmheiten war mit 43% relativ gering und es kam unabhängig

von der tatsächlichen Umsetzung zu keiner Verbesserung der Klauengesundheitssituation. Die Bereiche Liegekomfort, Sozialverhalten und Mensch-Tier-Beziehung benötigten in den meisten Fällen keine Interventionen und wurden von den Bauern selten als Zielbereiche in den Tiergesundheits- und Wohlergehensplänen gewählt. Basierend auf den Daten der 34 Milchviehbetriebe wurde weiterhin analysiert, ob sich Veränderungen von Tiergesundheit und Wohlergehen auf die technische Effizienz der Betriebe, ermittelt mit der Data Envelopment Analyse, auswirken. Technische Effizienz beschreibt, in welchem Maße Inputfaktoren (z.B. Fläche, Futter) zur Erzeugung eines Outputs (z.B. Milchmenge) umgesetzt werden. Betriebe mit besserer Tiergesundheit gemäß WQ-Prinzip „Good health“ zeigten höhere Effizienzwerte als Betriebe mit niedrigerem Tiergesundheitszustand im ersten Jahr der Studie. Änderungen im Tiergesundheits- und Wohlergehenszustand im Verlauf der Untersuchungen hatten keine Auswirkungen auf eine Veränderung der technischen Effizienz, dargestellt als Malmquist Index. Abschließend kann festgehalten werden, dass der strukturierte Prozess der Tiergesundheits- und Wohlergehensplanung zur Verbesserung mancher Bereiche beigetragen hat. Weitere Forschung wird nötig sein um abzuklären, wie sich Veränderungen in Tiergesundheit und Wohlergehen auf ökonomische Kenngrößen der Betriebe auswirken können.

Introduction

Dairy production in Austria

Dairy production plays a significant role in Austrian livestock farming (Waiblinger et al., 2001, BMLFUW, 2014). In 2013, dairy production contributed with a production value of 1.2 billion euros to approximately one third of the total livestock production value. Total milk production has constantly increased during recent decades, reaching about 3.4 million tons per year produced in 2013. At the same time, the total number of dairy cows has declined to about 525,000 dairy cows. Concurrently, the number of dairy farms has decreased by more than 50% within the last two decades, decreasing from 78,000 farms in 1995 to 33,000 farms in 2013. On average, a dairy farm in Austria keeps 13 cows. Milk yield per cow and year has constantly increased and is currently at about 7,200 kg per year across Austrian dairy cows (BMLFUW, 2014). Of all 405,000 dairy cows under milk recording, 73%, 13% and 11% belong to the breeds Austrian Fleckvieh, Braun Swiss and Holstein, respectively. Approximately 40% of all cattle are kept in tie-stall systems (Statistik Austria, 2010). However, as this figure does not differentiate between different types of cattle (i.e. dairy cows, beef cows, fattening cattle, calves), it is not possible to provide exact information on the relative distribution of housing systems for dairy cows.

Concepts of animal welfare

Animal welfare is a multidimensional concept combining several scientific disciplines. It is driven by ethical and societal concerns, as people are obligated towards animals in their care (Broom, 1996). Animal welfare is intrinsic for the animals and not something given to it by humans (Broom, 1996). The science of animal welfare emerged following the release of Ruth Harrison’s book “Animal Machines” (1964). This did not only lead to an intense public debate on how animals should be kept, but also motivated the UK government to form the Brambell committee (1965). As one outcome of the Brambell report, the Farm Animal Welfare Council subsequently developed guidelines known as “the Five Freedoms”. The Five Freedoms define welfare as the freedom: 1) from hunger and thirst; 2) from discomfort; 3) from pain, injury or disease; 4) from fear and distress; and 5) to express normal behaviour (FAWC (Farm Animal Welfare Council), 2009).

Scientists have proposed several definitions of animal welfare and one of the most common and accepted conceptualizations of farm animal welfare has been stated by Fraser et al. (1997). It includes three main approaches in defining animal welfare: 1) the animal’s feelings and emotions define whether the animal is feeling well or is suffering from hunger, thirst, pain etc.; 2) the animal’s biological functioning in terms of health and production of the animal; and 3) the animal’s naturalness describes the ability of the animal to perform normal behaviour and live, as far as possible, a natural live. These three areas overlap (von Keyserlingk et al., 2009). For example, a dairy cow suffering from clinical mastitis is likely to be in pain (affective state) (Leslie and Petersson-Wolfe, 2012), has reduced milk production and milk quality (biological functioning) (Hagnestam et al., 2007), and spends more time standing and less time lying (natural living) (Siivonen et al., 2011).

The multidimensional concept of animal welfare (Fraser et al., 1997) requires a broad approach in assessing welfare states on-farm (Botreau et al., 2007). Animal welfare can either be assessed by evaluating resource provision as well as management practices that are applied (resource-based measures, influencing factors; Waiblinger et al., 2001) or by assessing the animal directly (animal-based measures, welfare indicators; Waiblinger et al., 2001). Resource-based measures have shown to be quickly and easily assessed on-farm (Johnsen et al., 2001, Waiblinger et al., 2001) and produce reliable data (Bracke, 2007). This may be one reason for the inclusion of resource-based measures in early concepts of on-farm welfare assessment (e.g. Animal Needs Index (Bartussek, 1999) or quality assurance schemes (e.g. RSPCA Freedom Food scheme; Main et al., 2003). However, the validity of using resource-based measures in terms of assessing the actual health and welfare state is questionable due to the indirect approach and interactions with other resource parameters (Alban et al., 2001, Waiblinger et al., 2001). Since welfare refers to the animal itself rather than something given to it (Broom, 1996), indicators related to the animal have to be taken into account (Waiblinger et al., 2001, Whay et al., 2003). The first paper of this study (Tremetsberger and Winckler, 2015) reviews existing approaches for on-farm welfare assessment. Practical approaches to evaluate animal welfare include both resource-based as well as animal-based indicators (Bracke, 2007, Whay, 2007), the latter measured directly at the animal or through treatment records and production level (Ivemeyer et al., 2007).

Throughout this study, the terms “health and welfare” are used. This may appear tautological since health is an essential component of animal welfare (Keeling et al., 2011) and good health is fundamental to good welfare (Dawkins, 2008). However, this was chosen in order to clearly indicate the inclusion of animal welfare into the concept of herd health plans (Main et al., 2003, Sibley, 2006). Furthermore, for example lameness does not only reduce animal health, but, as highlighted by von Keyserlingk et al. (2009), also affects the three overlapping areas of welfare concerns described by Fraser et al. (1997).

Animal health and welfare of dairy cows in Austria

During the last decade, in total three scientific on-farm studies addressed the health and welfare state of Austrian dairy herds (Table 1). The studies applied pathological indicators (e.g. lameness, mastitis, integument alterations), physiological indicators (e.g. body condition) and ethological indicators (e.g. agonistic interactions, lying behaviour). Some areas of health and welfare state of Austrian dairy cows are incompletely reviewed, for instance, udder health was only addressed by two studies (Table 1). The high variation in udder health indicators (e.g. milk somatic cell count; treatment incidences udder diseases) and the sometimes poor situation (e.g. maximum 70% lame cows (Dippel et al. 2009); 5.1 agonistic interactions per animal per hour (Rouha-Mülleder et al. (2010)) indicates a need for more detailed analyses among a larger sample of dairy farms. In general, these studies show that health and welfare problems occur on Austrian dairy farms and highlight a large variability of these problems between farms. This points out the need for improvement, but also the potential for improving health and welfare of Austrian dairy cows.

Table 1 Prevalences/incidences of health and welfare indicators in Austrian dairy cows

Health and welfare area	Indicator	Median	Min - max	n farms	Reference
Udder health	Somatic cell score	2.8 ± 0.61	-[4]	39	Gratzer (2011)
	Somatic cell count (cells/ml milk)	192,100[3]	63,6601 - 789,000	80	Rouha-Mülleder et al. (2010)
	Treatment incidence udder diseases (%)	41	0 - 117	39	Gratzer (2011)
Leg health	% of lame cows	31[3]	6 - 70	30	Dippel et al. (2009)
	% of lame cows	36	0 - 77	80	Rouha-Mülleder et al. (2010)
	% of lame cows	23	0 - 59	39	Gratzer (2011)
	% of severely lame cows	4	0 - 43	80	Rouha-Mülleder et al. (2010)
	% of severely lame cows	6	0 - 27	39	Gratzer (2011)
Metabolic health	% of very fat cows	29	0 - 82	80	Rouha-Mülleder et al. (2010)
	% of very lean cows	8	0 - 55	80	Rouha-Mülleder et al. (2010)
	% of very lean cows	0	0 - 50	39	Gratzer (2011)
	Treatment incidence ketosis (%)	0	0 - 9	39	Gratzer (2011)
	Treatment incidence milk fever (%)	0	0 - 27	39	Gratzer (2011)
Integument	% of cows with integument alterations at the tarsal joint[4]	54	0 - 100	80	Rouha-Mülleder et al. (2010)
	% of cows with hairless area at the tarsal joint	23	3 - 100	39	Gratzer (2011)
	% of cows with lesions at the tarsal joint[1]	63	17 - 100	34	Brenninkmeyer et al. (2013)[5]
	% of cows with lesions at the tarsal joint	9	0 - 57	39	Gratzer (2011)
	% of cows with swellings at the tarsal joint	3	0 - 26	39	Gratzer (2011)
	% of cows with integument alterations at the carpal joint[2]	88	26 - 100	80	Rouha-Mülleder et al. (2010)
Fertility	Calving interval (days)	386[3]	340 - 430	80	Rouha-Mülleder et al. (2010)
	Calving interval (days)	395	-[4]	39	Gratzer (2011)
	Treatment incidence reproductive disorders (%)	8	0 - 54	39	Gratzer (2011)

[1] Includes scabs, wounds, and swellings, but no hairless areas; [2] Includes hairless areas; [3] Mean value; [4] Data not reported; [5] Describes same data set as Dippel et al. (2009)

Table 1 continued Prevalences/incidences of health and welfare indicators in Austrian dairy cows

Health and welfare area	Indicator	Median	Min - max	n farms	Reference
Cleanliness	% of cows with dirty udder (incl. teats)	73	28 - 100	39	Gratzer (2011)
	% of cows with dirty udder (incl. teats)	4	0 - 38	80	Rouha-Mülleder et al. (2010)
	% of cows with dirty hindquarter	54	0 - 100	39	Gratzer (2011)
	% of cows with dirty hindquarter	23	0 - 71	80	Rouha-Mülleder et al. (2010)
	% of cows with dirty lower hind legs	86	5 - 100	39	Gratzer (2011)
	% of cows with dirty lower hind legs	27	0 - 84	80	Rouha-Mülleder et al. (2010)
	% of cows with dirty belly	9	0 - 64	80	Rouha-Mülleder et al. (2010)
Lying behaviour	Duration of lying down movement (sec)	5.3	3.9 - 11.1	39	Gratzer (2011)
	% of cows with difficulties in rising movement	90	29 - 100	80	Rouha-Mülleder et al. (2010)
	% of cows with difficulties in lying down movement	83	31 - 100	80	Rouha-Mülleder et al. (2010)
Social behaviour	Agonistic interactions (per cow and hour)	1.1	0.1 - 3.7	39	Gratzer (2011)
	Agonistic interactions (per cow and hour)[1]	1.8	0.4 - 5.1	80	Rouha-Mülleder et al. (2010)
	Positive social interactions (per cow and hour)	0.4	0 - 1.2	80	Rouha-Mülleder et al. (2010)
Human-animal relationship	Avoidance distance at the feeding rack (cm)	8	0 - 70	39	Gratzer (2011)
	Avoidance distance at the feeding rack (cm)	20	0 - 70	80	Rouha-Mülleder et al. (2010)
	Avoidance distance in the stable (cm)	-[2]	0 - 150	35	Waiblinger et al. (2003)

[1] Includes interactions with physical contact; [2] Data not reported

Knowledge gaps

Gaps in knowledge regarding the application and effectiveness of health and welfare planning in dairy herds were identified as follows:

- At the onset of this thesis, a sound review on current approaches of animal health and welfare planning in dairy herds was lacking. There existed no compilation of scientific studies in this field with respect to health and welfare planning strategies, their uptake by farmers and their effectiveness.
- Dairy cattle health and welfare planning among Austrian farms has only been performed by Gratzer (2011) for organic cattle, achieving no significant improvement in health and welfare states. A study covering dairy cows on conventional farms was lacking.
- The economic impacts of poor health and welfare states have frequently been reported (e.g. Kossaibati and Esslemont,1997; Hogeveen et al., 2011). However, effects of improved health and welfare on farm economics have seldom been evaluated. Most studies have applied modelling when addressing the question, whether improved health and welfare is beneficial for the economic performance of a farm. Economic analyses in the context of on-farm studies are widely missing.

Aims of the thesis

The overall aim of this thesis was to apply an assessment system for the on-farm evaluation of health and welfare of dairy cows on a sample of Austrian dairy farms and, furthermore, to evaluate the effects on health and welfare as well as on farm economics.

The first chapter entitled "*Effectiveness of animal health and welfare planning in dairy herds: a review*" was published in 2015 in *Animal Welfare.* It deals with animal health and welfare planning and discusses studies in dairy cow farming that aim at improving health and welfare states by applying strategies while having several key indicators in common: initial assessment and evaluation of health and welfare by an external person, implementation of farm-specific measures as well as constant review and adaptation of measures. This structured process includes farmer ownership of goals and measures, involvement of all relevant people and the acknowledgment of good aspects on the farm. Furthermore, this chapter reviews current knowledge and existing methods for the evaluation of the success of health and welfare planning studies with respect to changes in health and welfare, farm economics and non-monetary benefits for the farmer.

The second research paper "A*nimal health and welfare planning improves udder health and cleanliness but not leg health in Austrian dairy herds*" (published in 2015 in *Journal of Dairy Science*) presents an on-farm study on the initiation of health and welfare plans in Austrian dairy cattle herds. In total 34 voluntarily participating dairy farmers were included in this study and their farms were assessed twice within one year. Data on health and welfare states as well as resource provision and management practices were collected. Based on the first assessment, farm-specific interventions in management and housing system were discussed on the farms and farmers were encouraged to implement these measures in their farms. This chapter discusses the results of the study with respect to the uptake of the measures and to the changes in health and welfare based on the interventions.

The same sample of farms was analysed in the third research paper "*Animal health and welfare state and technical efficiency of dairy farms: possible synergies*" which has been submitted for publication to *Animal*. Regarding effects of welfare state on farm economics, data envelopment analysis, a non-parametric method for the determination of technical efficiency, was applied. Moreover, Malmquist indexes were used in order to assess possible changes in efficiency over the period of the study and whether these changes were related to improvement or deterioration of health and welfare of the cows.

Journal contributions

This thesis is based on the three following publications:

I Tremetsberger, L., and C. Winckler. 2015. Effectiveness of animal health and welfare planning in dairy herds: a review. Animal Welfare 24, 55-67.

II Tremetsberger, L., C. Leeb, and C. Winckler. 2015. Animal health and welfare planning improves udder health and cleanliness but not leg health in Austrian dairy herds. Journal of Dairy Science 98, 6801-6811.

III Tremetsberger, L., C. Winckler, and J. Kantelhardt. submitted for publication. Animal health and welfare state and technical efficiency of dairy farms: possible synergies. Animal.
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Effectiveness of animal health and welfare planning in dairy herds: a review

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Abstract

Maintaining and promoting animal health and welfare are important but challenging goals in livestock farming. Animal health and welfare planning aims to contribute to improvements in the herd through interventions in a structured way. This review provides an overview of current scientific approaches to and improvements achieved by health and welfare planning in dairy herds regarding the health and welfare state of the cows, economic effects, and non-monetary benefits to farmers. Implementation of changes in management and housing is based on an assessment of the health and welfare state and relies on the participation of all involved persons. Farm-specific measures of management and housing, high levels of compliance with those measures, continuous review, and prompt adaptation are decisive. Improvements in health and welfare following the use of planning have been shown by several on-farm studies, especially in the context of mastitis and lameness. Studies on health and welfare planning that consider a more comprehensive view of welfare are scarce and the limited evidence available indicates that improvements may be less likely to be achieved. Apart from health and welfare benefits for the animals, economic and non-monetary benefits for the farmers are equally important. Costs of diseases and impaired health are available, while costs and benefits of interventions have been estimated with regard to mastitis and lameness only. Non-monetary factors (eg job satisfaction) have been reported as motivating factors for farmers but have attracted little scientific interest. Further research should focus on welfare aspects that go beyond the most important production diseases and the economic and non-monetary benefits of improving health and welfare in dairy cattle.

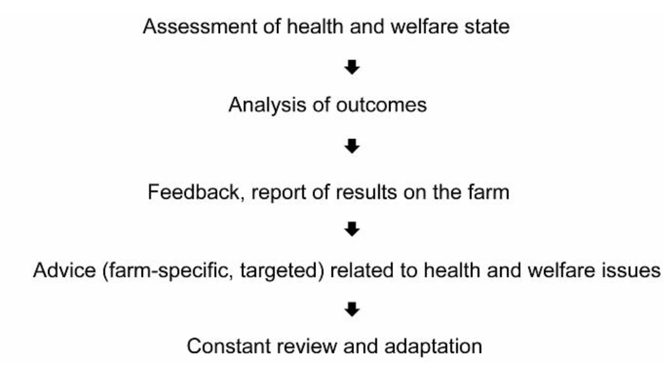
Keywords: *animal welfare, costs, dairy cows, improvement strategies, non-monetary benefits, on-farm welfare assessment*

Introduction

Animal welfare has received increased attention among European consumers (European Commission 2007), and during the last two decades farm animal welfare science has evolved into a well-recognised scientific discipline (Millman *et al* 2004). While welfare-friendly housing systems and management procedures (eg studies on cow comfort; Cook & Nordlund 2009) have been developed, surveys indicate that health problems, such as lameness, mastitis or skin lesions, are still highly prevalent and often exceed expert-derived intervention thresholds (eg Whay *et al* 2003; Green *et al* 2007; Leach *et al* 2010a; von Keyserlingk *et al* 2012). Beyond this focus on animal health (biological functioning), a more comprehensive approach in defining animal welfare also includes the animals' feelings (affective state) and their ability to express natural behaviour (natural living) (Fraser *et al* 1997). However, surveys on the latter two areas are rare and cover only parts of it (eg von Keyserlingk *et al* [2012] on lying times in dairy cattle). Although it may seem tautological to use the term 'animal health and welfare planning', as health is one of the three aspects of animal welfare, we keep this term throughout this paper to make explicit that we are discussing all aspects of animal welfare. Moreover, most health and welfare planning activities that will be discussed in the present review had a strong focus on promoting animal health or on increasing welfare through enhancing health parameters. Substantial progress in developing valid, reliable and feasible assessment systems has been made (Main *et al* 2007; Knierim & Winckler 2009), but more effort is needed to actually improve animal welfare (Whay 2007). Assessing the health and welfare state and identifying and implementing appropriate interventions on-farm have received increased attention during recent years.

In dairy cattle, farmers, veterinary and agricultural advisors, and scientists have focused particularly on lameness (eg Whay *et al* 2003) and mastitis (eg Green *et al* 2007). However, despite a vast body of scientific evidence on (potential) risk factors, the implementation in terms of changes in housing conditions and management on-farm appears still inadequate (Valeeva *et al* 2007; Whay & Main 2010). Hence, improving health and welfare of dairy cows seems to rely on getting information across to farmers in a more suitable way and in encouraging decisions in favour of the animals (Jansen *et al* 2009; Garforth 2011).

Figure 1



Key features of animal health and welfare planning.

Animal health and welfare planning appears to be a promising way to achieve this. It is a structured process that builds on assessment of health and welfare, identification of risk factors, development and implementation of interventions, and constant review and evaluation. Animal health and welfare planning thus goes beyond the approach of herd health plans which were developed in the UK during the last two decades and became a significant part of UK farm assurances schemes (Nicolas & Jasinska 2008).

Although planning strategies for implementing changes directed at welfare improvements in dairy farms exist, few studies have analysed how effective these interventions were. Besides, an improved welfare state of dairy cows, economic and social benefits, such as increased productivity and enhanced work satisfaction, may arise for the farmers. Although research into motivating factors and incentives has shown a number of non-monetary incentives for improving animal welfare (Valeeva *et al* 2007; Leach *et al* 2010b), these benefits have been barely investigated.

This review discusses existing studies on animal health and welfare planning in dairy herds with a focus on the evaluation of their effectiveness concerning animal welfare improvements, as well as economic and non-monetary benefits to farmers. Moreover, it covers key features of health and welfare planning and discusses the implementation of measures with respect to housing and management. Furthermore, this review provides insights into methodological aspects of measuring efficiency and identifies factors for successful animal health and welfare planning.

Key features of animal health and welfare planning

Several scientific studies have covered different aspects of health and welfare in dairy herds and have applied different planning strategies (eg Vaarst *et al* 2007; Bell *et al* 2009; Brinkmann & March 2010). These approaches have either focused on single welfare concerns or on more comprehensive planning. Comprehensive approaches consider welfare issues besides health-related issues in the planning process, and a multitude of areas are covered simultaneously. In both cases, there exist common features as outlined below (Figure 1).

Assessment of health and welfare state

An initial part of all studies is the assessment of current health and welfare in order to find and implement management changes for welfare improvement. In most instances, the existing animal welfare systems focus on negative welfare states rather than aspects of positive welfare. However, there is increasing interest in positive welfare that goes beyond the prevention of impaired negative states (Boissy *et al* 2007), but knowledge on its assessment and on improvement strategies is still lacking. Early concepts of on-farm animal welfare assessment such as the 'Animal Needs Index' ANI-35 (Bartussek 1999) mainly focused on resource-based parameters addressing housing and management provisions (see Table 1). Similarly, farm assurance schemes developed (mainly in the UK) with the aim of assuring welfare, environmental, and food safety standards have also relied heavily on resource-based measures. They were used as veterinary tools to ensure acceptable levels of animal welfare and were oriented at assessing the husbandry provision (Main *et al* 2003). Resource-based protocols can easily be applied on-farm with considerable reliability but questionable validity, as they are only indirectly linked to the animals' welfare state (Alban *et al* 2001; Waiblinger *et al* 2001). Welfare as a multi-dimensional construct that includes the animals' emotional state and their ability to behave naturally requires more direct ways of assessment. Animal-based parameters are meant to better reflect how the animals are coping with their environment (Whay *et al* 2003). These parameters may be roughly divided into health- and behaviour-related measures (Table 1), with lameness, mastitis or skin injuries being typical examples of health-related measures. Animal-based parameters can either be assessed directly from the animal (via examination or observation) or through routinely

Table 1 Overview of animal- and resource-based measures for assessing health and welfare of dairy cows.

Type of measures	Parameter	Reference
Animal-based measures		
Health-related	Locomotion score	Winckler & Willen (2001); Whay *et al* (2003); Flower & Weary (2009)
	Mastitis incidence*	Green *et al* (2007); Ivemeyer *et al* (2009)
	Mortality*	Welfare Quality® (2009)
	Integument alterations, injuries	Weary & Taszkun (2000); Rutherford *et al* (2008); Brenninkmeyer *et al* (2013)
	Body condition score	Welfare Quality® (2009)
	Cleanliness of animals	Zurbrigg *et al* (2005)
Behaviour-related	Incidence of agonistic behaviour	Welfare Quality® (2009)
	Avoidance distance towards humans	Windschnurer *et al* (2008)
	Lying down behaviour	Pleasch *et al* (2010)
	Standing up behaviour	Chaplin & Munksgaard (2001)
	Lying time	Ito *et al* (2009)
	Qualitative behaviour assessment	Wemelsfelder *et al* (2001)
Resource-based measures		
	Provision of water	Welfare Quality® (2009)
	Access to outdoor loafing area, pasture	Welfare Quality® (2009)
	Design criteria (eg type of housing system, dimensions of cubicles, alleys)	Bartussek (1999); Welfare Quality® (2009)
	Floor condition	Bartussek (1999)
	Cleanliness of lying area	Bartussek (1999)
	Ventilation system	Bartussek (1999)

* Parameter obtained through routine collection of health data.

collected data (such as treatment incidences, or mortality rates). 'Affective states' could for instance be assessed through qualitative behaviour assessment or measuring the avoidance distance towards humans whereas, for example, lying behaviour or agonistic social behaviour would be assessments of 'natural living' (Fraser *et al* 1997). The Welfare Quality® assessment protocols (Welfare Quality® 2009) represent a mostly animal-based assessment approach and cover several livestock categories, including dairy cows. Designed for practical on-farm conditions, animal-based indicators are combined with measures in housing and management (Bracke 2007; Whay 2007) as well as using databases and farm records for insights into production level and treatment data (Ivemeyer *et al* 2007).

Analysis of outcomes and provision of feedback

Following the assessment, the outcomes are analysed and reports created and given back to the farmer (Figure 1). The report should act as a decision support tool on the farm, and the structure has to be readable and problem-oriented (Bonde *et al* 2001; Vaarst 2003). A well-balanced welfare report should thus give an overview as well as being comprehensive enough to provide detailed information on specific welfare concerns, which is essential for achieving welfare benefits (Bonde *et al* 2001; Bell *et al* 2006). In many cases, a benchmarking reporting system was used to allow comparison between the farms in question (Whay *et al* 2003; Brinkmann & March 2010; Ivemeyer *et al* 2012; von Keyserlingk *et al* 2012). Benchmarking can demonstrate what might be achievable through implementing specific measures (Huxley *et al* 2004), and it is a method to encourage farmers to participate in animal health and welfare planning (Gray & Hovi 2002).

Farm-specific, targeted advice

Knowledge of the actual health and welfare states of the animals will simultaneously serve as the basis for attempts to improve health and welfare. Advising in terms of proposing measures derived from experimental studies or from practical experience has for a long time been seen as a way of disseminating knowledge. For example, in a mastitis control study, Green *et al* (2007) involved two veterinary surgeons who were in charge of creating a mastitis diagnosis and control plan for the 52 participating farms. It was the veterinarians' task to come up with measures that were then presented to the farm personnel, and compared to

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already existing preventive measures on the farms. Across the 26 intervention farms, Green *et al* (2007) achieved an equal number of farms that implemented more than two-thirds, between one- and two-thirds, and less than one-third of the measures (such as improvements in post-milking teat disinfection, milking machine function, or detection of mastitis cases) after one year. Using a similar approach, Barker *et al* (2012) presented recommendations to the farmers participating in a lameness control study. Based on an assessment of the farm and an evaluation of possible risk factors, improvement measures were proposed to the farmers by one of the researchers. The farmers could then either agree, disagree, or state that they were uncertain about implementing the recommended changes. This resulted in an overall level of compliance with the recommended measures of 31%. In both studies, advice was always provided by external experts or scientists. Similarly, Main *et al* (2012) encouraged farmers with respect to taking action in lameness management and potential benefits and barriers of the whole process were discussed. The researchers had a comprehensive overview of good husbandry practice on other farms and used that insight in the discussion. However, a key aspect of animal health and welfare planning is the inclusion of all involved parties in the process of implementation, comprising, eg veterinary surgeons, nutritional consultants, and agricultural advisors. This was taken up by a UK study on dairy heifer lameness (Bell *et al* 2009) where the unique farmer-veterinarian pair was responsible for agreeing on the lameness action plan and measures that could realistically be implemented. The programme was based on an analysis of hazards and critical control points, and the results were reported on the farms by their regular veterinary surgeons. However, they reported 'less than satisfactory' concordance with lameness control plans. No farm complied with all areas agreed upon, and most farms implemented less than two elements of the plan.

The farmer has been identified as the main stakeholder in promoting animal welfare (Gray & Hovi 2002; Whay & Main 2010; Vaarst *et al* 2011), and especially the steps of setting targets at what to improve and developing suitable intervention measures on the farm require the full inclusion and motivation of all participants. Therefore, an even more interactive planning approach involves the participating farmers and their wishes and expectations in the planning step. This approach has resulted in farmer-owned decisions on problem areas that require improvement. Consequently, it is also up to the farmers to formulate suitable intervention measures while external persons, ie the advisors or researchers, act as facilitators and may support decisions with external knowledge. Recent studies have covered more comprehensive health and welfare planning (Brinkmann & March 2010; Gratzer 2011). Depending on the focus area of the health and welfare plan, Gratzer (2011) reported degrees of implementation between 67 and 44% for udder health and fertility, respectively. Implementation rates increased with time in Brinkmann and March (2010) with 32 and 72% one and five years, respectively, after measures for a range of health and welfare concerns had been discussed.

All the above-mentioned ways of communicating and advising can be extended to groups acting in the process of animal health and welfare planning. The so-called 'Stable Schools', first introduced by Vaarst *et al* (2007), builds on this approach. Guided by a facilitator, participating farmers form groups where they jointly become involved in setting goals on what to improve and developing measurements to examine change. The facilitator's role is to help the group maintain a fruitful discussion, and not to act as an advisor who disseminates knowledge and advice. It is important to have in mind the farmers' ownership of his or her farm and the farm-specific goal (eg minimising antibiotic treatment in dairy cattle; Vaarst *et al* [2007]). Attention has to be turned to an ongoing dialogue between the farmers in a group. Each of the participants shares and receives information and knowledge at the same time.

Measures for improvement, irrespective of the method of communication, need to be valid with regards to their potential effect and the number of measures addressing a specific health or welfare issue depends on the farm-specific situation and the problem itself. Measures applied in health and welfare planning can be derived from a pool of measures that are based on sound scientific findings (eg Telezhenko *et al* 2009; von Keyserlingk *et al* 2012; Brenninkmeyer *et al* 2013) or on farming expertise. However, choosing appropriate measures is not always a clear decision as knowledge on various management procedures, housing standards and technologies changes over time or effectiveness depends on the specific circumstances on the farms. For instance, Barker *et al* (2012) express doubts that all measures recommended for reducing claw lesions are beneficial for the cows. Although intended to increase lying comfort, the abrasive properties of sawdust as a bedding material deteriorated leg health. Such unintended consequences of recommendations may therefore explain a lack of positive effects on health and welfare and should be taken carefully into account (Bell *et al* 2009).

Continuous review and adaptation

Continuous review of a plan once established is decisive as health and welfare states undergo frequent changes and are not constant. A constant review process is essential to monitor targets established in the health and welfare plan, which allows for adaptations whenever targets are not met (Vaarst *et al* 2011). Reviews should take place annually or even more frequently to take seasonal variation into account (Bell *et al* 2006; Sibley 2006).

Evaluation of effectiveness

Measures developed during the planning process can only effectively improve health and welfare if they are actually implemented on-farm. The degree of implementation can thus be regarded as a measure of success. However, as outlined in the previous section, implementation rates vary considerably and not all studies report the levels of compliance. Reasons for varying degrees of implementation will be further discussed in due course (see *Success and risk factors for health and welfare improvement*). Most studies investigating animal health and welfare planning have focused on the assessment of possible improvements regarding the health and welfare of the animals themselves. However, in the following section we also regard a broader range of aspects, such as cost-benefit analyses and non-monetary benefits to the farmers that are important for a comprehensive evaluation.

Animal health and welfare improvements

Mastitis is often an important component of studies on health planning approaches, and these have demonstrated that successful improvement of udder health can be achieved. Focusing on clinical mastitis, Green *et al* (2007) implemented a mastitis control plan intervention on 26 UK dairy farms that did not differ significantly from a control group in herd size, milk yield or in the total incidence of clinical mastitis and the proportion of cows affected by clinical mastitis at the start of the study. During a one-year period, the mean incidence of cows affected by clinical mastitis as well as the mean incidence of clinical mastitis decreased on the intervention farms, on average, by 4% and increased on the control group farms by 19 and 18%, respectively. Level of compliance with the mastitis control plan is important, however. Farms with more than two-thirds of the measures implemented achieved a reduction in both the number of cows affected and the total number of mastitis cases of about 20%. Udder health deteriorated slightly in low-compliance farms (less than one-third of the measures implemented).

On 65 Swiss farms, which implemented changes in housing and management after a structured evaluation (such as improving housing conditions, milking technology or feeding management), the use of antibiotic treatments for mastitis decreased from 38.1 to 26.2 treatments per year per 100 cows within a two-year period (Ivemeyer *et al* 2008). When analysing the first year separately (Ivemeyer *et al* 2009), these improvements were not as pronounced as after two years. At the same time, bulk milk somatic cell count (BMSCC), as a means of assessing (subclinical) udder health, did not change significantly (178,000 vs 181,000 cells per ml in year 0 and year 2, respectively). A reduction in the use of antibiotics for mastitis treatment by approximately 50% was also achieved through the implementation of a one-year 'Stable School' (Vaarst *et al* 2007; Bennedsgaard *et al* 2010).

While tackling mastitis through structured planning processes seems to be promising, the effects of animal health and welfare planning on dairy cattle lameness as another significant welfare concern are ambiguous. Lameness prevalence decreased by about 12 percentage points over a three-year period on farms (n = 117) that received support from the research team on how to improve foot health as well as on farms (n = 72) which were only monitored (Main *et al* 2012). Baseline lameness prevalence was slightly, but significantly, lower in the support group than in the control group. When accounting for initial lameness, a significant interaction between year and support, a more pronounced reduction in lameness over time in the supported group was found. However, a clear reduction in lameness prevalence was achieved in the course of a four-year lameness intervention study on German organic dairy herds (Brinkmann & March 2010). In accordance with the farm managers' interests and motivation, the farms were allocated to either an intervention or a control group with 21 and 19 farms, respectively. Baseline levels of lameness were higher in intervention farms, but even when accounting for this effect, lameness prevalence on the intervention farms was significantly reduced (33.0 to 14.5%), whereas the change in the control group was less pronounced (18.5 to 15.4%). These changes were highly consistent over the study period. Besides the changes in lameness prevalence, the occurrence of swellings at the carpal joint was reduced significantly from 25.2 to 8.0% on the intervention farms.

Other studies were less successful in reducing lameness. In a two-year intervention study on heifer lameness that reported low levels of compliance with the changes in housing and management, no significant changes in lameness prevalence were observed (Bell *et al* 2009). A more recent study among 40 UK dairy farms (Barker *et al* 2012), allocated to either an intervention or control groups with 22 or 18 farms, respectively, resulted neither in a significant reduction in lameness nor changes in the prevalence of claw lesions.

Studies on more comprehensive animal health and welfare planning are rare, but the results indicate that improvement may be more difficult to obtain when several clinical issues are addressed simultaneously. For example, Ivemeyer *et al* (2012) aimed to reduce medicine use by addressing several health and welfare issues, such as udder health, fertility, metabolic disorders, and lameness on 128 organic dairy farms in seven EU countries. It was up to the participating farmers to choose area(s) of interest and one or several farm-specific goals for improvement. Most frequently, metabolic disorders, udder health and lameness were addressed. The total treatment incidence significantly decreased within the one-year project duration. However, as the vast majority of treatment were related to udder health, medicine use in this area was only significantly lower at the end of the survey period. This was paralleled by a significant improvement of the somatic cell score, again indicating the potential for effective interventions as regards udder health. When the data of 40 German dairy herds participating in the above-mentioned study were analysed separately for intervention effects regarding udder health, metabolic state and reproductive disorders, not only was a significant improvement in udder health found (14 intervention vs 26 control farms), but also treatment incidences of retained fetal membrane and endometritis were lower among the intervention herds (nine intervention vs 31 control farms; Brinkmann & March 2010). Regarding metabolic disorders, only slight and inconsistent changes were obtained. Improvement within a one-year period of comprehensive planning is not always found. For instance, changes in animal health and welfare were not found in the Austrian subsample of 39 dairy herds from the previous study (Gratzer 2011), however, only a small number of

Table 2 Economic costs of lameness and mastitis in dairy cattle as published in peer-reviewed papers.

	Lameness	Mastitis	
		Clinical	Clinical and sub-clinical
Kossaibati and Esslemont (1997)	357†/369‡	265†/316‡	
Enting *et al* (1997)	104†/23‡	–	
Ettema & Østergaard (2006)	192†	–	
Bruijnis *et al* (2010)	57‡	–	
Yalcin (2000)	–	–	233‡
Huijps *et al* (2008)	–	63‡	140‡
Hagnestam-Nielsen and Østergaard (2009)	–	428†/97§	
Hultgren and Svensson (2009)	–	529†/68§	

To facilitate comparison of results all currencies were converted into € (exchange rate used was that for the year of publication).
† Costs per case;
‡ costs per average cow in the herd;
§ costs per cow-year.

farms chose to address a multitude of health and welfare areas at one time. The relatively small sample size, and the fact that few farms addressed welfare-related besides purely health-related issues may explain these results.

Other areas of animal welfare, such as human-animal relationship or the incidence of agonistic interactions, have hardly ever been part of intervention studies. Hemsworth *et al* (2002) achieved behavioural and attitudinal changes in stockpeople toward dairy cattle in an intervention group compared to a control group. As a result, the mean flight distance of the cows, as a means of human-animal relationship, was significantly lower for the intervention group. However, the effect size was small (mean flight distance of 4.49 vs 4.16 m for control and intervention farms, respectively).

Economic effects

The inclusion of disciplines other than agricultural and veterinary sciences and ethics into the process of assessing and improving farm animal welfare has been repeatedly proposed (Lund *et al* 2006; Whay 2007). Economic aspects, however, have only been rarely taken into account in dairy health and welfare planning (Green *et al* 2007). It should be mentioned that economic evaluations are complex, and data on economics in health and welfare planning only exist to a small extent.

Animal health and welfare planning generates costs at different levels. The costs associated with this process can be generally categorised into costs of health and welfare problems, costs of the assessment itself, and costs of intervention measures (eg review on udder health economics by Hogeveen *et al* [2011]). If external advice is requested, the costs of these services have to be considered as well. While on-farm studies with a comprehensive view of welfare have not included economic evaluations, data are available on economic aspects of specific health concerns. For dairy cattle, the impact of mastitis and lameness on farm economics has been addressed specifically (Table 2). Costs of specific diseases vary largely, which may be attributed to different methodological approaches and factors included (Halasa *et al* 2007). This range of costs underlines the economic relevance of these health aspects and indicates that improvements (eg in udder health and lameness) might also be of economic interest.

Economic costs of other diseases have been rarely investigated. Reproductive performance was recently evaluated by Inchaisri *et al* (2010), computing an annual economic loss from poor reproductive performance of €88 per cow. Kossaibati and Esslemont (1997) estimated costs arising from vulvar discharge, retained fetal membrane, and milk fever amount to €235, €120, and €319 per case, respectively. Besides these figures, other areas, for example those related to animal behaviour, have not been analysed with respect to possible economic aspects.

Regarding the costs of the assessment, yearly costs of welfare assessment on dairy farms with automated milking systems have been estimated to amount to €2,430 for herds with 60–120 cows (Sørensen *et al* 2007). However, the true costs are likely to show a wide range as they depend largely on the comprehensiveness of the assessment protocol, labour costs of the assessor, the frequency of farm assessments, the availability of already recorded data from databases, and automation level of data acquisition.

If farmers are to change housing and/or management, decision support for animal health and welfare planning requires precise knowledge about costs of different intervention measures (Huijps *et al* 2010). Standard figures for costs of management routines as well as buildings and equipment are available in some countries (eg KTBL 2010). However, investment costs in particular, may vary to a great extent between countries or regions, while the labour demand for implementing certain management practices rather depends on the production system.

Particularly for mastitis and lameness, costs of interventions have been analysed by two recent studies (Huijps *et al* 2010; Bruijnis *et al* 2013). Labour costs and expenditures for different intervention measures showed considerable variation when computed for a default Dutch dairy farm with 65 dairy cows. For example, yearly costs of 18 management measures for the control of contagious and environmental mastitis pathogens ranged from €34 for rinsing milking clusters after milking cows with clinical mastitis to €7,994 for rinsing milking clusters after milking a subclinical mastitis case (Huijps *et al* 2010). The analysis of interventions for lameness identified measures associated with low annual costs per animal, such as additional foot trimming (€7 per cow per year), whereas labour-intensive management changes led to high costs, eg manual floor cleaning (€56 per cow per year) (Bruijnis *et al* 2013).

Besides the costs arising from the implementation of changes on a farm, benefits resulting from these management or housing changes are also of interest. For lameness, Bruijnis *et al* (2013) estimated the probability of a cow becoming lame when different intervention measures were applied. Comparing this situation with the default simulation without intervention revealed measures such as improving the lying surface with mattresses (€7 benefit per cow per year) or bedding (€1 per cow per year) or applying regular foot trimming (€1 per cow per year) as cost-efficient, while reducing stocking density only achieved a break-even.

In recent years, 'technical efficiency' has been developed as a comprehensive approach to investigating a farming system's efficiency. The technical efficiency of farms reflects how well farms convert inputs (such as land, animals, feed, and labour) into outputs (eg milk and milk components) (Stokes *et al* 2007). A widely used method for assessing technical efficiency is the data envelopment analysis, a non-parametric method where no assumptions on the underlying production function have to be made (Cooper *et al* 2003). With this approach, the performance of each dairy farm in terms of technical efficiency can be measured and benchmarked to the other farms in the sample. The outcomes of studies that have applied data envelopment analysis rely to a large extent on the quality and availability of data, and the sample of farms needs to be homogeneous (Dyson *et al* 2001; Barnes 2006). The technical efficiency approach also allows for calculating efficiency scores for non-economic factors, such as animal health and welfare (Barnes *et al* 2011) and farmer-related social and intellectual factors (Uzmay *et al* 2009).

Several studies have dealt with technical efficiency scores for dairy farms (Lawson *et al* 2004; Stokes *et al* 2007; Uzmay *et al* 2009; Huijps *et al* 2010; Barnes *et al* 2011; Hansson *et al* 2011), but few have focused on animal health and welfare as a factor. Recently, Barnes *et al* (2011) included lameness in dairy cattle as a measure of animal health and welfare into the calculation of technical efficiency using data envelopment analysis. Within a sample of 80 British dairy herds, farms with lameness prevalence below 10% were more efficient than farms with a higher percentage of lame animals.

Benefits from implementing management changes on a farm for mastitis have been analysed by Huijps *et al* (2010) using data envelopment analysis. Percentage improvement in udder health was derived from Monte Carlo expert evaluation analysis. In total, 18 different management practices were analysed, and results showed that four of these measures were the most cost-efficient ones: keeping cows standing after milking, rinsing milking clusters after clinical mastitis cases, using separate cleaning material for each animal, and wearing milkers' gloves. Although wearing milkers' gloves had only small effects on udder health, the very low costs associated with this measure resulted in a high cost-efficiency. In contrast, post-milking teat disinfection showed the highest efficacy concerning udder health but was not identified as a cost-efficient measure (Huijps *et al* 2010).

Hansson *et al* (2011) aimed to identify management practices that were more common on fully efficient Swedish dairy farms. Common management routines that are known to be successful to improving udder health, like post-milking teat disinfection, choice of bedding material or frequency of cleaning stalls, were less important for farm technical efficiency, although they may still have a positive effect on animal health and welfare. On the other hand, management decisions, such as culling cows with high somatic cell count or contacting a veterinary surgeon, were associated with a fully efficient farm (Hansson *et al* 2011). These findings point to a mismatch between what may be viewed best for the animals' health and welfare and for being cost-efficient. However, more expensive options may in some cases be needed to effectively improve welfare and giving advice to farmers based solely on cost-benefit considerations could hamper an improvement in animal health and welfare due to waiving successful interventions for the animals simply because they are less cost-efficient (Bruijnis *et al* 2013).

Non-monetary effects for the farmer

Besides economic benefits, farmers may experience other aspects of improved animal health and welfare as rewarding. Their goals may go beyond maximising economic profit, to include aspects such as job satisfaction (Hogeveen *et al* 2011). Such non-monetary social aspects are difficult to quantify, and so far have not been considered in animal health and welfare planning studies. However, they seem to be important factors for farmers and influence their motivation to implement changes. Such aspects have frequently been self-reported by farmers when analysing their motivation to become involved in animal welfare improvement (Valeeva *et al* 2007; Leach *et al* 2010b). For example, it has been shown that 'internal esteem' and 'taking pleasure in healthy animals on the farm' play a meaningful role in motivating farmers to control mastitis, and are equally as important as monetary factors (Valeeva *et al* 2007). With regard to their motivation to improve lameness, farmers even deemed 'being proud of a healthy herd' more important than the fact that 'lame cows lose money' (Leach *et al* 2010b). Thus, these non-monetary aspects should also be taken into consideration when influencing farmers' action.

Success and risk factors for health and welfare improvement

Awareness of problems

The farmers' awareness of animal health and welfare issues has to be considered in health and welfare planning (Vaarst *et al* 2006; Valeeva *et al* 2007; Jansen *et al* 2009). Different welfare concerns have shown to be unequally perceived by the involved farmers. For example, lameness in dairy cattle is often underestimated (Whay *et al* 2002; Main *et al* 2003; Barker *et al* 2010; Leach *et al* 2010a). Uncertainty and differences in the definition of a lame animal and lack of knowledge and training (Whay *et al* 2002) may be responsible for the misidentification of lameness, as well as the occupation of the farm staff with other work than observation of gait (Leach *et al* 2010a). Similarly, a certain level of lameness prevalence may be considered 'normal' and therefore not questioned further (Whay *et al* 2002; Leach *et al* 2010a; Šárová *et al* 2011). With regard to such inattentional blindness of the farm situation, Gratzer (2011) highlighted the potential of external, independent persons to overcome such barriers in the planning process. Compared with lameness, mastitis incidence is estimated more precisely by the farmers (Whay *et al* 2003). Farmers' estimations of economic losses caused by mastitis are, however, inaccurate as they overrate direct costs such as veterinary assistance but underestimate indirect costs caused by, eg increased replacement rates (Huijps *et al* 2008). Immediate penalties for decreased milk quality due to mastitis cases may be seen as one reason why awareness of mastitis is more pronounced (Whay *et al* 2003). The financial consequences of lameness seem to be less obvious to the farmer (Leach *et al* 2010a). However, with increasing duration of monitoring and advice, Brinkmann and March (2010) observed an improved detection of lame animals by the farmers themselves.

Comprehensiveness of approach

In general, focusing on one single aspect of health and welfare at a time seems to be more promising than comprehensive approaches. Farmers participating in studies that implement comprehensive plans (eg Ivemeyer *et al* 2012) prefer to focus on single but essential areas (Brinkmann & March 2010). In line with this, few farmers addressed welfare issues that contribute to a more comprehensive strategy when given the choice to address one or several areas (Gratzer 2011). Areas such as udder health, lameness, or fertility, were more important to the farm personnel, indicating the greater importance of disease and production-related issues in such comprehensive planning approaches. The farmers were less familiar with welfare-related areas such as human-animal relationship or the incidence of agonistic social behaviours.

Benchmarking

When providing feedback on the farms, too much detail and information can easily lead to losing the overview of the situation (Bonde *et al* 2001), and can furthermore hamper successful welfare improvement. Regarding the benchmarking approach, the participating farmers in a dairy cattle lameness intervention study appreciated the chance for comparison and competition with other farms (Brinkmann & March 2010). This may have increased the awareness of health- and welfare-relevant aspects of lameness, which is essential for any change in farmers' behaviour. Also, for health and welfare planning in organic pig production, Leeb *et al* (2010) underlined the relevance of benchmarking as a positive aspect for the farmer. However, in the context of lameness, UK dairy farmers were not convinced of the usefulness of being compared with other farmers (Leach *et al* 2010b).

Farmer attitudes

Farmers' commitment as regards the actual implementation of recommended measures is a main success factor for welfare improvement (Bell *et al* 2006). For example, improvement in udder health was associated with the rate of implementation of measures (Green *et al* 2007). The reasons for a lack of implementation often remain unclear or are not further discussed (Bell *et al* 2009). However, important properties appear to be the feasibility of implementation on the farms (Sibley 2006) and farm-specificity of interventions (Goeritz *et al* 2007; March *et al* 2007; Kristensen & Enevoldsen 2008).

Farmers that explicitly stated an aim of improving udder health achieved a reduction in BMSCC compared to farmers with other motivations (eg interested in herd health management; Ivemeyer *et al* 2008). Also, Brinkmann and March (2010) showed an improvement in udder and leg health, respectively, when the farms were allocated to the intervention group according to their motivation to actively improve the herd health state. This shows that farmers interested in such an intervention study can benefit from it; however it might not indicate that this approach would work for the average farm. The farmers have to acknowledge the plan as an effective management tool that benefits them and their animals (Hovi *et al* 2004; Bell *et al* 2006; Sibley 2006). The early participation of farmers giving their own perspective in finding practicable solutions is essential for the implementation of these changes, and should not be underestimated (Vaarst *et al* 2002; Hovi *et al* 2004; Vaarst *et al* 2007). For instance, assigning veterinary surgeons to implement a lameness control plan on the farms was not efficient in tackling lameness (Bell *et al* 2009). The veterinarians received the results of the assessment of the farms and were asked to develop lameness control plans. However, only after this stage were farmers involved in the planning process, which both veterinarians and farmers had to agree upon and this may have led to a low concordance with the plans.

External expertise

The latter example does not exclude the importance of involving external expertise, eg from agricultural advisors, nutritionists or veterinarians. According to Kristensen and Enevoldsen (2008), Danish dairy farmers were explicitly interested in involving experienced veterinarians. Also, Derks *et al* (2013) underlined the importance of high quality veterinarian advice and mutual trust in the context of veterinary herd health management. To meet this demand, veterinarians have to be able to combine classical veterinary disciplines with management and business to create a whole farm management plan.

Continuous review of the on-farm plan

A frequent review of the health and welfare plan is desired, but in practice not always achieved. Among 61 UK dairy farms, 87% had some form of written plan but only half of the farmers had reviewed their plans within the last 12 months (Bell *et al* 2006). It has been further shown that the frequency of coaching has an influence on how well the recommended measures will be put into practice (Green *et al* 2007; Ivemeyer *et al* 2009; Brinkmann & March 2010). Lameness reduction, as shown by Brinkmann and March (2010), relied to a certain extent on frequent advisory meetings on the farms especially in the first year after implementing the plan (up to four times). This allowed immediate adaptation of the improvement measures as necessary.

Baseline level of welfare issues

Farms with comparatively low health and welfare status show a higher potential for improvement (Green *et al* 2007; Ivemeyer *et al* 2009). Indeed, organic dairy farms in Denmark with high incidence of mastitis treatments considerably reduced the use of treatments, whereas initially good farms were less able to further improve their udder health situation (Bennedsgaard *et al* 2010). Similarly, the rate of improvement in lameness was positively associated with the initial prevalence (Brinkmann & March 2010; Main *et al* 2012).

Although this has never been further investigated, the fact that farms with an already high health state are less likely to improve may be attributed to two reasons. First, they may already be good at detecting problems and therefore retain a low incidence rate. Second, depending on the parameter, a ceiling effect may occur making health improvement beyond a certain point less likely.

Time-frame for effective interventions

Considering the variety of welfare areas and their multidimensional backgrounds, interventions are likely to require different time-periods in order to successfully improve health and welfare. The limited number of studies provides a heterogeneous picture but indicates that longer monitoring periods are more likely to reveal significant changes. Improvements in mastitis incidence have been found after one year (Green *et al* 2007), but Ivemeyer *et al* (2009) reported only trends for improvement of udder health after this period. However, two years advice on mastitis prevention resulted in significant improvements, for example, with regard to treatment incidence (Ivemeyer *et al* 2008). Long-term studies exceeding a two-year time-span are uncommon. Both Brinkmann and March (2010) and Main *et al* (2012) found a significant improvement in lameness after one year but improvement continued through the following three years. Changes in daily management and routine procedures might be easier and more quickly implemented whereas more fundamental changes will require a longer time-period (Ivemeyer *et al* 2009). Longer monitoring periods offer more time for the farmer to implement the proposed measures and, on the other hand, considerable improvements such as major changes in housing system or breed, require longer periods to become effective (Brinkmann & March 2010). For instance, adjusting the feed ration that involves adaptation of forage production will take at least one growing season to be noticeable. Similarly, the animals' response to, eg measures focusing on reproductive disorders, may require time. Improvements may also only become apparent at herd level when previously affected animals have left the herd since, for example, animals having suffered from lameness are more likely to recur (Hirst *et al* 2002; Dippel *et al* 2009).

Animal welfare implications

Innovative and effective approaches to improve dairy cattle welfare are urgently needed. Structured planning as outlined in this review seems to be a promising way to promote health and welfare in dairy cattle. While improvements have been achieved mainly with respect to lameness and mastitis so far, more comprehensive approaches that go beyond health-related aspects of animal welfare appear important but have been rarely studied. Similarly, information on economic aspects of health and welfare planning is scarce, but may contribute to improvement efforts in future. The inclusion of examination of non-monetary benefits to farmers also appears to be promising in this context.

Conclusion

Targeted animal health and welfare planning has been shown to be a promising approach for enhancing udder health. However, efforts to reduce lameness are not always successful. Studies on more comprehensive approaches addressing welfare in a wider sense are rare and the results less convincing. Further research regarding planning strategies should focus therefore on welfare aspects that go beyond the most important production diseases. While the costs of impaired health and welfare have been analysed, studies on the overall economic implications of improving health and welfare are scarce. Moreover, investigation of non-monetary benefits has frequently been demanded, but rarely been carried out. Successful planning processes are based on the participation of all involved persons and on mutual trust. Furthermore, appropriate and farm-specific measures in management and housing, a high compliance with those measures, continuous review and prompt adaptation appear to be decisive in ensuring plans are effective.

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Animal health and welfare planning improves udder health and cleanliness but not leg health in Austrian dairy herds

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ABSTRACT

Animal health and welfare planning is considered an important tool for herd management; however, its effectiveness is less well known. The aim of this study was to conduct animal health and welfare planning on 34 Austrian dairy farms and to evaluate changes in health and welfare after 1 yr. After an initial assessment using the Welfare Quality protocol (Welfare Quality Consortium, Lelystad, the Netherlands), results were reported back to the farmers. Health and welfare area(s) in which both the farmer and the researcher regarded improvement as important were discussed. Management practices and husbandry measures were chosen according to the respective farm situation. One year after interventions had been initiated, farms were reassessed, and the degree of implementation of improvement measures was recorded. The average implementation rate was 57% and thus relatively high when compared with other studies. High degrees of implementation were achieved related to cleanliness and udder health, at 77 and 63%, respectively. Intervention measures addressing udder health were mostly easy to incorporate in the daily routine and led to a reduced somatic cell score, whereas this score increased in herds without implementation of measures. The decrease in cows with dirty teats was more pronounced when measures were implemented compared with control farms. The implementation rate regarding leg health (46%) was comparably low in the present study, and leg health did not improve even when measures were implemented. Lying comfort, social behavior, and human–animal relationship did not require interventions and were therefore seldom chosen by farmers as part of health and welfare plans. In conclusion, the structured, participatory process of animal health and welfare planning appears to be a promising way to improve at least some animal health and welfare issues.

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Key words: animal health and welfare planning, dairy cow, implementation, Welfare Quality

INTRODUCTION

High levels of animal health and welfare are important for successful dairy cattle farming. However, health concerns such as lameness and mastitis have repeatedly been described during the last decades. Several studies indicate that foot and leg health (e.g., prevalence of lame cows) is at an unacceptable level (Whay et al., 2003) and has not improved appreciably during this time (Clarkson et al., 1996; Haskell et al., 2006; Dippel et al., 2009). Furthermore, levels of milk SCC and mastitis incidence are both relevant for welfare and farm economics (Huijps et al., 2008), thus emphasizing the importance of improving udder health (Green et al., 2007; Ivemeyer et al., 2008, 2012). The substantial between-farm variability of these health problems indicates that achieving or maintaining a high health state is possible within existing systems.

Improvement in health and welfare may be facilitated by approaches based on education, enforcement (i.e., legislation), or encouragement (Whay and Main, 2010). Advisory activities in livestock production have frequently been based on the dissemination of knowledge in a top-down approach and on providing technical information for improvement (Whay and Main, 2010). However, more recently, participatory involvement of the farmer has been considered crucial for successful interventions (Whay and Main, 2010; Main et al., 2012). For instance, the fact that a lameness control plan was only poorly implemented in UK dairy farms could be attributed to insufficient integration of farmers (Bell et al., 2009). On the contrary, encouraging farmers to take action to improve undesirable health and welfare states has proven successful in the past with respect to udder and leg health. For example, providing information on how to tackle lameness and supporting farmers in formulating a farm-specific lameness action plan rather than imposing predefined control measures by the researchers resulted in a decrease of lameness prevalence by approximately 12 percentage points in UK dairy herds (Main et al., 2012). Similarly, in a 2-yr study among 65 Swiss dairy farms, when farmers were included in the development of suitable improvement measures, treatment incidence of mastitis decreased by about one-third without deterioration of udder health (Ivemeyer et al., 2008).

Animal health and welfare planning constitutes an approach to integrate farmers' participation and encouragement. It was first introduced into British farming (Sibley, 2002) and made compulsory in most UK assurance schemes commencing in 2000 (Main et al., 2001). Several intervention studies (e.g., Bennedsgaard et al., 2010; Brinkmann and March, 2010; Ivemeyer et al., 2012) also applied the animal health and welfare planning approach. These studies emphasize the initial assessment and evaluation of health and welfare by an external person, implementation of farm-specific measures, and constant review and adaptation of measures as key aspects. The structured process includes farmer ownership of goals and measures, involvement of all relevant people, and the acknowledgment of good aspects on the farm (Vaarst et al., 2011; Tremetsberger and Winckler, 2015).

Until now, attempts to improve dairy cattle health and welfare have focused on the reduction of negative health states. However, the scientific concept of animal welfare reflects a comprehensive view, including the animals' emotional state (Duncan, 1996) and their ability to behave naturally (Fraser et al., 1997). On-farm studies addressing welfare improvement in terms of the animals' behavior such as human–animal relationship (**HAR**) and social behavior are rare, however. To our knowledge, so far only Gratzer (2011) has considered these aspects in dairy health and welfare planning.

The aim of the present study was to carry out animal health and welfare planning on 34 Austrian dairy farms and to evaluate changes in a range of indicators that reflect the multidimensional nature of animal health and welfare.

MATERIALS AND METHODS

Study Design and Farm Selection

The study was conducted from December 2011 to April 2013 on 34 dairy farms in 3 federal states in Austria (Lower Austria, Upper Austria, and Styria). Because the aim was to motivate farmers to implement improvement measures, farmers had to express initial motivation to take part. Recruitment of farms took place through various channels: in 3 districts in Lower Austria, farms were provided with a one-page information leaflet distributed by the milk recording service or by 3 veterinary surgeons. Farmers interested in participating could then approach the researcher directly. Within each region, some farms were included in the study after they had been informed by participating farmers, following a so-called snowball approach (Micheel, 2010).

All participating farms were family-run and averaged 39 ± 21 ha (mean ± SD) in size. On all farms, dairy cows were kept in cubicle housing systems (average age of the housing system: 9.1 ± 5.3 yr). Cows did not have access to pasture, but 11 herds had permanent access to a concrete outdoor run. The predominant breed was Austrian Fleckvieh, with 25 herds consisting of more than 90% of this breed. The remaining 9 farms kept either Holstein Friesian (2 farms), Brown Swiss (3 farms), or a mixture of all 3 breeds (4 herds).

Data Collection

During the study period, 3 visits in total to each farm took place. Data collection was carried out by one researcher (LT). The baseline health and welfare status was assessed during the first farm visit (winter 2011–2012; year 0). A second farm visit 55 ± 26 d (mean ± SD) after the initial assessment was used for developing the animal health and welfare plan (winter/spring 2011–2012; see below), during which improvement measures were initiated (i.e., health and welfare planning). Final data collection took place 423 ± 29 d after the health and welfare planning visit (year 1). On average, 368 ± 11 d elapsed between the health and welfare planning visit and the final visit.

Data collection was based on the Welfare Quality assessment protocol for dairy cattle, which relies, largely, on animal-based measures (Welfare Quality, 2009). The measures can be grouped into parameters assessed directly on the animal (observation of social behavior, avoidance of an approaching human, and clinical examination of the animals) or assessed through routinely collected herd data (e.g., milk SCC, mortality rates). A detailed description of the assessment procedure and the definitions of the parameters can be found in Welfare Quality (2009). Beyond the Welfare Quality assessment protocol, data collection was complemented by indicators of metabolic health (e.g., percentage of animals with a milk fat:protein ratio >1.5 as indicator of risk of ketosis; Table 1). This was done to collect detailed information about herd health status needed for detailed feedback on the farms. Similarly, dirtiness of teats was recorded more in detail (slightly and severely dirty teats) to be more precise in discussing possible interventions for increasing teat cleanliness. Additionally, SCS and the percentages of animals with a SCC >100,000 and >400,000 cells/mL, respectively, were included in the assessment protocol to obtain a broader picture of udder health.

These animal-based measures were complemented by the assessment of some resource-based parameters and management procedures using an interview with the farmer on the day of the assessment. All parameters were expressed at the herd level (e.g., percentage of lame animals). All but one of the farms participated in the nationwide milk recording scheme, which provided data on SCC and milk constituents, as well as average milk yield, average number of lactations, and herd size. The farm not participating in the milk recording scheme was excluded from the respective analyses.

Health and Welfare Focus Areas

Health and welfare indicators were used at the single-measure level and allocated to 6 focus areas (Table 1). Due to low prevalences, some indicators of disease (e.g., percentage of cows with nasal discharge) and the frequency of collisions with housing equipment during lying down were not considered as part of the health and welfare plans in the present study.

Health and Welfare Planning Process

The second farm visit was dedicated to the implementation of a health and welfare plan. For this purpose, data obtained from the first farm visit were reported back to the farmer using a written report. This report included presentation of farm-specific data benchmarked against the mean of peer farms. The visits for implementation of the plan started after 10 farms had been assessed, whose baseline situation was used as the benchmark. The benchmark data were updated after having assessed 20 and 30 farms; however, it did not change substantially in the course of the implementation visits.

The report was presented to each farmer by the researcher, and all focus areas described in Table 1 were subsequently discussed. In a first step, farmers chose one or more focus areas where action was regarded as important and the farmers also decided on which areas to prioritize. Specific, quantifiable aims were agreed upon; for example "reducing milk somatic cell count," "reducing lameness prevalence," or "reducing agonistic interactions." Prior to the visit, a list of potential improvement measures was developed based on a review of scientific literature, recommendations for good farming practice, and expert opinion. This list comprised interventions regarding management (e.g., teat disinfection, provision of bedding) as well as resources (e.g., protective gates for concentrate dispenser, rubber flooring), grouped into several sub-areas (e.g., cow hygiene, feeding; Table 2). During the discussion, farmers chose measures that were relevant to their situation and appeared to be suitable to achieve their chosen aim. Implementation of measures (yes or no) agreed in the health and welfare plans was recorded using a questionnaire and a resource checklist during the third farm visit (i.e., second data assessment visit).

Statistical Analyses

All statistical analyses were carried out at the farm level using the statistical computing software R (R Core Team, 2013). Farm characteristics in year 0 and year 1 were compared using *t*-tests. For analysis of the effectiveness of the health and welfare planning approach, farms were allocated to 1 of 3 groups per focus area. The "implementation group" consisted of farms implementing measures that had been discussed, chosen, and written down as measures for a specific focus area in the animal health and welfare plan. Farmers who had agreed on measures and documented them in their plan but did not implement them were treated as a "nonimplementation group." The "control group" consisted of farms that did not choose the respective focus area.

Multilevel mixed models were applied with health and welfare indicators as response variables and farm as random factor using the lme-function in R (Pinheiro et al., 2014). The effects of group affiliation (implementation vs. nonimplementation vs. control) and assessment time (year 0 vs. year 1) and their interaction were used as factors. In the case of too few farms (less than 10% of the sample, i.e., 4 farms) in the "nonimplementation" group (focus areas udder health, cleanliness, and social behavior/HAR), comparisons were only carried out only between control and implementation groups. For post hoc comparisons including all 3 groups, Tukey's multiple comparison correction was applied. Residuals were checked graphically for normal distribution by Q-Q plots and data were transformed where necessary. Square-root transformation was used for the indicators "risk of acidosis," "risk of ketosis," "overall lame," "dirty udder," "dirty hindquarter," "lying outside," and "median ADF" (median avoidance distance at the feeding rack, cm). The indicators "SCC400" (% of animals with SCC >400,000 cells/mL), "mild integument alterations," "lying down," and "agonistic interactions" were log-transformed. A normal distribution was not achieved for the indicator "very lean" and therefore the indicator was not considered further in the analyses. The means given in the results are based on the non-transformed data, whereas the *P*-values were calculated using the transformed variables as described above.

Table 1. Description of focus areas, associated health and welfare indicators, and respective data source

Focus area	Indicator	Description and unit	Data source[1]	Protocol[2]
Udder health	SCS	Mean SCS: SCC (cells/mL) of the 12 mo before the assessment was log-transformed to obtain normal distribution for further analyses [SCS = $\log^2$ (SCC/100,000) + 3; Ali and Shook, 1980; Wiggans and Shook, 1987]. An SCS of 3.00 corresponds to an SCC of 100,000 cells/mL of milk.	MRS	CM
	SCC100	Percentage (%) of animals with SCC >100,000 cells/mL. Mean percentage of 12 mo before the assessment.	MRS	CM
	SCC400	Percentage (%) of animals with SCC >400,000 cells/mL. Mean percentage of 12 mo before the assessment.	MRS	CM
Metabolic health	Very lean	Prevalence (%) of very lean animals. Cows are assessed visually at 4 body regions: cavity around tail head; visible depression between backbone and hip bones; ends of transverse processes distinguishable; tail head, hip bones, spine and ribs visible.	CS	WQ[5]
	Very fat	Prevalence (%) of very fat animals. Cows are assessed visually at 4 body regions: tail head cavity full and folds of fatty tissue present; convex between backbone and hip bones; transverse processes not discernible; outlines of fat patches visible under skin.	CS	WQ
	Suboptimal BCS	Prevalence (%) of either very lean or very fat animals	CS	WQ
	Risk of acidosis	Percentage (%) of animals with a milk fat-protein ratio <1.0. Mean percentage of 12 mo before the assessment.	MRS	CM
	Risk of ketosis	Percentage (%) of animals with a milk fat-protein ratio >1.5 in d 1–100 of lactation. Mean percentage of 12 mo before the assessment.	MRS	CM
Leg health	Moderately lame	Prevalence (%) of moderately lame animals based on gait assessment. Imperfect temporal rhythm in stride creating a limp.	CS	WQ
	Severely lame	Prevalence (%) of severely lame animals based on gait assessment. Strong reluctance to bear weight on one limb, or more than one limb affected.	CS	WQ
	Overall lame	Overall prevalence (%) of lame animals (moderately lame and severely lame)	CS	WQ
	Mild integument alterations	Prevalence (%) of animals with mild integument alterations at the lower hindleg, hindquarter and carpal joint (at least one hairless patch, no lesion or swelling)	CS	WQ
	Severe integument alterations	Prevalence (%) of animals with severe integument alterations at the lower hindleg, hindquarter and carpal joint (at least one lesion or swelling)	CS	WQ
Cleanliness	Overall dirty teats, udder, hindquarter, lower hindleg	Prevalence (%) of animals with dirty teats, udder, hindquarter, lower hindleg. Three-dimensional layers of dirt amounting to the size of the palm of a hand.	CS	WQ
	Slightly dirty teats	Prevalence (%) of animals with splashes of dirt on the teats	CS	CM
	Severely dirty teats	Prevalence (%) of animals with teats covered with dirt on an area >2 cm diameter	CS	CM
Lying comfort	Lying down	Mean duration of lying down movement (s)	BO	WQ
	Lying outside	Percentage (%) of animals lying outside the designated lying area	BO	WQ
Social behavior/HAR[3]	Agonistic interactions	Incidence of agonistic interactions (per animal per hour)	BO	WQ
	Median ADF	Median avoidance distance at the feeding rack (cm)	BT	WQ

[1]Data sources: MRS = milk recording scheme; CS = clinical scoring; BO = behavior observation; BT = behavior test.

[2]Protocols: CM = complementary measure; WQ = Welfare Quality Consortium (Lelystad, the Netherlands) definitions for dual-purpose cows.

[3]HAR = human–animal relationship.

Table 2. Examples of improvement measures assigned to health and welfare focus areas and sub areas

Focus area	Sub area	Examples of measures
Udder health		
	Cow hygiene	More frequent cubicle cleaning; adding more bedding material
	Milking hygiene	Teat cup disinfection; use of milking gloves; postmilking teat disinfection
	Mastitis treatment, drying-off strategy	Alternative drying-off methods; bacterial examination of milk samples for mastitis detection
Metabolic health		
	Feeding (roughage, concentrates, water supply)	Feeding concentrates according to demand; constant provision of roughage
	Herd management	Lock cows in feeding rack during concentrate feeding
Leg health		
	Claw conformation	More frequent claw trimming
	Cubicle dimensions/hygiene	Adjust cubicle dimensions; more frequent cubicle cleaning
	Flooring surface/hygiene	Fitting rubber flooring mats; clean floor several times per day
	Herd management	Reduce stocking density
	Feeding	Decrease (maximum amount) of concentrates
Cleanliness		
	Cow comfort	Install cow brush
	Cubicle dimensions/hygiene	Install brisket board; increase amount of bedding material
	Flooring hygiene	Clean floor several times per day
Lying comfort		
	Cubicle dimensions/hygiene	Adjust head rail; improve lying surface
Social behavior/HAR[1]		
	Herd management	Improve herd observation and animal contact
	Housing environment	Install protection gate at concentrate dispenser
Other[2]		
		Herd health management contract with veterinarian; improve heat detection

[1]HAR = human–animal relationship.

[2]Other aspects that could not be allocated to listed areas.

RESULTS

Farm Characteristics

Mean baseline herd size was 35 ± 7 cows (mean ± SD) and did not change significantly during the study (year 1: 36 ± 8 cows). Mean milk yield per lactation was 8,321 ± 951 kg and 8,478 ± 1,047 kg in year 0 and year 1 (not significant), respectively. Herd age and average lactation number remained unchanged at 4.9 ± 0.5 yr and 3.4 ± 0.6 lactations, respectively.

Aims and Implemented Measures for all Focus Areas

All health and welfare focus areas were discussed on all 34 farms (Table 3). A median number of 3 focus areas (range 1–4) were identified per farm. Metabolic, leg, and udder health were most frequently chosen, whereas lying comfort and social behavior/HAR were rarely selected. Approximately 80% of the measures included related to changes in management practices; the remaining 20% addressed modifications of existing housing equipment or installation of new equipment.

All except one farm implemented measures (median of 2 focus areas per farm; range 1–4). Across all areas, in total 112 measures were implemented, with a median of 3 measures (1–8) per farm (Table 3), resulting in an overall degree of implementation of 58% (95% CI: 26–83%). Across all implemented measures, 56% (37–74%), 15% (0–32%), and 29% (10–48%) were changes in daily management routines, occasional management routines, and changes to the housing system, respectively (Table 3). Measures that resulted in changes in daily working routines (e.g., postmilking teat disinfection) were frequently implemented in the focus areas cleanliness, metabolic health, and udder health. A large proportion of measures that needed to be implemented only once (e.g., adjusting cubicle dimensions) were found in the focus areas lying comfort and social behavior/HAR. In the focus area leg health, more than 60% of the implemented measures were occasional changes (e.g., more frequent claw trimming).

Baseline Health and Welfare State

For most parameters, the baseline situation (year 0) did not differ between groups. All implementation groups had a numerically less favorable mean baseline situation than the respective control herds. Mean baseline SCS and the overall prevalence of dirty teats were significantly higher in implementation herds than in control herds ($P = 0.049$ and $P = 0.050$, respectively).

Table 3. Number of farms addressing the single focus areas in the animal health and welfare plan, number of selected and implemented measures, and degree and type of measures implemented for each focus area

Focus area	No. of farms addressing focus area	No. of measures included in the plans		No. of measures implemented		Degree of implementation [%; mean (95% CI)]	Type of measures implemented [%; mean (95% CI)]		
		Total	Per farm (median, range)	Total	Per farm (median, range)		Every day	Occasionally	Only once
Udder health	18	55	3 (1–5)	35	2 (1–4)	63 (49–76)	67 (51–84)	21 (7–34)	12 (0–25)
Metabolic health	26	49	1.5 (1–7)	27	1 (1–5)	50 (33–67)	75 (59–90)	14 (2–26)	12 (0–26)
Leg health	20	38	1.5 (1–5)	16	1 (1–3)	46 (26–65)	33 (8–59)	61 (33–89)	6 (0–16)
Cleanliness	14	23	1 (1–4)	18	1 (1–3)	77 (57–96)	92 (82–100)	0 (0–0)	8 (0–18)
Lying comfort	13	19	1 (1–4)	10	1 (1–3)	52 (26–78)	21 (0–48)	13 (0–37)	67 (34–99)
Social behavior/HAR[1]	5	7	1 (1–2)	4	1 (1–1)	57 (0–69)	50 (0–100)	0 (0–0)	50 (0–100)
Other	3	3	1 (1–1)	2	1 (1–1)	67 (1–100)	50 (0–100)	50 (0–100)	0 (0–0)
All areas	—	194	5 (2–12)	112	3 (1–8)	58 (26–83)	56 (37–74)	15 (0–32)	29 (10–48)

[1]HAR = human–animal relationship.

Changes in Animal Health and Welfare from Year 0 to Year 1

Regarding udder health, mean SCS decreased numerically in the implementation group, whereas it increased significantly in control herds ($P_{group \times year} = 0.013$; Table 4). A similar pattern was observed for the percentage of cows with a SCC exceeding 100,000 cells/mL ($P_{group \times year} = 0.007$). The percentage of cows with a SCC greater than 400,000 cells/mL remained unchanged in the implementation herds, whereas it increased in the control group ($P_{group \times year} = 0.034$). Regarding metabolic health, percentages of animals with a risk of ketosis ($P_{year} = 0.035$) and suboptimal BCS ($P_{year} = 0.032$) decreased over time in all 3 groups. No significant changes were observed for the prevalence of lame cows. Across all herds, prevalence of severe integument alterations (i.e., at least one lesion or swelling) increased from year 0 to year 1 ($P_{year} = 0.025$).

In the focus area cleanliness, a significant group × time interaction ($P_{group \times year} = 0.049$) was observed for the overall prevalence of dirty teats. We observed an overall decrease from year 0 to year 1 ($P_{year} < 0.001$), but the reduction was more pronounced on implementation farms. When the degree of dirtiness of teats was considered, mean prevalence was lower in year 1 for both slightly and severely dirty teats ($P_{year} < 0.001$ and $P_{year} = 0.003$, respectively), and implementation herds had a higher prevalence of slightly dirty teats than control herds ($P_{group} = 0.029$). As for the overall prevalence of dirty teats, the reduction in the percentage of severely dirty teats was more pronounced for implementation farms ($P_{group \times year} = 0.017$). We detected no changes in measures of lying comfort. Implementation herds showed a higher average incidence of agonistic interactions than control herds ($P_{group} = 0.049$).

DISCUSSION

Improvement measures regarding husbandry and management were implemented to a relatively high degree, leading to a significant improvement of udder health and cleanliness of teats. Furthermore, the percentages of animals with suboptimal body condition and risk of ketosis were reduced in all herds.

With a mean of 35 cows, the participating farms kept considerably more cows than the average Austrian dairy farm, with a mean herd size of 13 dairy cows (BMLFUW, 2012). This above-average herd size was desirable to minimize the effect of single animals on herd-level prevalences. At the same time, these farmers might be more willing than the average farmer to implement changes in housing and management to improve animal health and welfare. However, farmers

Table 4. Health and welfare indicators for control, nonimplementation, and implementation groups (LSM ± SE) before (year 0) and after (year 1) initiating the health and welfare plan[1]

Focus area	Indicator[2]	Year	Control	Non-implementation	Implementation	Model effects: Group	Model effects: Year	Model effects: Group × year
Udder health			(n = 16)	(n = 1)	(n = 17)			
	SCS	0	**3.30 ± 0.12**	—	3.75 ± 0.13	0.222	0.393	**0.013**
		1	**3.51 ± 0.10**	—	3.65 ± 0.09			
	SCC100 (%)	0	**31 ± 3**	—	39 ± 3	0.427	0.522	**0.007**
		1	**35 ± 3**	—	36 ± 3			
	SCC400 (%)	0	**5 ± 1**	—	8 ± 2	0.244	**0.034**	**0.034**
		1	**7 ± 1**	—	8 ± 1			
Metabolic health			(n = 8)	(n = 10)	(n = 16)			
	Very fat (%)	0	14 ± 4	21 ± 5	20 ± 3	0.341	0.073	0.199
		1	15 ± 3	19 ± 4	13 ± 2			
	Suboptimal BCS (%)	0	21 ± 5	24 ± 4	22 ± 2	0.442	**0.032**	0.652
		1	18 ± 3	21 ± 4	16 ± 2			
	Risk of acidosis (%)	0	9 ± 1	10 ± 2	15 ± 2	0.128	0.764	0.138
		1	12 ± 2	13 ± 2	14 ± 2			
	Risk of ketosis (%)	0	12 ± 1	16 ± 2	14 ± 2	0.544	**0.035**	0.990
		1	11 ± 2	14 ± 2	12 ± 2			
Leg health			(n = 14)	(n = 8)	(n = 12)			
	Overall lame (%)	0	31 ± 4	42 ± 5	46 ± 5	0.442	0.087	0.579
		1	37 ± 4	43 ± 5	48 ± 3			
	Moderately lame (%)	0	18 ± 2	25 ± 3	24 ± 2	0.072	0.344	0.677
		1	21 ± 2	24 ± 3	26 ± 2			
	Severely lame (%)	0	13 ± 2	17 ± 4	23 ± 4	0.169	0.413	0.702
		1	16 ± 2	20 ± 5	22 ± 4			
	Mild integument alterations (%)	0	34 ± 3	37 ± 5	42 ± 4	0.446	0.137	0.262
		1	32 ± 3	38 ± 4	33 ± 3			
	Severe integument alterations (%)	0	15 ± 4	14 ± 4	20 ± 5	0.176	**0.025**	0.388
		1	19 ± 3	16 ± 3	29 ± 5			
Cleanliness			(n = 20)	(n = 2)	(n = 12)			
	Overall dirty teats (%)	0	**57 ± 4**	—	**72 ± 4**	0.080	**<0.001**	**0.049**
		1	**41 ± 4**	—	**45 ± 4**			
	Slightly dirty teats (%)	0	34 ± 2	—	40 ± 3	**0.029**	**<0.001**	0.962
		1	24 ± 2	—	30 ± 3			
	Severely dirty teats (%)	0	22 ± 3	—	**30 ± 3**	0.830	**0.003**	**0.017**
		1	17 ± 3	—	**15 ± 2**			
	Dirty udder (%)	0	16 ± 3	—	19 ± 3	0.452	0.653	0.076
		1	19 ± 3	—	14 ± 2			
	Dirty lower hindleg (%)	0	38 ± 5	—	51 ± 7	0.197	0.831	0.519
		1	40 ± 5	—	46 ± 7			
	Dirty hindquarter (%)	0	43 ± 6	—	48 ± 7	0.836	0.230	0.330
		1	40 ± 5	—	37 ± 6			
Lying comfort			(n = 21)	(n = 5)	(n = 8)			
	Lying down (s)	0	5.9 ± 0.1	6.1 ± 0.3	6.0 ± 0.4	0.973	0.073	0.466
		1	5.8 ± 0.1	5.6 ± 0.3	5.8 ± 0.2			
	Lying outside (%)	0	9 ± 3	3 ± 1	13 ± 5	0.702	0.887	0.691
		1	8 ± 2	4 ± 1	10 ± 4			
Social behavior/HAR[3]			(n = 29)	(n = 1)	(n = 4)			
	Agonistic interactions (per animal/h)	0	1.2 ± 0.2	—	2.2 ± 0.2	**0.049**	0.950	0.309
		1	1.2 ± 0.2	—	1.6 ± 0.4			
	Median ADF[4] (cm)	0	14 ± 3	—	23 ± 9	0.510	0.988	0.589
		1	12 ± 2	—	14 ± 4			

[1]Per indicator, significant model effects ($P < 0.05$) are highlighted in bold. Similarly, significant differences between years within groups are highlighted for indicators where the group × year interaction was significant.

[2]Indicators: SCC100 = percentage of animals with SCC >100,000 cells/mL; SCC400 = percentage of animals with SCC >400,000 cells/mL.

[3]HAR = human–animal relationship.

[4]Median ADF = median avoidance distance at the feeding rack (cm).

participated on a voluntary basis and one of the main criteria was therefore the motivation to enroll in a health and welfare improvement project. In general, the alterations made to management and housing systems on the study farms would also be applicable to small to medium-sized herds.

In the present study, the baseline situation for some health and welfare indicators was poorer in the implementation and nonimplementation groups than in the respective control herds. This reflects the aim of the study, which was to mimic advisory activities where farms with an already satisfactory level would not need action. Furthermore, the study aimed at improving negative health and welfare situations and not at improving the average farm or farms with an already high health and welfare state. Due to the setup of the study, it was not possible to blind the assessor regarding the allocation of the farms to the groups. However, the second on-farm assessment (year 1) was performed without recalling the results from the previous assessment or the chosen focus areas of the respective farm, in order to minimize a possible bias. Furthermore, on most farms, all animals were assessed, thus keeping a potential sampling bias small.

With an implementation rate of 57%, measures in management and housing were implemented to a similar or higher degree compared with other intervention studies. Following a similar planning approach, Gratzer (2011) obtained the same implementation rate during a 1-yr herd health and welfare planning study among 39 Austrian organic dairy farms. Reasons for good acceptance of health and welfare plans may be seen in the structured, participatory process as well as in the farm-specific aims and interventions (Tremetsberger and Winckler, 2015). In contrast, in one of the few other studies that applied the Welfare Quality assessment protocol (in beef fattening farms), the uptake of measures proposed by the researchers was low, and health and welfare indicators did not change during the 6-mo study period (Kirchner et al., 2014). This might have been due to a more prescriptive advisory approach and the rather short duration of the study.

In the present study, as in Gratzer (2011), implementation rates varied between different focus areas. In total, 77 and 67% of the projected measures for the focus areas cleanliness and udder health were implemented, respectively. The implementation rate for udder health measures was similar to that in Gratzer (2011) and Green et al. (2007), where at least 66% of the farms implemented more than 33% of the measures, and greater than the rate of 43% observed by Brinkmann and March (2010). A relatively low uptake was found for measures relating to improvements in foot and leg health in the present study, in agreement with Barker et al. (2012) and Bell et al. (2009), who observed a similar degree of implementation (31%), and “less than satisfactory” implementation rates, respectively. Higher rates were reported by Gratzer (2011; 53%) and Brinkmann and March (2010) for a lameness intervention study in Germany, where after approximately 1 yr, 11 out of 21 farms had implemented more than two-thirds of the measures. However, unlike in Brinkmann and March (2010), farmers participating in the present study had to allocate their efforts to several focus areas within the 1-yr period. Similar to Gratzer (2011), measures relating to social behavior were seldom chosen and implemented by the farmers in the present study.

The implementation of measures developed during the planning process improved udder health state and teat cleanliness on the participating farms. Following interventions, SCS as well as the percentages of animals with SCC exceeding 100,000 and 400,000 cells/mL decreased in the implementation herds, whereas they increased in the control group. Baseline udder health was on a moderate level as regards, for example, SCC (Bennedsgaard et al., 2010; Ivemeyer et al., 2012). Unfortunately, unlike Green et al. (2007), we were not able to include treatment incidences in our analysis, as data were unreliable due to implausible within-farm variation in treatment incidences as well as incomplete farm records. It has been shown that farms with low health status have a higher potential for improvement and might therefore be easier to enhance (Green et al., 2007; Ivemeyer et al., 2009). In accordance with Green et al. (2007), who achieved a 20% reduction in clinical mastitis incidence, one reason for the effects found in this study might be the high implementation rate of agreed measures within this area compared with areas such as leg health. The high degree of implementation related to udder health could result from high awareness of the negative health consequences of impaired udder health (e.g., reduced milk yield, treatment costs, replacement costs), at least when compared with lameness (Whay et al., 2003). The measures discussed and agreed upon with regard to udder health may have been relatively easy to implement and well defined, which facilitated the incorporation of measures into the farm routine. All measures regarding udder health were management changes and about two-thirds of the measures affected the daily working routine, which required small capital investments.

Farms that implemented measures addressing cleanliness achieved a more pronounced reduction in the prevalence of overall dirty teats as well as severely dirty teats than control farms. Applying good management practices, especially bedding management, has been shown to be beneficial for teat and teat tip cleanliness (Plesch and Knierim, 2012). Implementation farms may have aimed more specifically at a reduction of severe dirtiness, as this poses a greater health risk, for example, for udder health (Schreiner and Ruegg, 2003; Ellis et al., 2007).

For both udder health and cleanliness, the response of nonimplementation farms (i.e., farms that discussed but did not implement any of these measures) could not be tested because of too few farms in the nonimplementation groups. It might be expected that farmers who decided to take action but did not initiate the agreed interventions could still have affected the animals; for example, by increased awareness of health problems or by introducing changes other than those included in the health plan. However, for the focus areas where the distinction between nonimplementation and implementation was possible (i.e., metabolic health, leg health, lying comfort), no differences between the 3 groups were obtained. Valid conclusions on a lack of effect would have to be drawn from larger samples, but in our data we did not find any indication that nonimplementation farms benefitted from the mere discussion of the respective animal health and welfare planning issues.

However, there were some indications that, across groups, the mere involvement in the study affected the behavior of the farmers, known as "Hawthorne effect" (Whay et al., 2012). For example, the proportion of animals with slightly dirty teats generally decreased within the study period. This may be explained by an increased general awareness regarding cleanliness following the process of health and welfare planning. March et al. (2014) reported a reduction in dirtiness of udders and bellies, even when the area was not selected as specific aim for improvement. In the present study, however, cleanliness of other body regions was not improved, presumably because no direct relevance for animal health and welfare was perceived. Regarding metabolic health, changes were observed across all farms irrespective of whether the farmers had chosen the respective focus areas. The percentage of cows with a risk of ketosis (milk fat:protein ratio >1.5 in the first 100 d of lactation) as well as the prevalence of cows with suboptimal body condition (very fat and very lean cows) decreased in all groups, indicating an improved periparturient metabolic situation (Roche et al., 2009). Furthermore, for control and nonimplementation farms, carryover effects of interventions in other focus areas could have occurred; however, quantifying such influences on other areas is challenging.

Severe integument alterations increased across all farms within the 1-yr period. It is not clear what might have caused this development, because knowledge on how integument alterations such as hairless patches, lesions, and swellings change in type and severity over time is scarce (Norring et al., 2008).

Not all focus areas changed significantly within the 1-yr period. However, the lack of significant changes has to be interpreted with caution, as the relatively small sample sizes may not allow for a detection of changes. For example, overall lameness prevalence remained unaffected in the 3 groups, but variable success has been reported for lameness intervention. Our findings are in accordance with Bell et al. (2009) and Barker et al. (2012), who did not achieve improvements after 1 yr due to inadequate implementation. Compared with other focus areas, implementation of measures relating to leg health was also relatively low in the present study. In contrast, although baseline lameness prevalence was slightly lower, Brinkmann and March (2010) achieved a relatively high implementation rate, and leg health improved even after 1 yr. In our study, more than 50% of the implemented measures addressing leg health were occasional changes, such as regular claw trimming. However, additional management measures such as improvements in bedding and lying area, respectively, which are known to be beneficial for leg health (Main et al. 2012), were less frequently implemented. This could also have compromised improvements in leg health. Farmers often underestimate lameness prevalence (Whay et al., 2002; Barker et al., 2010; Šárová et al., 2011) and the possible health and welfare relevance as well as financial aspects of impaired leg health (Leach et al., 2010). However, understanding these factors is essential for achieving success, and action can only take place when a problem is detected (Whay and Main, 2010). For instance, Leach et al. (2013) reported how efforts in training farmers to score lame cows in their herds resulted in an improved detection. In our study, it was not possible to visit the farms for follow-up advice during the year after the implementation had started. This may have hampered the proper implementation and adaptation of measures, as highlighted by Brinkmann and March (2010).

The focus areas "lying comfort" and "social behavior/HAR" were rarely chosen. Gratzer (2011) also reported that only 8 out of 39 farms implemented measures focusing on behavior, indicating that this topic was relatively new to farmers and of minor relevance compared with health issues. Additionally, the baseline situation in our study did not necessarily require interventions; for example, regarding the mean duration of lying down movements and the prevalence of animals lying outside the cubicles (Welfare Quality, 2009; Plesch et al., 2010). Similarly, the level of agonistic behaviors and avoidance distance at the feedrack as a measure of HAR were mostly within a satisfactory range (Windschnurer et al., 2008; Welfare Quality, 2009; Gratzer, 2011).

Furthermore, temperament may be regarded as more important in extensively managed beef cattle than in dairy cattle (Le Neindre et al., 1996).

CONCLUSIONS

The aim of improving health and welfare of dairy cows was achieved for some focus areas. Udder health and cleanliness of teats improved significantly 1 yr after farms had implemented changes in husbandry practices. Changes in management routines may have predominantly accounted for the effects of the interventions on udder health. We did not find evidence that the approach chosen led to an improvement of leg health. The 1-yr process of animal health and welfare planning, as carried out on the 34 farms, therefore appears to be a promising approach to improve some animal health issues. In particular, the participatory approach when discussing farm-specific aims and measures and the structured process seem to be crucial.

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Animal health and welfare state and technical efficiency of dairy farms: possible synergies

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Short title: Technical efficiency of dairy farms

Abstract

The present study investigated if animal health and welfare states and changes in health and welfare affect technical efficiency in a sample of 34 Austrian dairy farms. Health and welfare were assessed twice using the Welfare Quality® (WQ) assessment protocol for dairy cattle. After the initial assessment, farm-specific health and welfare planning was conducted on the farms. This included the identification and selection of measures in housing and management that aimed at improving health and welfare states. One year after implementation of the animal health and welfare plans the farms were reassessed to detect changes in health and welfare states. Based on the initial assessment, farms with higher health state (higher WQ principle score "Good health") were technically more efficient. In order to measure efficiency change within the study period we calculated the Malmquist index. Across all farms the situation remained fairly stable (mean ± sd Malmquist index 1.02 ± 0.10) and there were no significant differences in Malmquist index between farms that improved or deteriorated in the health and welfare state. Our results show possible synergies between health and welfare states and farm efficiency and we regard the method of data envelopment analysis as valuable for analyzing such relationships.

Keywords: dairy cows, data envelopment analysis, Malmquist index, on-farm assessment, Welfare Quality®

Implications

This paper identified a positive association of good animal health with technical efficiency in a sample of 34 Austrian dairy farms. We consider this result as important for promoting dairy cattle welfare. Although changes in health and welfare states during the one-year study period were not reflected in technical efficiency changes, our results shall contribute to a better understanding of the relationships between animal welfare and efficiency. Furthermore, we regard the methodology applied (data envelopment analysis) to be of value for studying these relationships.

Introduction

Animal health and welfare plays an important role in successful dairy cattle husbandry, but on-farm surveys show that intervention levels are often exceeded (Whay *et al*., 2003; Green *et al*., 2007; Leach *et al*., 2010; Tremetsberger and Winckler, 2015). Health and welfare states improvement has been investigated for example regarding mastitis (e.g. Green *et al*., 2007; Ivemeyer *et al*., 2008; Tremetsberger *et al*., 2015) and lameness (e.g. Main *et al*., 2012). These studies report primarily on the effect of intervention measures in management and provision of resources on animal health (i.e. udder and leg health, respectively) and welfare of dairy cows. However, animal welfare is not only shaped by animal health. A comprehensive view on animal welfare also includes the animals' feelings (affective state) and their ability to express natural behavior (natural living) (Fraser *et al*., 1997). In the past decade, scientific attempts have been made to assess animal welfare on the farm level and comprehensive protocols such as the Welfare Quality® (WQ) assessment protocol for cattle have been developed (Welfare Quality®, 2009). Recent studies on dairy cow and beef cattle welfare state have been based on this protocol (Ivemeyer *et al*., 2012; Andreasen *et al*., 2013; De Vries *et al*., 2013; Kirchner *et al*., 2014; Tremetsberger *et al*., 2015). The outcomes of the assessment allow identifying welfare problems and introducing interventions on the farms in terms of changes e.g. in management routines and housing systems.

Compromised health and welfare states may also have economic implications (e.g. Kossaibati and Esslemont, 1997; Huijps *et al*., 2008). For instance, Hansson *et al*. (2011) identified preventive measures against mastitis such as revision of hygiene routines as beneficial for the whole-farm economic outcome. Similarly, in a study on 80 UK farms Barnes *et al*. (2011) showed that farms with high lameness prevalence were significantly less technical efficient than farms with satisfactory leg health. Technical efficiency describes the transformation of production inputs into outputs and to what degree this transformation is achieved (Coelli *et* *al*., 2005). It has been used in several other studies to assess the economic performance of dairy farms in different production systems (Barnes *et al*., 2011; Hansson *et al*., 2011; Kelly *et al*., 2012a; Steeneveld *et al*., 2012; Heinrichs *et al*., 2013).

In a recent study in German dairy farms (Allendorf and Wettemann, 2015), indicators related to welfare such as cow losses, replacement rate and calving interval were negatively correlated with technical efficiency. To our knowledge, no scientific work has yet been performed on the consequences of shifts in the health and welfare states of cattle on technical efficiency of the farm. The aim of the present study was therefore to analyze the impact of animal health and welfare outcomes according to the WQ protocol (Welfare Quality, 2009) on technical efficiency of 34 dairy farms in Austria in the first year of a two-year study on health and welfare planning. Technical efficiency was derived from a data envelopment model (DEA), which allows for the consideration of multiple inputs and outputs while not requiring identical units (Charnes *et al*., 1978) and the selection of this methodology even enabled us to consider non-monetized production factors. Second, we assessed if changes in health and welfare states from the first to the second year of the study had effects on changes in technical efficiency. In order to analyze these changes we applied a Malmquist index (i.e. total factor productivity change) model, which was based on a DEA model. We hypothesized a positive association between health and welfare states and technical efficiency, and that an increase in health and welfare also was accompanied by a positive technical efficiency change.

Material and methods

Farm set description

Data were collected on 34 Austrian family-run dairy farms voluntarily participating in an animal health and welfare planning project (Tremetsberger *et al*., 2015). On all farms, dairy cows were kept in cubicle housing systems without access to pasture; 11 herds had permanent access to an outdoor run. The predominant breed was Austrian Fleckvieh with 25 herds consisting of more than 90% Fleckvieh. The remaining 9 farms kept either Brown Swiss (3 farms), Holstein Friesian (2 farms), or a mixture of all three breeds (4 herds). Dairy cows were either fed grass silage and hay or rations consisting of maize silage, grass silage and hay. Concentrates were fed manually on the feed bunk, by total mixed rations, or via concentrate dispensers, respectively.

Welfare assessment

During the study period, all farms were visited three times by the same observer. A one-day visit at the beginning of the study (winter 2011/12; Year 0) was used for data collection based on the Welfare Quality® assessment protocol for dairy cattle (Welfare Quality®, 2009). The assessment primarily rests upon animal-based indicators and all results are expressed on herd level. During the on-farm assessment, dairy cows were individually scored for clinical health and cleanliness. Behavior was assessed using an avoidance distance test, observation of spontaneous social and resting behavior as well as qualitative behavior assessment of the herd. Provision of resources and management procedures were assessed using checklists and questionnaire-based interviews with the farmer at the day of the assessment (for details see Welfare Quality®, 2009 and Tremetsberger *et al.*, 2015). During a second farm visit, which took place 55 ± 26 days (mean ± sd) after the initial visit, animal health and welfare planning was carried out on the farms (see below). Health and welfare states of the dairy cows were reassessed according to the procedures used during the first visit on average 368 ± 11 days after the health and welfare planning visit (Year 1). Data for economic calculations were collected only during the third farm visit by interviewing the farmer following a questionnaire. This included questions on three input factors (average herd size, annual labor, concentrate use; see below) and one output factor (milk yield per cow and year) in the period between the first and third farm visit, respectively (Year 1). Concerning annual labor, annual work hour estimates were specified for each working step, namely milking, feeding, hygiene measures and herd management. Furthermore, it was assessed whether inputs and output had changed during the study period compared to the 12-month period prior the first farm visit in order to calculate values for Year 0.

Health and welfare planning

Formulating farm-individual health and welfare plans followed key aspects highlighted by Vaarst *et al*. (2011), such as: i) assessment of health and welfare states; ii) analysis of outcomes; iii) feedback of outcomes to the farmer; iv) (farm-specific and targeted) advice related to health and welfare issues; and v) constant review and adaptation of the formulated plan. Farmers were asked to address one or several health and welfare focus areas (“udder health”, “metabolic health”, “leg health”, “cleanliness”, “lying comfort” and “social behavior and human-animal relationship”). The aim was to develop changes in management practices and housing system to improve health and welfare, which were specific for each farm. The individually selected measures were written down in the health and welfare plan by the farmer himself/herself and the farmers were encouraged to implement these measures. For example, addressing the focus area “udder health” comprised improvement measures focussing at cow hygiene (e.g. stall maintenance), milking hygiene (e.g. teat cup disinfection) or mastitis management (e.g. bacterial examination of milk samples). A more detailed description of the planning process and an overview of improvement measures included in the health and welfare plans is provided in Tremetsberger *et al.* (2015).

The health and welfare plans were based on the results of each farm as provided on the parameter level (e.g. herd prevalence of lame animals). None of the farms used contracted advisory services with regard to herd management. Standard sources of advice were farm veterinarians and sporadically (company bound) nutrition advisors. Additionally, a limited number of farms participated in farmer groups focusing on dairy production.

Technical efficiency and Malmquist index

The methodology underlying technical efficiency estimation is based on the fact that dairy farms combine inputs to produce outputs with varying degrees of efficiency. Technical efficiency is defined as “the ability to obtain maximal output from a given set of inputs” (Coelli *et al*., 2005). On a whole farm scale, it can be analyzed by applying data envelopment analysis (Charnes *et al*., 1978). This method allows formulating a best-practice frontier over all observed data points, e.g. farms. The farms operating at their highest level of efficiency lie on the frontier and the other farms are radially measured against this frontier. Technical efficiency scores can range from 0 to 1 with values of 1 indicating fully efficient farms in the present sample. Data envelopment analysis models are specified regarding returns to scale, i.e. how inputs are transformed to outputs. For calculating technical efficiency one output was considered explained by three inputs in Year 0 and Year 1 (Table 1). Following other studies investigating technical efficiency of dairy systems (Barnes *et al*., 2011; Kelly *et al*., 2012a), milk yield was chosen as the output as this reflects the main product sold by a dairy farm. Herd size, annual labor and concentrate use were included as production factors commonly used (Barnes *et al*. 2011). In order to obtain reliable results, the sample size is preferred to be greater than twice the product of inputs and outputs (Dyson *et al*., 2001), which was ensured in the present study. Regarding DEA model formulation, constant returns to scale (CRS) assumes that farms are operating at their optimal scale and outputs change proportionally to inputs. Due to the homogeneous farm sizes, scale effects were not expected and thus only CRS efficiency scores were calculated and reported.

Data envelopment analysis is a suitable method for determining the efficiency of farms at a particular point in time, relatively to the other farms included in the sample at this particular point in time. However, no assumptions can be made on how efficiency values of farms change over time. A way to account for temporal aspects is to calculate the total factor productivity change (productivity considered as the ratio of outputs to inputs). Methodologically, the Malmquist index, first proposed by Malmquist (1953) and further developed by e.g. Färe *et al*. (1994), can be applied to calculate total factor productivity change. For two periods t and t+1, the Malmquist index for the *i*-th farm can be represented as the following distance function:

$$M_{it}(x_{it},y_{it},x_{i,t+1},y_{i,t+1}) = \frac{\Delta_{i,t+1}(x_{i,t+1},y_{i,t+1})}{\Delta_{it}(x_{it},y_{it})} \bullet \left[\frac{\Delta_{it}(x_{i,t+1},y_{i,t+1})}{\Delta_{i,t+1}(x_{i,t+1},y_{i,t+1})} \bullet \frac{\Delta_{it}(x_{it},y_{it})}{\Delta_{i,t+1}(x_{it},y_{it})} \right]^{\frac{1}{2}} = EC_{it} \bullet TC_{it} \quad (1.2)$$

This index can be decomposed into efficiency change and technological change (first term (EC_{it}) and second term (TC_{it}) in the equation 1.2, respectively) (Färe *et al*., 1994). First, efficiency change characterizes the shift in the position of a farm relative to the production frontier ("catching up"). Efficiency change shows how much closer, or further away, the farm in question has moved to the frontier over time. Second, technological change illustrates the shift in the production frontier over time ("technical change" or "innovation"). This component indicates whether the best-practice frontier has improved, stagnated or deteriorated. The decomposition of the Malmquist index makes it possible to separate the progress or regress in technical efficiency from year to year from shifts in the frontier itself (Färe *et al*., 1994; Tone, 2004).

Figure 1 illustrates these relationships for a given Farm A, in a case where only two inputs, x1 and x2, and one output y are used. The best-practice frontiers F_t and F_{t+1} mark the most efficient combinations of inputs and output for each time point t and t+1, respectively (Figure 1). Farm A is inefficient in both years, as it is not located on the respective frontier. Efficiency change (EC) for farm A indicates if and how the farm has changed its position relative to the frontier and can be described with the following equation 1.3:

$$EC_{At} = \left(\frac{0d}{0A_{t+1}} \right) \div \left(\frac{0a}{0A_t} \right) \quad (1.3)$$

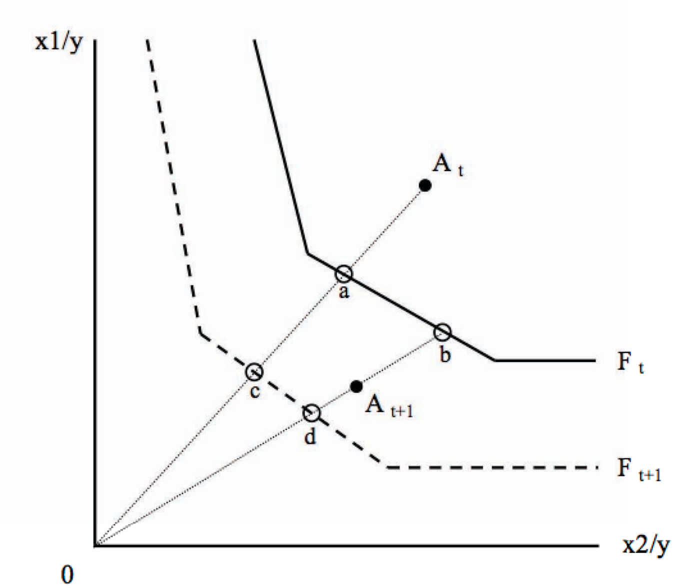

Figure 1 Malmquist index for farm A under constant returns to scale production frontiers using two inputs (x1 and x2 related to output y) for two time periods t and t+1

Farm A increases in technical efficiency from time t to time t+1, as it has moved proportionally closer to the respective frontier, the efficiency change component would be larger than 1. Technology change (TC) for farm A marks the shifts in the frontier and is depicted as follows in equation 1.4:

$$TC_{At} = \left(\frac{0b}{0d} \bullet \frac{0a}{0c} \right)^{\frac{1}{2}} \qquad (1.4)$$

Advancement in technology has occurred for farm A, as the frontier has moved closer to the origin, thus less input is needed for the same level of output production. This would be represented by a technology change above 1.

A drawback of DEA and consequently also of the Malmquist index is that the efficiency scores may be influenced by sampling variation and are likely to be biased towards the upper end. Simar and Wilson (1998) recommended a “smoothed bootstrap approach” to account for the bias in the sample. This is especially important if the sample is small, as it is the case in the present study. The application of such a bootstrapping approach provides bias-corrected efficiencies and constructs confidence intervals for the “true” efficiency score.

Data analysis

WQ assessment results were calculated according to the formulas published in the WQ assessment protocol for dairy cattle. Mean values for animal-based WQ-measures assessed on-farm are presented in Supplementary Table S1. In brief, scores which may range from 0 (poor welfare state) to 100 (excellent welfare state) were first calculated for 12 criteria that are then aggregated into 4 principle scores ("Good feeding", "Good housing", "Good health", "Appropriate behavior"; Table 2; for a detailed description see Welfare Quality®, 2009). Overall WQ classification is based on the principles scores and revealed 18 and 15 "enhanced" and "acceptable" farms in Year 0, whereas 2 farms were "not classified". In Year 1, 16, 16 and 2 farms were classified as "enhanced", "acceptable" and "not classified", respectively. No farm reached the category "excellent" in any year. Overall farm classification was not further used for this analysis.

Data envelopment analysis was performed in two parts using the FEAR package (Wilson, 2013) for the statistical computing software R (R Core Team, 2013). First, single input-orientated bootstrapped DEA models were applied in order to calculate technical efficiency scores under CRS frontiers for both Year 0 and Year 1. Furthermore, as described above, we used the bootstrapping feature provided by the FEAR package for R (Wilson, 2013) with 2,000 bootstrap iterations. Second, total factor productivity change from Year 0 to Year 1 was calculated with the same data set by estimating Malmquist indices. Again, following the approach proposed by Simar and Wilson (1999), bootstrapping with 2,000 replications was applied for the calculation of the bias-corrected Malmquist indices and confidence intervals (Wilson, 2013). This approach ensures that the time-dependent structure of the dataset is considered in the calculation. The scores for Malmquist index and its decomposition provided in the results section are those derived from the bootstrapping procedure.

Table 1 Type, description, data source and mean values (± SD, min - max) for output and input factors used in data envelopment analysis and Malmquist indices calculation for Austrian dairy farms (n = 34) in Year 0 and Year 1

					Year 0		Year 1	
Factor	Type	Description	Data source	Unit	Mean (SD)	Min – max	Mean (SD)	Min – max
Milk yield	Output	Annual milk yield per herd	National milk recording scheme	*1,000 kg/herd per year	244 (62)	142 – 452	253 (75)	144 – 510
Herd size	Input	Number of dairy cows at the time of the assessment	Farm assessment	Number of dairy cows	35 (7)	24 – 56	36 (8)	2 – 63
Annual labor	Input	Annual labor with respect to dairy cows	Farmer questionnaire	h/herd per year	2,338 (695)	1,162 – 4,208	2,361 (753)	1,300 – 4,381
Concentrate use	Input	Maximum amount of concentrates	Farmer questionnaire	kg/herd per day	292 (104)	75 – 473	284 (108)	81 – 504

Table 2 Median values (25% – 75% quartile range) for Welfare Quality (WQ) criterion and principle scores in Year 0 as well as the respective change in Year 1 (difference Year 0 and Year 1) in Austrian dairy farms (n = 34)

		Year 0		Difference Year 0 – Year 1	
Variable[1]	Description	Median	25% – 75% quartile	Median	25% – 75% quartile
C1	Absence of prolonged hunger	78	62 – 100	0	-18 – 23
C2	Absence of prolonged thirst	80[4]	3: 4 farms, 32: 4 farms, 60: 4 farms, 100: 20 farms	-4[4]	-68: 1 farm, -57: 1 farm, -40: 2 farms, 0: 29 farms, 68: 1 farm
C3	Comfort around resting	30	16 – 32	1	-4 – 18
C4	Thermal comfort[2,3]	100	-	0	-
C5	Ease of movement[2]	100	-	0	-
C6	Absence of injuries	35	23 – 41	5	-4 – 13
C7	Absence of disease	43	37 – 57	0	-8 – 16
C8	Absence of pain induced by management procedures	41[4]	20: 1 farm, 28: 15 farms, 52: 18 farms	0[4]	-
C9	Expression of social behaviours	64	46 – 81	1	-15 – 13
C10	Expression of other behaviours[3]	0	-	0	-
C11	Good human-animal relationship	64	56 – 74	3	-5 – 15
C12	Positive emotional state	25	16 – 36	-1	-10 – 16
P1 (C1-2)	Good feeding	71	45 – 100	0	-14 – 4
P2 (C3-5)	Good housing	56	47 – 57	1	-3 – 12
P3 (C6-8)	Good health	34	30 – 39	2	-2 – 7
P4 (C9-12)	Appropriate behaviour	19	15 – 24	0	-4 – 6

[1] C: Welfare Quality Criteria; P: Welfare Quality Principle

[2] As yet, no measure is developed

[3] No between-farm variation regarding these criteria

[4] Mean value

The influence of health and welfare state on technical efficiency in Year 0 was tested using censored Tobit regression models (Tobin, 1958) as efficiency scores are constrained at the upper level (Bogetoft and Otto, 2011). WQ principle scores as well as WQ criterion scores were regressed separately on technical efficiency scores. Similarly, in a second step, multiple linear regression models using stepwise backward selection were applied to test the relationship between changes in WQ principle scores as well as WQ criterion scores and changes in technical efficiency, expressed as Malmquist indices. The WQ criteria “Absence of prolonged thirst” and “Absence of pain induced by management procedures” were treated as categorical variables as the respective scores are derived from decision tree classification (Welfare Quality, 2009). Scores of the WQ criteria “Ease of movement” (all herds were kept in loose housing systems), “Thermal comfort” (no measure has been developed yet) and “Expression of other behaviours” (based on access to pasture, which was not provided in any farm) did not show any variation and were therefore excluded from the regression analysis. Differences in input and output factors (Table 1) between Year 0 and Year 1 were analyzed using t-tests.

Results

On average, the farms had an efficiency score of 0.79 (± 0.11), ranging from 0.58 to 0.96 in Year 0. In Year 1, the mean efficiency score was 0.67 (± 0.12), with values ranging from 0.46 to 0.88. These mean efficiency scores indicate that farms would on average have to reduce their inputs by 21% and 33% to become technically efficient in Year 0 and Year 1, respectively. No farm was identified as fully efficient in the present sample in any of the two years.

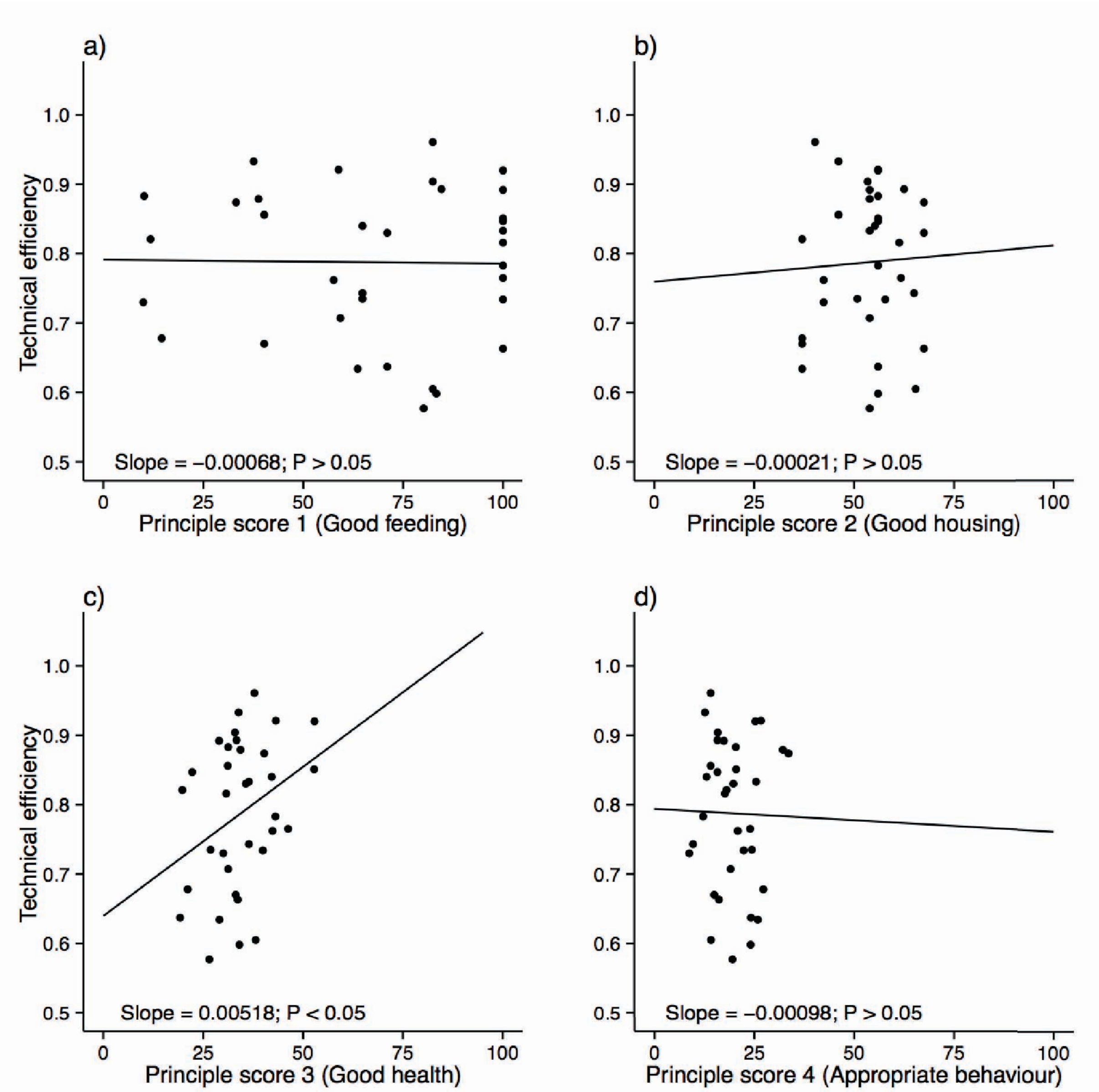

Figure 2 Technical efficiency scores in relation to the WQ principle scores for Good feeding (a), Good housing (b), Good health (c), and Appropriate behaviour (d) in Year 0 of Austrian dairy farms (n = 34)

Table 3 Tobit regression estimates of WQ criterion scores on technical efficiency scores in Year 0 for Austrian dairy farms (n = 34)

Variable[1]	Description	Estimate	SE	Significance
Intercept		0.502	0.140	***
C1 (P1)	Absence of prolonged hunger	-0.001	0.001	
C2 (P1)	Absence of prolonged thirst (score of 32)	-0.115	0.066	.
	Absence of prolonged thirst (score of 60)	-0.128	0.061	*
	Absence of prolonged thirst (score of 100)	-0.163	0.053	**
C3 (P2)	Comfort around resting	-0.001	0.001	
C6 (P3)	Absence of injuries	0.006	0.001	***
C7 (P3)	Absence of disease	0.002	0.001	.
C8 (P3)	Absence of pain induced by management procedures (score of 28)	-0.143	0.100	
	Absence of pain induced by management procedures (score of 52)	-0.132	0.090	
C9 (P4)	Expression of social behaviours	0.003	0.001	***
C11 (P4)	Good human-animal relationship	0.002	0.001	
C12 (P4)	Positive emotional state	-0.001	0.001	

[1] Welfare Quality criteria (C) contributing to Welfare Quality principles (P)

Regarding WQ principle scores, regression analysis revealed that out of the four WQ principles only the principle “Good health” was significantly positively associated with technical efficiency scores in Year 0 (Figure 2). An increase by 10 points in the WQ principle “Good health” caused technical efficiency scores to increase by 5 percentage points. More specifically, both the WQ criteria “Absence of injuries” and “Absence of disease”, which contribute to the principle “Good health”, were positively associated with technical efficiency with a less pronounced effect of the criterion “Absence of disease” compared to “Absence of injuries” (Table 3). On criterion level, less agonistic interactions (depicted as a high score in “Expression of social behavior”) were significantly related to higher technical efficiency scores. Furthermore, a higher score for “Absence of prolonged thirst” was negatively associated with technical efficiency (Table 3).

Across all farms, the mean Malmquist index was 1.02 (± 0.10), thus indicating a fairly stable situation with regard to technical efficiency. Decomposition of the Malmquist index showed that across all farms technical efficiency increased on average (1.11 ± 0.13), whereas the mean technology change decreased (0.93 ± 0.09). Further analysis revealed no relationship between Malmquist index, efficiency change and technology change and the differences in WQ scores between Year 1 and Year 0 (both at principle as well at criterion level).

Discussion

Regarding technical efficiency scores, the average bias-corrected technical efficiency scores were lower than non-corrected scores (data not shown) because efficiency scores can be overestimated without applying the bootstrapping procedure (Simar and Wilson, 1998). Due to differences in dairy production systems and respective samples of farms, a direct comparison to DEA technical efficiency scores from other studies is not appropriate. However, in the present study, technical efficiency scores for both years ranged in the order of magnitude as recently reported by Barnes *et al*. (2011) and Kelly *et al*. (2012b) for dairy farms in Scotland and Ireland, respectively.

The positive association between the WQ principle “Good health” and technical efficiency could generally reflect that herds with higher health states have higher milk yields, have to spend less on treating animals or have less (direct and indirect) yield losses that arise from poor health states. Especially lameness, which contributes to the criterion “Absence of injuries”, poses a major health issue in dairy cattle (median prevalence of lame cows in Year 0: 37%, min 13%, max 69%) and is responsible for treatment costs (Bruijnis *et al*., 2012), reduced fertility (Hernandez *et al*., 2001) or reduced milk yield (recently reviewed by Huxley, 2013). Farms with higher levels of lameness might therefore face higher costs and reduced milk yields.

Compared with the criterion “Absence of injuries”, the criterion “Absence of disease” had a smaller effect on technical efficiency, which could be due to the fact that some of the indicators associated with “Absence of disease” do not necessarily reflect health problems that are treated (e.g. nasal discharge) or cannot be reliably assessed using spot observations (e.g. vulvar discharge). Furthermore, in the WQ protocol udder health problems are taken into account as the percentage of animals with a somatic cell count above 400,000 cells per ml milk. This parameter has a low weight and thus only small effects on the “Absence of disease” scores (De Vries *et al*., 2013) and might therefore not fully reflect the costs associated with udder health problems. The criterion “Pain induced by management procedures” reflects the procedures used for disbudding of calves or dehorning of adult cows. This is welfare relevant for calves but less for cows, as very few cows were dehorned on the farms in this study. Long-term effects of pain induced by management procedures on milk yield have not been studied yet.

Apart from “Good health”, no other WQ principles were associated with technical efficiency. The principle “Good feeding” comprises the prevalence of very lean animals and resource-based measures of water provision. However, very lean cows were seldomly observed on the farms (median prevalence of very lean cows in Year 0: 2.9%, min 0%, max 19.4%). Thus, the principle score “Good feeding” is mainly determined by the provision of water. However, it remains difficult to explain how e.g. providing more drinker space and clean drinkers should be connected to lower technical efficiency scores. The large impact of this criterion on principle scores regarding “Good feeding” has however been critizised for not being a valid reflection of the actual welfare impact of a lack of water provision (De Vries *et al*., 2013) and this may also explain the lack of a meaningful relationship between water provision and technical efficiency. The principle “Good housing” reflects lying comfort (criterion “Comfort around resting”) and the results indicate a fairly decent situation where significant effects on farm efficiency may not be expected. A lack of effect at the “Appropriate behaviour” principle level may be due to relatively little variation in the principle scores (min 9, max 34). On criterion level, increased head butts and displacements can be a result of competition for resources, such as water, food, or lying space (DeVries and von Keyserlingk, 2006). Agonistic behavior may therefore detrimentally influence milk yield as reported by Rouha-Mülleder *et al*. (2010).

The results indicate no relationship between the mean Malmquist index and differences in WQ scores between Year 1 and Year 0. This finding might have several reasons. First, the study period of approximately one year was rather short compared to the periods used in other DEA studies (Latruffe *et al*. 2012, Allendorf and Wettemann, 2015). It was not possible to consider a longer time period as most of the data in the present study was collected on-farm at the day of assessment only once per time point (Year 0 and Year 1). Studies that rely on farm accounting data (e.g. Allendorf and Wettemann, 2015) benefit from the possibility to use data from several years. This reduces the influence of single years on farm efficiency results. Second, the changes in WQ scores (Table 1) might have been too small to exert a significant effect on farm efficiency. Marked increases or declines in WQ scores from Year 0 to Year 1 were mainly observed for the WQ principles “Good feeding” and “Good housing”. Based on the weak relationship between these two WQ principles and technical efficiency (see Tobit-regression results above; Table 3), we did not expect a significant influence of improvements or deteriorations of these areas on changes in efficiency. On the other hand, Tobit regression analysis revealed a positive relationship between principle scores for “Good health” and technical efficiency for Year 0. However, although in the present study health and welfare planning enhanced udder health and cleanliness (Tremetsberger *et al*., 2015), the changes in the scores for this principle (Year 0 to Year 1) were smaller than those observed for “Good feeding” and “Good housing”. The observed shift in the principle “Good health” might not have been sufficient to exert clear effects on farm efficiency. It is not clear how much improvement in health and welfare areas would be necessary to be reflected in changes in farm efficiency. Furthermore, improvements in some criterion scores or principle scores could be hidden by deteriorations in other areas, or vice versa. For instance, a farm improving in leg health (criterion “Absence of injuries”) but at the same time deteriorating in udder health (criterion “Absence of disease”) may not show changes in the respective aggregated principle score “Good health”.

Conclusions

This study describes how to integrate on-farm health and welfare assessment outcomes and technical efficiency measures from data envelopment analysis. Our results show that some areas of health and welfare of dairy cows affect technical efficiency, which emphasizes the basic importance of animal welfare for the economic success of a farm. This underlines, that animal welfare is not only of societal interest, but also of fundamental relevance for the farmers. Correspondingly, economic consequences of improving animal welfare could be more explicitly integrated into the communication with farmers on animal welfare interventions.

However, the results of our study also show a clear need for future research. Firstly, our analysis was limited with regard to capturing the effects of animal welfare management measures on technical efficiency. Mainly due to data restrictions we were not able to analyze the underlying factors and interlinkages steering such changes; future studies should contribute to better understand these mechanisms. Furthermore, future studies should aim at covering longer time periods. This would allow even accounting for effects of such measures, which exert their impact only in the long run often connected with adopting new techniques on the farms.

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Supplementary Table S1 Median values (25% – 75% quartile range) for Welfare Quality (WQ) measures in Year 0 as well as the respective change in Year 1 (difference Year 0 and Year 1) in Austrian dairy farms (n = 34)

			Year 0		Difference Year 0 – Year 1	
WQ measures	Unit	WQ principle[1] / criteria[2]	Median	25% – 75% quartile	Median	25% – 75% quartile
Very lean cows	%	P1 / C1	2.9	0.0 – 6.2	0.0	-3.1 – 2.9
Duration of lying down movement	sec	P2 / C3	5.9	5.5 – 6.1	-0.1	-0.6 – 0.2
Lying down movements with collisions	%	P2 / C3	33.3	12.5 – 42.9	-9.3	-27.4 – 8.7
Lying cows which lie partly/completely outside lying area	%	P2 / C3	4.2	0.0 – 13.9	0.1	-3.7 – 2.1
Cows with dirty lower legs	%	P2 / C3	42.9	27.1 – 57.2	4.9	-22.2 – 16.2
Cows with dirty udder	%	P2 / C3	62.9	54.5 – 75.7	-17.5	-28.7 – -3.3
Cows with dirty flank and upper legs	%	P2 / C3	40.0	27.3 – 65.7	-10.3	-19.9 – 12.9
Not lame cows	%	P3 / C6	60.6	50.0 – 74.3	-3.4	-10.5 – 4.9
Moderately lame cows	%	P3 / C6	20.8	16.6 – 27.0	1.5	-3.6 – 7.5
Severely lame cows	%	P3 / C6	13.5	9.1 – 24.6	2.3	-6.6 – 6.0
Cows with no hairless patch and no lesion	%	P3 / C6	38.9	30.6 – 48.5	26.4	18.5 – 34.0
Cows with at least one hairless patch and no lesion	%	P3 / C6	32.4	27.1 – 46.2	-15.1	-23.3 – -8.9
Cows with at least one lesion	%	P3 / C6	20.0	12.1 – 33.3	-10.6	-18.2 – 0.9
Frequency of coughing	per cow per 15 min	P3 / C7	0.1	0.1 – 0.2	0.0	-0.1 – 0.0
Cows with nasal discharge	%	P3 / C7	0.0	0.0 – 0.0	0.0	0.0 – 0.0
Cows with ocular discharge	%	P3 / C7	0.0	0.0 – 3.2	0.0	-2.9 – 0.0
Cows with increased respiratory rate	%	P3 / C7	0.0	0.0 – 0.0	0.0	0.0 – 0.0
Cows with diarrhoea	%	P3 / C7	6.9	3.8 – 18.3	5.9	-6.3 – 10.3
Cows with vulvar discharge	%	P3 / C7	0.0	0.0 – 3.1	0.0	0.0 – 0.0

Mastitis (milk somatic cell count > 400 000)	%	P3 / C7	7.2	3.2 – 12.3	1.9	-2.9 – 4.5
Mortality during the last 12 months	%	P3 / C7	0.0	0.0 – 3.3	0.0	-2.7 – 0.2
Dystocia	%	P3 / C7	2.8	0.0 – 5.5	0.0	-3.9 – 2.6
Downer cows	%	P3 / C7	2.8	0.0 – 6.0	0-0	-3.0 – 2.6
Frequency of headbutts	per cow per hour	P4 / C9	0.7	0.4 – 1.2	-0.1	-0.5 – 0.2
Frequency of other aggressive events (displacements, chasing, fighting, chasing-up)	per cow per hour	P4 / C9	0.3	0.2 – 0.7	0.0	-0.2 – 0.3
Cows that can be touched	%	P4 / C11	42.9	30.9 – 50.9	-4.5	-15.8 – 9.9
Cows that can be approached by 50 cm but not touched	%	P4 / C11	41.4	34.7 – 52.2	9.1	1.9 – 17.4
Cows that can be approached between 50 cm an 1 m	%	P4 / C11	10.3	5.7 – 19.3	-2.9	-8.8 – 0.0
Cows that can’t be approached	%	P4 / C11	0.0	0.0 – 4.3	0.0	-3.9 – 0.0
Positive emotional state	WQ-score	P4 / C12	25.6	15.8 – 37.8	0.8	-16.3 – 9.8

[1] P: Welfare Quality principle; P1 Good feeding; P2 Good housing; P3 Good health; P4 Appropriate behaviour

[2] C: Welfare Quality criteria; C1 Absence of prolonged hunger; C3 Comfort around resting; C6 Absence of injuries; C7 Absence of disease; C9 Expression of social behaviours; C11 Good human-animal relationship; C12 Positive emotional state

General discussion and conclusions

The following sections cover key aspects of the methodology applied in this thesis that were not or only partially discussed in the journal contributions as well as application of the results and future research perspectives.

Methodological aspects

Farm selection

The on-farm research for the present study (i.e. Paper II and Paper III) was carried out on commercial dairy farms in Austria. The farms were included in the study based on the following criteria: i) loose housing system; ii) no automatic milking system; iii) herd size greater than 30 cows; iv) participation in the national milk recording scheme; v) motivation to participate in the project. This resulted in a convenience sample of farms, which differs from the average Austrian dairy farm (see Materials and methods as well as Discussion in Paper II). However, there is no evidence that the approach chosen in this study as well as the farm-specific measures developed would not be applicable to smaller herds or different housing systems.

Sample size

The sample size of in total 34 dairy farms is comparable with other studies in this field in Austria (Gratzer, 2011), Germany (Brinkmann and March, 2010) and the UK (Barker et al., 2007). However, only in the present study, data collection and health and welfare planning was carried out by one single researcher. This limited the sample size due to time restrictions and workload. Involving two or more researchers visiting and assessing the farms, allows for investigating larger sample sizes with regard to health and welfare improvement. For example, 52 dairy farms in England and Wales (Green et al., 2007) or 77 organic dairy farms in Switzerland (Ivemeyer et al., 2009) were included and with 189 dairy farms in the UK a considerably higher number of farms were assessed by four assessors as part of a lameness intervention study (Main et al., 2012). However, the sample size of the present study offers the advantage that all data were assessed by one researcher, thus inter-observer reliability did not have to be considered and it was possible to identify effects of interventions by carrying out multiple farm visits. On the other hand, a larger sample size would probably have allowed for an evaluation of areas, that have rarely been addressed in the course of health and welfare planning (e.g. social behaviour). Furthermore, true effects of health and welfare planning related to health indicators with high variance (e.g. lameness prevalence) might have been detectable with higher statistical power in a larger sample size.

As regards the technical efficiency calculations using data envelopment analysis (Paper III), although some studies analysed larger sample sizes (Barnes et al., 2011; Hansson et al., 2011), smaller sample sizes have been considered as well. For instance, when evaluating technical efficiency of US dairy farms, Stokes et al. (2007) compared 34 dairy farms, a sample size which is comparable with the present study. Drawbacks of small sample sizes (e.g. less statistical power) can be counteracted by choosing a homogeneous data set (Dyson et al., 2001). The farms in the present study were relatively similar to each other with regards herd size, housing system, feeding management and workforce. Furthermore, the setup of the data envelopment analysis applied in this study (number of input and output factors) corresponded to the recommendations by Dyson et al. (2001).

Study duration

The participating farms were visited three times during the study. Final data collection took place on average 423 ± 29 days after the initial assessment. This schedule follows the design used in several other on-farm studies addressing health and welfare improvements in dairy cattle. Regarding timeframe, the present study goes in hand with studies on health and welfare planning (Gratzer, 2011) and intervention programs on udder health (Ivemeyer et al., 2009, Green et al., 2007), with approximately one year between initial and final data collection. Studies lasting two years have been reported for lameness in heifers (Bell et al., 2009) and udder health (Ivemeyer et al., 2008). Longer time periods of intervention studies aiming at improving lameness in dairy cattle were also reported (Brinkmann and March, 2010, Main et al., 2012). Based on the existing literature on intervention studies in dairy health and welfare, it cannot be concluded that longer monitoring periods would be more promising in terms of health and welfare improvements. From the above-mentioned studies, there seems to be no clear association between study duration and improvements in health and welfare. This indicates that improvement might rather be a matter of the health and welfare area(s) addressed and the rate of implementation of measures (see also paper I) rather than time. In the present study, the main improvement regarding health and welfare was observed for udder health. This area can be positively addressed in studies lasting one year as reported by Green et al. (2007), where the proportion of cows affected with clinical mastitis and the incidence of clinical mastitis was significantly reduced. The lack of improvement in other areas, such as lameness, has also been shown by other studies (Bell et al., 2009, Gratzer, 2011, Barker et al.,

2012) and might be due to the fact that some health and welfare areas probably need longer durations to be effectively addressed. Additionally, farmers might have benefitted from a more intense coaching to detect lameness in their herds than it was performed in the present study, as it has been shown by Brinkmann and March (2010) for improvements of leg health. One other aspect could be that for the case of comprehensive health and welfare plans (i.e. consisting of several distinct health and welfare areas) not all health and welfare areas can be addressed simultaneously and with the adequate effort to reach improvements after one year (see also paper I). It might be possible that farmers preferred to address some areas more than others (e.g. udder health versus leg health).

Welfare assessment method

In the present study, assessment of health and welfare of dairy cows was primarily based on the Welfare Quality assessment protocol for dairy cattle (WQ) (Welfare Quality, 2009). Here, the assessment relies to a large extent on animal-based parameters (e.g. prevalence of lame cows). This protocol has been applied also by other studies (Andreasen et al., 2013, De Vries et al., 2013a, de Boyer des Roches et al., 2014), however, without the aim of using the outcomes for achieving health and welfare improvements on the farms. In order to fully accomplish the requirements of the present study, the WQ protocol was adapted and further measures were included.

Already existing parameters were adapted with regards to the level of scores used in WQ. Similarly to Gratzer (2011), body condition was assessed using a more detailed 5-point scoring system based on Lowman et al. (1973), Mulvaney (1977), and Wildman et al. (1982). This scoring system was preferred over the WQ system that only distinguishes between very lean cows, cows with regular body condition, and very fat cows, respectively. The adapted scoring system was meant to describe the body condition of dairy cows on a more detailed level that would provide more precise information when formulating the health and welfare plan regarding metabolic health. This scoring system was chosen because many Austrian dairy farmers are used to this system. When reporting data on body condition back to the farmers in written form, for simplification purposes results were expressed according to the WQ definitions, however, in discussions during health and welfare planning, the more detailed scores were also considered which turned out to be helpful (e.g. when differentiating between degrees of overcondition). Similarly, in order to obtain more detailed information for health and welfare planning, udder and teat cleanliness was scored differently than defined in the WQ protocol. According to the WQ protocol, “udder” and “teats” are considered as one body region. Thus, no differentiation can be made between dirt on the udder and dirt on the teats, which may have different reasons. Furthermore, dirt on the teats might pose a higher risk for infection with environmental pathogens leading to mastitis than dirt on the udder (Plesch and Knierim, 2012). As the WQ protocol does not distinguish between dirty udder and dirty teats, as well as between slightly and severely dirty teats, this differentiation was included in the present protocol. Slightly dirty teats might have other reasons than severely dirty teats (e.g. minor splashing from dirty alleys versus severe soiling from badly maintained stall bases), thus requiring different interventions when improving teat cleanliness.

The assessment protocol was extended by a number of health and welfare parameters, which have not been included in the WQ protocol. Data derived from the national milk recording scheme were assessed and used for health and welfare planning. For instance, somatic cell counts of all animals were used for calculating herd-level somatic cell scores (Wiggans and Shook, 1987) as well as percentages of animals with a somatic cell count greater than 100,000 and 400,000 cells/ml milk, respectively. This information was essential in evaluating udder health situation on the farms. Evaluations based solely on the information obtained from the WQ protocol (i.e. proportion of cows with a somatic cell count exceeding 400,000 cells/ml milk in the last three months) would have limited the data for health and welfare planning. Data on milk constituents (i.e. milk fat, milk protein, milk urea) were also obtained from the national milk recording scheme and served for an analysis of metabolic health states. Again, this information would not have been gained from the WQ protocol. To describe leg health more precisely, claw condition was scored in this study. This parameter was based on the visual assessment of the claw (e.g. length, angle, surface).

No parameter of the WQ protocol was omitted from the on-farm assessment in this study, not least because a complete score calculation is impossible with missing data. This implied, that also Qualitative behaviour assessment (QBA; Wemelsfelder et al., 2001) was performed as part of the on-farm assessments, since it is the only measure addressing positive welfare. However, results were not reported back to the farmer and included in the herd health plans due to a lack of feasible methods for communicating QBA results. In WQ, QBA results are expressed as a single score from 0 to 100. However, unlike herd prevalences or incidences (e.g. lameness prevalence; mastitis treatment incidence) that are well known by farmers, interpreting these QBA results is to be difficult. While the general principles of QBA using terms to describe animals' expressive qualities of animal behaviour seems familiar to farmers, as it reflects their daily routine with cattle, the rather abstract transformation into QBA scores is unfamiliar and obscure. Furthermore, at least prevalences of clinical parameters can easily be back-translated into individual affected animal, thus getting information on which animals to treat, whereas this is not possible with QBA results.

WQ may be regarded a useful protocol for the on-farm assessment of dairy cow health and welfare. It provides validated parameters not only for health issues but also parameters for behaviour, which were included in this study to comprehensively cover several dimensions of animal welfare. For the purpose of this study, WQ results were reported on the farm as herd prevalences/incidences as farmers are used to such data. Aggregation of criterion scores and principle scores according to WQ was only applied for analysing data with regard to economic considerations (see Paper III).

Data quality

Valid and reliable data that can be obtained by feasible ways of assessment are important aspects of robust on-farm welfare assessment (Knierim and Winckler, 2009). Regarding reliability of the data, a thorough training session was undertaken before the initial on-farm data collection. The researcher conducting this study was instructed for on-farm welfare assessment following the WQ protocol for dairy cattle. The training was carried out by a researcher well experienced in on-farm welfare assessment and animal health and welfare planning in dairy cows. In this training session, inter-observer reliability was acceptable (Cohen's Kappa and Spearman rank correlation > 0.7) with regard to the agreement between the two researchers for each welfare indicator. Contrary to other studies in the field of health and welfare planning (Green et al., 2007, Bell et al., 2009, Ivemeyer et al., 2009, Brinkmann and March, 2010, Gratzer, 2011, Main et al., 2012), all data were collected by one researcher throughout the study. Thus, inter-observer reliability among two or more observers carrying out the on-farm data collection was of no relevance.

However, unlike inter-observer reliability, forms of intra-observer bias might be relevant in the present study design. Although being a key element of sound scientific work, studies on animal behaviour rarely report on a possible observer bias. A form of observer bias, the expectation bias (i.e. expectancy effect) describes the tendency of observers to unwittingly obtain the results they expect (Rosenthal and Rubin, 1978). Expectation bias has recently been described for the assessment of farm animal behaviour (Tuyttens et al., 2014). So far, no study in the field of health and welfare planning considered observer bias in their study design or (critically) discussed this topic, although this might be relevant. Tuyttens et al. (2014) admit that accounting for a potential observer bias in studies on animal behaviour is difficult to achieve. In the present study, observer blinding was not possible due to the set-up, although this would be an effective way of minimizing conscious or unconscious observer bias. However, developing a study set-up that would have acknowledged observer blinding was not possible due to several reasons. It would have required more personnel, which was not practicable due to financial reasons. It would have been too expensive and too time-consuming to keep apart the steps of data collection and health and welfare planning. Nevertheless, some aspects regarding observer bias were considered in this study. The researcher conducting the farm visits was particularly concerned not to recall the farm results (i.e. health and welfare data) from the initial assessment prior to the final assessment. Therefore, conscious or unconscious effects of knowing the outcomes of the initial assessment on the results of the final assessment should have been minimized. Furthermore, the researcher also did not call up the health and welfare plan that had been developed at the beginning of the study on each farm until terminating the on-farm data collection. However, knowing some key topics of the health and welfare plan on each farm was unavoidable.

One other factor potentially affecting the results of a study such as the present is observer drift. This means that observers can change the way they use definitions of parameters over time (Kazdin, 1977). This can be due to getting familiar with the definitions and that observers unconsciously change or adapt the definitions (Martin and Bateson, 2007). Observer drift is especially likely for indicators that are not clearly defined. In the present study, the parameters were comprehensibly defined using pictures (e.g. ocular discharge), measurements (e.g. defined minimum area for integument alterations) or precise descriptions of behaviour (e.g. agonistic interactions). Furthermore, the definitions were not changed throughout the farm assessments. Intense training including on-farm assessments as well as video and picture material served as a solid foundation for on-farm assessments. Acceptable levels of inter-observer reliability were reached between the observer in this study and either a well-trained observer conducting the training (e.g. for cleanliness assessed on-farm) or reference values derived from expert ratings (e.g. for lameness scored from videos). During the course of the present study, the author participated in several training courses regarding the (reliable) application of the WQ protocol and, in addition to this, (co-) supervised parts of these trainings. The trainings involved explaining and where necessary clarifying the definitions, re-training and re-testing of all parameters in the protocol. The author reached at least acceptable levels of inter-observer reliability. All this does not give reason for concern that observer drift may have occurred. Furthermore, for some effects of interventions an observer effect can be excluded. For example, the effect of interventions on udder health as regards somatic cell score was based on analysing data derived from the national milk recording scheme. This data was not susceptible to observer drift.

Besides assessing health and welfare state of the animals, further data was collected in this study. Part of the data obtained was based on farmer interviews and was used for economic analyses using data envelopment analysis (Paper III). For these calculations, the parameter “Annual labour” was assessed by interviewing the farmer. The interview was based on a questionnaire consisting of several questions related to work with the dairy cows. The questions covered annual work hours specified for the main working steps (milking, feeding, hygiene and herd management) rather than an overall question regarding annual work. This procedure of explicitly covering several areas was different to the approach chosen by Barnes et al. (2011) where data on overall annual labour was based on a simple estimate given by the farmer (Rutherford, 2011, personal communication). The procedure applied in the present thesis may have contributed to achieving reliable data for this parameter.

Data analysis

Data analysis in the paper II focussed on herd-level prevalences/incidences for single parameters rather than aggregated criterion or principle scores (Welfare Quality, 2009). The main reasons for this approach were the fact that during health and welfare planning all aims and measures were discussed and set at the single parameter level (e.g. reducing the number of lame cows) and farmers were familiar with these indicators from their daily work. The WQ protocol comprises single measures that may be aggregated following a process on three steps: aggregation of 63 measures into 12 criteria; 12 criteria aggregated into 4 principles; 4 principles into 1 overall classification (low to high: “not classified” > “acceptable” > “enhanced” > “excellent”) (Botreau et al., 2009). Recently, concerns have been raised whether this multi-criteria evaluation applied in the WQ protocol is suitable for detecting the effects of changes in single measures of health and welfare (De Vries et al., 2013a, Heath et al., 2014). For instance, herds with high prevalences of lame cows were still classified at least as “acceptable”. A herd with 36% animals with somatic cell count greater than 400,000 cells/ml milk was classified as “enhanced” (De Vries et al., 2013a). This highlights a mismatch between the current aggregation system in WQ and the perception of major health and welfare topics, such as lameness and mastitis. Although not intended (Veissier et al., 2011), to a certain extent criterion scores can be compensated for by each other, which can blur the effect of single health and welfare measures on the classification of the farms. In the present study, it was refrained from aggregating measures for health and welfare planning as an aggregation might have caused preferably approaching areas where small changes can lead to a major impact on farm classification. Furthermore, it was the aim of equally considering all measures of health and welfare and to prevent any selection of areas to address. Admittedly, aggregated WQ results were used for classifying the sample for data envelopment analysis (Paper III). This approach was chosen as alternative ways of aggregating are lacking. However, aggregation may indeed be useful and indispensable for other purposes than health and welfare planning such as farm certification.

Intervention strategy

The intervention strategy chosen in this study was based to a large part on the principles described by Vaarst et al. (2011). Key elements of the strategy were identified and discussed in the literature review as part of paper I of the present thesis: i) assessment of current health and welfare state and risk factors; ii) evaluation of the health and welfare state in participation with the farmer; iii) introduction of farm-specific measures for improvement of health and welfare; iv) final evaluation. Due to time constraints, it was not possible to carry out an interim review of the situation some time after introducing improvement measures (e.g. after 6 months), which is in fact considered helpful for the long-term success of such an intervention study (Vaarst et al., 2011).

Regarding communication with the farmers in this study, farmers were included in every stage of discussing the results of the initial health and welfare assessment with the researcher. Furthermore, farmers were intensively involved in setting farm-specific aims on what to improve (e.g. improving teat cleanliness) as well as developing farm-individual measures for achieving these aims (e.g. more frequent provision of new bedding material). The researcher supported the farmer in reaching his or her goal(s). First of all, understanding risk factors and limitations of the own farm can be seen as crucial for a satisfactory implementation of measures (Vaarst et al., 2011). For instance, if farmers wish to improve leg health in their herds, awareness of the problem is fundamental, but research has shown that farmers often underestimate lameness prevalences in their herds (Whay et al., 2002, Barker et al., 2010, Šárová et al., 2011). Due to time constraints it was not possible in the present study to undergo a lameness scoring training with the famers, which might have helped farmers to detect lame animals (Brinkmann and March, 2010). However, it was the farmer who finally decided on the aims and measures and documented them in his or her health and welfare plan. Following Vaarst et al. (2011) it is not sufficient that the farmer agrees on measures that have been proposed by the researcher. The researcher did not entirely act as an expert providing knowledge on improving health and welfare problems but rather supported the farmer in developing own solutions. External expertise was however provided by the researcher when needed in the discussion. The farmers appreciated the role of the researcher “from outside the farm” as well as examples of successful improvement measures from other dairy farms. Ownership over the planning process was with the farmer, which is according to Vaarst et al. (2011) a key point of health and welfare planning. A strength of the approach chosen in this study may be seen in the development of farm-specific interventions in participation with the farmer. The researcher did not present already predefined measures to the farmer and recommended their implementation but rather helped and supported the farmer in analysing his or her own farm and finding weak points and risk factors.

One other important element of health and welfare planning is seen in frequently reviewing the once established plan in order to quickly react to changes and adaptations of measures (Vaarst et al., 2011). A study on leg health improvement (Brinkmann and March, 2010) has intensively accompanied the participating farms. Part of the considerable reduction in lameness prevalence was related to the frequent farm visits and the review of aims and measures. This was however not possible in the present study and may have limited a successful intervention regarding leg health. Indeed, as reported in paper II, leg health remained unchanged within the study period.

Practical application

If farmers, veterinarians or farm advisors strive for improving health and welfare of dairy cows, key aspects of the approach used in the present study may be applied (Whay and Main, 2010). Developing measures to improve areas of health and welfare requires knowledge of the health and welfare status and thus, assessing health and welfare is the initial step for improvement. Using the assessment protocol applied in this study offers a validated assessment method that can be used by farmers, veterinarians or farm advisors. Although the protocol applied in this study might in its present form be time consuming for commercial diagnostic or advisory purposes, a reduced version would most likely limit its usefulness for health and welfare planning. Attempts to reduce comprehensive health and welfare assessment approaches by omitting parameters (De Vries et al., 2013b) or replacing parameters with data routinely collected on-farm (Sandgren et al., 2009, Nyman et al., 2011, De Vries et al., 2014) have only been partly successful. Associations between routinely collected health data and welfare indicators may not necessarily involve clausal relationships and there is a higher risk to obtain relationships by chance due to the large number of variables tested (De Vries et al., 2014). Furthermore, data quality of routinely collected data might be uncertain, as discussed above for the situation in the present study. Such approaches offer limited potential to predict parameters and will need verification (De Vries et al., 2014). Furthermore, animal behaviour in on-farm welfare assessment should not be neglected as several studies, including the present thesis, highlighted that behavioural aspects of dairy cattle welfare may represent an area to be addressed, at least in a part of the farms. However, not all parameters of the WQ protocol are yet ready to be fully integrated in a practical application. As indicated above, methods for reporting QBA results will have to be developed before this parameter can be integrated in on-farm health and welfare planning.

When carrying out this study, it was initially planned to consider treatment records related to udder and metabolic health, respectively. In the course of the on-farm data collection, it became apparent that reliable data on treatments were not available on all farms. Treatment records are important for analysing for instance udder health status (e.g. treatment incidence of clinical mastitis) and valuable information on health states might be lost by an incomplete records. However, recording diagnoses and treatments by a nationwide database is increasing in Austria (Egger-Danner et al., 2012, Koeck et al., 2015) and might improve data quality and quantity for animal health and welfare planning.

Recently, research has been undertaken in developing effective ways of communicating with farmers, especially in the case of veterinarians (Derks et al., 2011, Lam et al., 2011). The intervention strategy applied in this study makes use of several key points that have been identified as being effective in communication with farmers (Garforth, 2011, Whay and Main, 2010). Farm advisors or veterinarians should no more be ‘supervisors’ recommending predefined solutions, but rather take up a proactive position and using the farmers’ social environment (Lam et al., 2011) and support farmers with knowledge and encourage them in taking action. Farmers have to be included in all steps of setting aims on what to improve as well as finding measures how to improve (Whay and Main, 2010).

Further research perspectives

Several aspects of health and welfare planning in dairy herds still need further evaluation. The present study shows that improvements in udder health and cleanliness can be achieved within one year applying this approach. However, an effect on other areas of health and welfare, such as leg health, was not obtained. The often poor leg health in dairy cattle urges for ways of improving the current situation. Achieving leg health improvements would possibly require more time and a more intensive support of the farmers (as shown by Brinkmann and March, 2010).

The farmers in this study seldom addressed some areas of welfare, for instance social behaviour or behaviour around resting. However, following a comprehensive definition of animal welfare such areas should still be included in welfare assessment, and in some farms in the present study the situation would have justified interventions (e.g. incidence of agonistic behaviours). By addressing such behavioural parameters, the farmers may also benefit, as shown for associations between human-animal relationship and udder health (Ivemeyer et al., 2011) and agonistic behaviour and milk yield (Rouha-Mülleder et al., 2010) as well as human-animal relationship and milk yield (Waiblinger et al., 2002). On the other hand, there exists less experience with integrating behavioural aspects into welfare planning and especially with regard to qualitative behaviour assessment, feasible methods for communicating the outcomes still need to be developed.

The economic evaluation in this study using data envelopment analysis has shown to be promising for capturing the effect of health and welfare state on technical efficiency. Yet, some aspects of this topic are still unanswered. It is not clear which results may have been obtained when a different set and/or number of input factors would have been used to build DEA models. Although the sample size used in the present study corresponds with other studies regarding DEA, relationships between health and welfare states and farm economics should be confirmed analysing a larger number of farms. Furthermore, the present data set represents one Austrian dairy production system (large share of farms with zero grazing, above average herd size and milk yield) and it remains open whether DEA models for other farm systems such as pasture-based dairy production may produce similar results.

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