

SCIENTIFIC REPORT OF EFSA

Scientific report on the effects of farming systems on dairy cow welfare and disease¹

Report of the Panel on Animal Health and Welfare

(Question No EFSA-Q-2006-113)

This report, annexed to the related opinions, published on 8 October 2009, replaces the earlier version published on 9 July 2009².

WORKING GROUP MEMBERS

Bosse Algers

Giuseppe Bertoni

Donald Broom

Joerg Hartung

Lena Lidfors

Jos Metz

Lene Munksgaard

Telmo Nunes Pina

Pascal Oltenacu

Jürgen Rehage

Jeffrey Rushen

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² Minor editorial changes have been amended on the report, namely the word “glossary” repeated twice on page 278 and the word “Holsein” corrected to “Holstein” on page 66. In the header of the cover page, the page number of the report was replaced with the page number of the opinion on “The overall effects of farming systems on dairy cow welfare and disease”. No further changes have been introduced in the opinion or its annexes. To avoid confusion, the original version of the opinion has been removed from the website, but is available on request as is a version showing all the changes made.

Frans Smulders
Elsbeth Stassen
George Stilwell
Susanne Waiblinger
John Webster

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BACKGROUND

Council Directive 98/58/EC concerning the protection of animals kept for farming purposes lays down minimum standards for the protection of animals bred or kept for farming purposes, including cattle, although no specific rules are laid down at Community level for dairy cows. The recently adopted Community Action Plan on the Protection and Welfare of Animals³ has as one of the main areas of action “upgrading existing minimum standards for animal protection and welfare...as well as possibly elaborating specific minimum standards for species or issues that are not currently addressed in EU legislation”.

In response to a request from the Commission, EFSA has recently issued a scientific opinion and report on welfare aspects of intensive calf farming systems⁴, updating a report on the welfare of calves⁵ adopted by the Scientific Veterinary Committee Animal Welfare Section on 9 November 1995. A scientific opinion on the welfare of cattle kept for beef production⁶ has also been issued by the Scientific Committee on Animal Health and Animal Welfare on 25 April 2001. However no scientific opinion has yet been issued concerning the welfare of dairy cows, except for that on Bovine Somatotrophin (SCAHAW, 1999).

TERMS OF REFERENCE

Against this background the Commission considers it opportune to request EFSA to issue a scientific opinion on the welfare of dairy cows. This opinion should consider whether current farming and husbandry systems comply with the requirements of the well-being of dairy cows from the pathological, zootechnical, physiological and behavioural points of view. In particular the impact that genetic selection for higher productivity has had on animal welfare should be evaluated, considering inter alia the incidence of lameness, mastitis, metabolic disorders and fertility problems. Where relevant for animal welfare, animal health and food safety aspects should also be taken into account.

Due to the great diversity of topics and the huge amount of scientific data, it was proposed that separate scientific opinions on different welfare subjects would be more adequate and effective. The WG Members and the AHAW Panel therefore agreed to subdivide the risk assessment process into four different subjects: i) metabolic and reproductive disorders, ii) udder disorders, iii) leg and locomotion problems and iii) behaviour, fear and pain. Since physiological and some other aspects of poor welfare in dairy cows are not evaluated in the risk assessments, in some cases, because of lack of scientific evidence, a fifth scientific opinion has also been produced as a global assessment including these aspects. This fifth scientific opinion also integrates conclusions and recommendations from the scientific report with the outcomes from the four separate risk assessments.

Therefore, the documents provided to the Commission as a response to the terms of reference of the mandate are the following:

Scientific Report

“Effects of farming systems on dairy cow welfare and disease”

³ http://europa.eu.int/comm/food/animal/welfare/actionplan/actionplan_en.htm

⁴ http://www.efsa.europa.eu/science/ahaw/ahaw_opinions/1516_en.html

⁵ http://europa.eu.int/comm/food/fs/sc/oldcomm4/out35_en.pdf

⁶ http://europa.eu.int/comm/food/fs/sc/scah/out54_en.pdf

Scientific Opinion – Udder problems

“Scientific opinion based on the risk assessment of the impact of different hazards, grouped as housing, nutrition and feeding, management and genetic selection, on udder problems in dairy cows.”

Scientific Opinion - Leg and locomotion problems

“Scientific opinion based on the risk assessment of the impact of different hazards, grouped as housing, nutrition and feeding, management and genetic selection on leg and locomotion problems in dairy cows.”

Scientific Opinion - Metabolic and reproductive problems

“Scientific opinion based on the risk assessment of the impact of different hazards, grouped as housing, nutrition and feeding, management and genetic selection, on metabolic and reproductive disorders in dairy cows.”

Scientific Opinion – Behavioural problems, fear and pain

“Scientific opinion based on the risk assessment of the impact of different hazards, grouped as housing, nutrition and feeding, management and genetic selection, on behavioural problems in dairy cows.”

Scientific Opinion - Overall

“Overall assessment of the effects of farming systems on dairy cow welfare and disease”

The present document refers only to the “Scientific Report on the effects of farming systems on dairy cow welfare and disease” as referenced above.

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INTRODUCTION AND OBJECTIVES

INTRODUCTION

This report categorises European dairy farming according to internationally used classifications of farming systems. Human and exogenous institutional factors are also important as they are superimposed on the farming system and affect the impact of the technical conditions of the system on the welfare, especially the health of the cows. The animals considered in this report are dairy cows, while lactating or not lactating, and calves and heifers that will become dairy cows. The welfare of dairy bulls is an important subject that is not covered in this report and it could be a subject of another report. The welfare of calves is covered in EFSA's scientific opinion on intensively kept calves (EFSA, 2005) whereas many reports from EFSA and previous EU scientific committees concern cattle diseases.

Welfare and related concepts are discussed briefly in chapter 1. The methods of assessing welfare and potential indicators of good or poor welfare are also discussed. A section on the needs of dairy cows (Chapter 2) forms the basis for the list of factors used in the risk analysis, as explained in chapter 5.2 and in the related sections in each of the four separate Scientific Opinions on the risk assessments on leg disorders, udder disorders, behaviour problems together with fear and pain, and metabolic and reproductive disorders. These risk assessments are limited to milking cows, rather than dry cows, heifers, calves or bulls. They only concern the four important areas listed above and consequently there may be aspects of poor welfare in dairy cows that are not evaluated in the risk assessments.

The purpose of this Scientific Report is to describe dairy cow welfare and to consider ways in which welfare can be adversely affected and possibilities for its improvement. The range of factors which have important consequences for dairy cow welfare are discussed. They include cow genetics, housing (e.g. space and pen design, flooring and bedding material, temperature, ventilation and air hygiene), feeding (e.g. liquid feed, concentrates, roughage), management (e.g. grouping, weaning), and human-animal relations.

The measures used to assess welfare include behavioural and physiological measures, pathophysiological measures and clinical signs, as well as production measures.

The Scientific Report refers to infectious diseases where management methods are likely to affect their incidence. However, no attempt is made to review this topic. On the other hand, production-related diseases are discussed in detail. It is considered that leg disorders, mastitis and reproductive disorders are considered major components of poor welfare in dairy cows and therefore there are substantial sections on these topics. The genetic selection of dairy cattle over many years is considered to be a major factor leading to poor welfare in dairy cows. This topic is considered in detail in the Report and in the four Risk Assessments.

OBJECTIVES

Objectives of this report are to review and report recent scientific literature on the welfare and disease of dairy cows (Chapter 4 to chapter 16) and to identify, where possible, animal based welfare outcomes or indicators (see the fifth Opinion that lists Conclusions and Recommendations).

Food safety implications of different farming systems are considered in a separate document produced by the Biohazards Panel.

MATERIALS AND METHODS

MATERIALS

The working group set out to systematically determine whether various factors potentially affecting dairy cow welfare are beneficial or constitute a potential hazard or risk. To the latter end their severity and likelihood of occurrence in dairy cow populations were evaluated and associated risks to dairy cow welfare estimated, hence providing the basis for decision makers to decide which measures could reduce or eliminate such risks. It should be noted, however, that this does not imply that a hazard that has a serious effect on just a few animals should not be dealt with by managers on farm level as the suffering imposed on some animals constitutes a major welfare problem for those individuals.

Due to the great diversity of topics and the huge amount of scientific data the risk assessment process was divided into four different subjects: i) metabolic and reproductive disorders, ii) udder disorders, iii) leg and locomotion problems and iv) behaviour, fear and pain. In line with the terms of reference, the working group carried out a semi-quantitative risk assessment approach, following the same approach developed in earlier reports, e.g. welfare of calves, welfare of pigs. Four Risk Assessments were performed and conclusions were written from the risk assessment results leading to 4 different Scientific Opinions on the above mentioned subjects. The risk assessment approach is extensively described in each of the four scientific opinions. A fifth scientific opinion has also been produced as an overall assessment of dairy cow welfare integrating the conclusions and recommendations from the data presented in this scientific report and the conclusions from the four separate risk assessments.

METHODS

1. Welfare concepts and assessment.

The wording of the Treaty of Amsterdam (EU, 1997) reflects the public concern about the welfare of farmed animals and hence there is a requirement that there be a scientific evaluation of animal welfare. Farmed animals are subject to human imposed constraints and for a very long time the choice of farming techniques was based primarily on the efficiency of production systems for the provision of food. However when choosing methods for keeping and managing animals in order to protect these animals against mistreatment and poor welfare, it is necessary to know how their welfare is affected by the various methodologies. These public concerns apply to cows.

Fraser (1999, 2008) point out that there are at least three different concepts considered when animal welfare is discussed. One set of concepts is focusing on the animal's health and biological functioning, a second set is focusing on the animal's ability to live a natural life, and a third set is focusing on the degree to which the animal experiences aversive or positive feelings, such as pain, fear or pleasure. As Fraser points out, there is actually a considerable degree of overlap between these three sets of concern. For example, both poor health and frustration of much normal behaviour of animals are likely to lead to suffering. However, Fraser did not advocate including degree of naturalness in the definition of welfare or its assessment. The separation into three aspects is also confusing because, as explained below, biological functioning is not distinct from suffering and other feelings since these are biological mechanisms. To some extent, the way in which any one person refers to how animals should be treated reflects his or her personal values. For example, farmers and

veterinarians often see animal welfare primarily in terms of health and good biological functioning. In contrast, animal welfare groups place more emphasis on the extent to which animals are not suffering from pain etc. Most of the disagreements about animal welfare reflect the fact that people differ in which aspects of animal welfare they emphasise. It is sometimes claimed that the number of different definitions of animal welfare shows that there is a widespread disagreement, even between scientists, about what constitutes good and poor welfare. This is not so. Often the definitions of animal welfare differ in wording or place more emphasis on certain aspects of welfare compared with others. There is a considerable degree of agreement between scientists in what they consider as the most serious risks to animal welfare, as this report demonstrates. Hence this report on animal welfare addresses the scientific concepts relevant to the concerns of the public and other stakeholders and explains how these are taken into account.

To be useful in a scientific context, the concept of welfare has to be defined in such a way that it can be scientifically assessed. This also facilitates its use in legislation and in discussions amongst farmers and consumers. As discussed below, knowledge of the types of environments in which animals have evolved can help identify some of the challenges to welfare that occur when animals are kept in conditions of modern agriculture. For example, cattle have evolved to graze outdoors with grass as their primary food source. In contrast, in modern agriculture, dairy cattle are often housed indoors, on concrete floors, with refined grains as their prime source of energy. These differences can pinpoint what are the most likely challenges to the welfare of dairy cattle (Spinka, 2006).

The concept of welfare is relevant to any kind of animal, although not to plants or inanimate objects. Welfare is a characteristic of an individual animal and is concerned with the effects of all aspects of its genotype and environment on the individual (Duncan 1981). The common convention is to use the term “welfare” to refer to the state of the animal itself, while ‘animal care’ is used to refer to the way that people treat animals. Thus the welfare of an animal can be poor or good regardless of whether it is living in the wild or in contact with people. The degree to which the welfare of an animal is good or bad is taken into account when considering what constitutes proper animal care.

Broom (1986) defines it as follows: the welfare of an animal is its state as regards its attempts to cope with its environment. Coping means maintaining control of mental and bodily stability in response to a challenge. Welfare therefore includes the extent of failure to cope, which may lead to disease and injury, but also the ease or difficulty in coping. Both the long-term and short-term costs of coping are important for an animal’s welfare. For example, an animal may cope with an acute stress in the short-term by taking action that results in a long term reduction in its welfare. For example, dairy cattle may be able to cope with the stresses associated with high milk in lactation, but this coping may result in long-term health problems that are apparent in later lactations. Following the lead of Broom (1986) the World Organization for Animal Health (OIE) defines animal welfare as the following. “Animal welfare means how an animal is coping with the conditions in which it lives. An animal is in a good state of welfare if (as indicated by scientific evidence) it is healthy, comfortable, well nourished, safe, able to express innate behaviour, and if it is not suffering from unpleasant states such as pain, fear, and distress. Good animal welfare requires disease prevention and veterinary treatment, appropriate shelter, management, nutrition, humane handling and humane slaughter/killing. Animal welfare refers to the state of the animal. The treatment that an animal receives is covered by other terms such as animal care, animal husbandry, and humane treatment.”

The welfare of an animal is strongly affected by the extent to which it suffers from unpleasant emotional states or feelings such as pain, fear or frustration. It is likely that animals can also experience positive mental states, such as happiness, and these may have beneficial effects on their welfare (Duncan, 1996; Fraser and Duncan, 1998; Boissy et al., 2007). Feelings are a part of many mechanisms for attempting to cope with good and bad aspects of life and most feelings must have evolved because of their beneficial effects (Broom, 1998). Although feelings cannot be measured directly, their existence may be deduced from measures of physiology, behaviour, pathological conditions, etc. Therefore care is necessary to avoid anthropomorphic interpretations. Good welfare can occur provided that the individual is able to adapt to or cope, without much difficulty, with the constraints to which it is exposed (Broom, 2006a). Hence, welfare varies from very poor to very good and can be scientifically assessed. Assessment of welfare means obtaining data that provides information about how good or poor the welfare is. This data will always be partial rather than complete. Some measures of welfare concern the short-term, i.e. minutes or hours, whilst others concern welfare during periods of days, weeks or longer.

Welfare measures relevant to the welfare of an animal in its living conditions, i.e. largely long-term problems, are described by Broom and Johnson (2000) and by Broom and Fraser (2007), while the measures that are most relevant to cattle are described in Rushen et al. (2007). There are many measures that we can use to assess the welfare of the animal. However, these measures generally indicate the existence of a particular welfare challenge rather than measuring the overall welfare of the animal. In order to judge the overall welfare of the animal, it is necessary to take a wide number of measures. Production criteria, such as measures of growth or milk production, have a place in welfare assessment but must be used with care. However, the failure to grow, reduced ability to reproduce etc. often indicates poor welfare, high levels of production do not necessarily indicate good welfare. For example, sudden drops in milk production, perhaps associated with an illness, might indicate a welfare problem. However, a low average level of milk production in a herd may reflect feeding management rather than the level of welfare per se. A high level of production could increase the risk of poor welfare. In general, to use levels of production to assess welfare, we need to know what the causes of the low production are. The same is true of measures of reproduction. A failure to reproduce does not in itself constitute proof that animal welfare is poor. In fact, the care and raising of young can itself lead to reduced welfare of the mother if the environment does not provide sufficient resources. However, a reduced ability to reproduce most often indicates that the individual is less able to cope with its environment. Therefore reduced fertility and other reproductive disorders can be used as indicators of poor welfare, provided that the causes of the reduced reproduction are understood. Absence of reproductive opportunity is an obvious example of reduced reproduction that does not indicate poor welfare. More subtle problems can also suggest poor welfare, e.g. where farmers are trying to get cows in calf but the inter-calving interval is long, failure to reproduce or substantial delay in reproduction is likely to be associated with poor welfare. For example, a cow that is not cycling when cows that are coping well are cycling.

Measures of animal health can also provide useful information about animal welfare. Mortality rate and life expectancy also give evidence about welfare. Animals that die earlier than expected often do so as a result of a problem in coping with adversity. The measures of reproduction that indicate poor welfare are the inability to reproduce in an animal that, if it was not adversely affected by some aspect of its environment, ought to be able to do so. The use of mortality or culling rates as welfare indicators of dairy cows is discussed in Chapter 15.

The word "health", like "welfare", can be qualified by "good" or "poor" and varies over a range. However, health refers to the state of body systems, including those in the brain, which combat pathogens, tissue damage or physiological disorder (Broom and Kirkden, 2004; Broom, 2006b). Welfare is a broader term than health, covering all aspects of coping with the environment and taking account a wider range of feelings and other coping mechanisms than those associated with physical or mental disorders. Disease, implying that there is some pathology, rather than just pathogen presence, always has some adverse effect on welfare (Webster, 2001; Broom and Corke, 2002) but not all welfare challenges involve poor health.

The pain system and responses to pain are part of the repertoire used by animals to help them to cope with adversity during life. Pain is clearly an important cause of poor welfare (Broom, 2001b). However, prey species may show no evident behavioural response to a significant degree of injury (Broom and Johnson, 2000). In some situations responses to a wound may not occur because endogenous opioids which act as analgesics are released. In contrast there are many occasions in humans and other species when suppression of pain by endogenous opioids does not occur (Melzack et al., 1982). However, the feeling of pain is not the only negative emotion that animals feel that can influence their welfare. Cattle can become frightened or frustrated, and these can have as large effect on animal welfare as pain.

Physiological measurements can be useful indicators of poor welfare. For instance, increased heart-rate, adrenal activity, adrenal activity following ACTH challenge, reduced heart-rate variability, or immunological response following a particular type of challenge, can all indicate that welfare is threatened more than following other challenges which do not result in such changes, or which result in smaller changes. Impaired immune system function and some of the physiological changes can indicate a pre-pathological state (Moberg, 1985). In interpreting physiological measurements such as heart rate and adrenal activity it is important to take account of the environmental and metabolic context, including activity level. Glucocorticoids have various important functions in the body, including facilitation of learning, (Poletto et al., 2003) and are not produced in all potentially damaging situations. Some hormones, such as oxytocin, may indicate pleasurable mental states in animals (Panksepp, 1998; Carter, 2001). In general, physiological measures have proven most successful in assessing the effect of short-term or acute procedures (e.g. dehorning) on an animal's welfare. Using physiological measures to assess longer term effects, such as those due to housing, is a far more complex enterprise, which has not proven as successful. Studies of the brain activity inform us about the cognitive ability of animals and they can also tell us how an individual is likely to be perceiving, attending to, evaluating, coping with, enjoying, or being disturbed by its environment so can give direct information about welfare (Broom and Zanella, 2004). Cows have complex brains so must have a great range of possibilities for good or poor welfare. In studies of welfare, there is an especial interest on how an individual feels. As this depends upon high-level brain processing, it is necessary to investigate brain function. Abnormal behaviour and preferred social, sexual and parental situations may have brain correlates. Brain measures can sometimes explain the nature and magnitude of effects on welfare.

Behavioural measures are also of particular value in welfare assessment (Wiepkema, 1983). Studies of animal preference are very useful tools. The fact that an animal avoids strongly an object or event, gives information about its feelings that are evoked when it encounters this object or event and hence about its welfare (Rushen, 1986; 1996). The stronger the avoidance the worse the welfare whilst the object is present or the event is occurring. An individual which is completely unable to adopt a preferred lying posture despite repeated attempts will

be assessed as having poorer welfare than one which can adopt the preferred posture. Other abnormal behaviour, which includes excessively aggressive behaviour and stereotypies, such as tongue-rolling in cows, indicates that the perpetrator's welfare is poor. There is some evidence that the performance of some forms of abnormal, stereotyped behaviour can improve the welfare of the animals performing the behaviour (Mason and Latham, 2004). This does not mean that the performance of the behaviour is a sign of good welfare. A large body of research shows that the conditions that lead animals to perform such behaviours are associated with poor welfare. However, in those conditions, the animals that do not perform these behaviours appear to fare worse than those that do perform the behaviours (Mason and Latham, 2004). Very often abnormal activities derive from activities that cannot be expressed but for which the animal is motivated. A single physiological, behavioural or other measure indicating that coping is difficult, or that the individual is not coping, can be sufficient evidence that welfare is poor.

Many people have the opinion that the welfare of animals will be improved if they are allowed to perform more of the behaviour shown in a natural environment. However, although preventing natural behaviour will sometimes cause poor welfare (Lindström and Redbo, 2000), there is no reason to think that an animal will inevitably suffer simply because it does not perform all the behaviour patterns shown by its wild ancestors. Indeed, allowing animals to perform some natural behaviour, such as aggressive behaviour or infanticide, may lead to worse welfare. Furthermore, even within a population of animals in natural environments, there will be marked differences between individual animals in the types of behavioural strategies adopted, raising the question of what should be considered as “the” natural behaviour (Spinka, 2006). Finally, many studies on different species have revealed how much artificial selection has altered the behaviour of domestic animals (e.g. Price 2002; Jensen 2006). Applying the concept of natural behaviour is troublesome for cattle since the ancestor of domestic cattle, the wild ox or aurochs (*Bos primigenius*) of the near east has been extinct for several centuries (Clutton-Brock, 1999). Furthermore, genetic analysis shows that domestic cattle (*Bos taurus* and *Bos indicus*) diverged from the wild species of Bovini (e.g. bison and buffalo) many thousands of years ago (Ritz et al., 2000). This makes it difficult to determine how much domestication has influenced cattle behaviour and to what extent modern breeds of cattle have retained the behavioural repertoire of their ancestors. From research that has been done on other species (pigs and poultry) it seems most likely that modern dairy cattle have diverged little from their ancestors in respect of most aspects of anatomy, physiology and behaviour. The changes are mostly to do with modifications that allow reproduction and some other functions when there is close human presence, together with changes leading to greater milk production. A key issue here concerns what are the needs of dairy cattle and whether or not these needs are met. It is important to know what is the normal behaviour of animals of the type used on farms (Wechsler, 2007).

Although the biological abilities of animals to adapt to the environments that they encounter are of major importance in determining the individual's welfare, it is only in this way that welfare is related to what is, or is not, “natural”. Good welfare is certainly not limited to environments that are “natural in the sense that they are wild” environments and there are many ways in which what happens to animals in the wild leads to poor welfare.

Whilst the wild conditions may give some indications as to what are important resources for animals, welfare will depend on the coping ability of animals of the genetic strain kept in captivity.

Many of the variables that have been found to lead to good welfare have been established following studies demonstrating positive preferences by animals (Dawkins, 1990). Methods of assessing the strengths of positive and negative preferences have become much more sophisticated in recent years. The price, which an animal will pay for resources, or pay to avoid a situation, may be, for example, a distance travelled, a weight lifted or the amount of energy required to press a plate on numerous occasions. The demand for the resource, i.e. the amount of an action which enables the resource to be obtained, at each of several prices can be measured experimentally. This is best done in studies where the income available, in the form of time or energy, is controlled in relation to the price paid for the resource. Methodologies for evaluating the importance of resources to animals have been developed (Kirkden et al., 2003). Good welfare in general, and a positive status in each of the various coping systems, should have effects that are a part of a positive reinforcement system, just as poor welfare is associated with various negative reinforcers. Once we know what animals strongly prefer, or strongly avoid, we can use this information to identify situations that are unlikely to fulfill the needs of animals and to design better housing conditions and management methods (Fraser and Matthews, 1997). However, as pointed out by Duncan (1978; 1992) and Dawkins (2004), all data from preference studies must be interpreted taking account of the following possibilities: firstly, an individual may show a positive preference for something in the short-term which results in its poor welfare in the long-term, and secondly, a preference in a simplified experimental environment needs to be related to the individual's priorities in the more complicated real world.

In order to promote good welfare and avoid suffering, a wide range of needs must be fulfilled as the needs have a key role in the interaction between an animal and its environment. A need is a requirement, which is part of the basic biology of the animal, to obtain a resource, receive stimuli or express particular behaviours (Hughes and Duncan, 1988; Jensen and Toates, 1993; Vestergaard, 1996). Needs are requirements that are necessary to maintain the biological functioning of the animal. For example, in order to stay healthy and alive, an animal needs an adequate supply of nutrients. When needs are satisfied there is, in some cases, an increase in a pleasurable experience, in some a decrease in negative experience, and in others a beneficial biological change without involvement of any feeling. Whilst the need may be satisfied by a physiological change in the body or by carrying out a particular behaviour, the need itself is reflected in a control centre in the brain. Evidence for needs includes indications of poor welfare when an individual does not have the resource or opportunity for action, or the results of studies that show that the individual has strong positive or negative preferences.

The list of the needs of cows in Chapter 2 includes those which, if not fulfilled, result in death in a few minutes or days or weeks and those that do not result in death. However, the impact of an unfulfilled need on welfare depends on motivational mechanisms as on imminence of harm or death. For example, avoidance of severe but non-lethal pain has high priority.

When the welfare of cows or other animals is assessed, sets of measures often have to be integrated, for example, physiological measures, behavioural and pathological measures. Whilst a single measure can indicate poor welfare, because of the variety of coping mechanisms used (Koolhaas et al., 1999) and the effects on individuals, a range of measures will usually provide better information about welfare.

Each assessment of welfare will pertain to a single individual and to a particular time range. Some problems for dairy cows, such as metabolic pressures associated with high milk production and various factors leading to lameness, result in poor welfare for a very long period, perhaps many months. In the overall assessment of the impact of a condition or

treatment of an individual, a very brief period of a certain degree of good or poor welfare is not the same as a prolonged period. However, a simple multiplicative function of maximum degree and duration is often not sufficient. If there is a net severity of poor welfare and this is plotted against its duration, the best overall assessment of welfare is the area under the curve thus produced, as shown in Fig. 1 (Broom, 2001c).

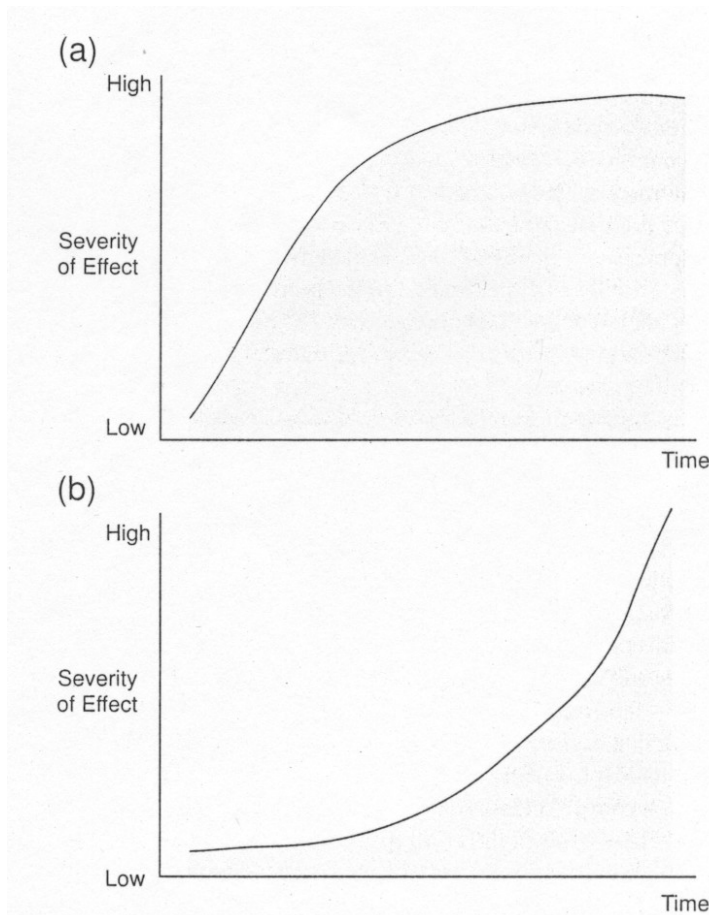


Figure 1 The net severity of poor welfare is plotted against the duration of the poor welfare in two examples here. The total magnitude of poor welfare is greater in (a) than in (b). Modified after Broom (2001c).

2. The needs of dairy cows.

As explained in Chapter 6, all animals have needs that drive their activity programs with the function of maintaining internal homeostasis and regulating interaction with the environment. Maintenance of homeostasis involves assessment of state in relation to tolerable ranges and positive and negative feedback control.

The overall need of a cow is to maintain bodily and mental integrity while growing and during adult life. In order to do this, cows have a series of needs that are relevant to the housing and management conditions imposed upon them by humans. A general need of a cow is to have sufficient control of her environment and some ability to choose what to do and when. The needs of cows are described in detail by Webster (1993), Broom (1998; 2001a; 2004). When needs are not fulfilled there are negative, often measureable, consequences for the animal. In listing needs and in later consideration of how to provide for them, it is assumed that extreme

human actions, such as deliberately creating a large wound or infecting an animal with a dangerous pathogen, will not occur.

The list of needs is not in order of importance. A previous report on the effects of bovine somatotrophin on the welfare of dairy cows (SCAHAW 1999) deals with some of the important issues covered in this report. Some needs require satisfying only at intervals of some hours or only when young or when adult. Some of the needs of cows will vary slightly according to genotype and phenotype, for example, an animal of a high milk-producing genetic line and an old cow that has a large stomach because of long-term high-level feeding will need more food per day than the average cow. Most needs, however, are little affected by domestication. The causes of some problems of cows are multifactorial and related to more than one need. Many of the needs of cows involve not only the avoidance of poor welfare but also the increase of likelihood of good welfare.

2.1. To breathe air of sufficient quality

Cows need air that has sufficient oxygen and a low level of noxious gases and other substances in it. Cows may be adversely affected, in that they have difficulty in breathing or are breathing in harmful substances, by some of the gaseous products of the breakdown of animal faeces or dust. They show preferences that help them to avoid any harm that these may cause. When the metabolic rate of dairy cows is high, for example when producing much milk, the dairy cow's limited capacity to take in enough air may cause problems for some individuals.

2.2. To have appropriate sensory input

Cows need to avoid certain sensory experiences and to receive certain inputs. Some examples are given here. They use their eyes to achieve many objectives in life and to see well enough to carry out the actions that help them to achieve important objectives. Ambient light that is not bright enough, or an inappropriate wavelength or that is flashing in certain ways can fail to meet a need to evaluate the environment or to avoid potential harm and can cause poor welfare in cows. They have great olfactory ability, good hearing and much tactile awareness. Very bright lights, very loud noises and certain other stimuli, including fear pheromones, can also cause poor welfare. A temporal pattern of lighting can be inadequate because there is too short a light period or too short a dark period. Cows also need to avoid too much sensory input and too little sensory input.

2.1. To rest and sleep

Cows need to rest and sleep in order to remain healthy and to recuperate from stress and illness and are more likely to do so at times when any possible danger of attack is low. Adult cattle usually sleep for about 4 hours a day and usually while lying down. Some slow wave sleep can occur when cows are standing but in order to have rapid eye movement sleep cattle must be able to lie down. Usually sleep (especially rapid eye movement sleep) occurs when the neck muscles are relaxed and the head is resting on the ground or the animal's body. Housing conditions that prevent cattle from lying down in this way may interfere with sleep. Cattle rest for about 12 hours a day and adequate rest is important to prevent fatigue and to maintain normal physiological functioning (e.g. normal secretion of growth hormone). Cattle usually rest in a posture in which the legs are partially extended. Sleep disruption may occur if comfortable lying positions cannot be adopted, as shown in calves, or if there is disturbance to

lying animals because they are trodden on or otherwise disturbed by other cows. If cows are diseased, or for other reasons in poor physical condition, their need for rest and sleep is increased and the amount of rest or sleep that they are able to achieve may be inadequate. Rest and sleep may also be insufficient because of disturbance by other cows which have to walk on or close to the sleeping cow, or by noise.

2.2. To exercise

Exercise is needed for normal bone and muscle development and to keep the cattle in good condition. Research on other species shows that exercise helps animals respond to stress. In cattle, exercise involves locomotion as well as other movements and the animals may need to carry out the locomotor and other movements in a coordinated way, rather than just to exercise the muscles and to benefit these and other tissues. Exercise can be difficult with some types of floors (e.g. floors that are too slippery or too hard) or if there is too small a space allowance.

2.3. To feed and drink

2.3.1. Drinking

Lactating cows have a very high demand for water. If the temperature is high, cows need to drink great amounts of water. Sick cows may also need more water. If water is not available, lactating, over-heated and sick cows will become dehydrated earlier than other cows. Moreover, free access to water is of importance for cows fed diets containing excess of potentially toxic substances that need to be excreted by the kidneys or when diets are fed to manipulate cation-anion balance. The quality of water required is to satisfy cows' needs to drink water without toxins or pathogens present to the extent that it is difficult for the cow to cope with them.

2.3.2. Nutrients

Food provides for the needs of nutrient intake, oral satisfaction, normal digestive function and carrying out foraging behaviour. A variety of macro- and micro-nutrients are needed by cows for maintenance and growth. If any are lacking in the feed, there will be adverse consequences if essential nutrients cannot be provided by other means. The diet of commercially reared cows seems to be generally good but the possibility that certain supplements, e.g. vitamins and trace elements at higher than historically recommended levels, may lead to better welfare indicates that the normal diet may now lack some nutrients, especially for cows from high performance genetic lines. Some diets are adequate in nutrient content but lead to digestion anomalies and pain or other poor welfare, whilst other diets have such effects because they have the wrong balance. In ruminants, such as cows, a diet composition leading to normal rumination is needed.

2.3.3. Foraging behaviour

Even when cows are fully supplied with the daily nutrient requirement for good health and performance, they may have other needs relating to the quantity or form of the diet. Foraging behaviour accounts for a large proportion (up to 80%) of the daily activity of cows kept in a semi-natural situation and they show a wide range of behaviours to investigate and manipulate

the environment. In addition to the need to feed, cows therefore need permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities. Cows are highly motivated to work for access to foraging material like straw. In the absence of an appropriate foraging environment, welfare can be poor.

2.4. To explore

Cows have a natural tendency to explore their environment and they show a fair amount of curiosity. When they are kept in the same environment they have very low levels of exploration. However, when they are moved to a new environment they show an initially high level of exploration. Exploration is shown by all cows allowing the individual to be prepared for effective food acquisition, response to danger from predators, attack by conspecifics and response to other adverse conditions or needs. Exploration will be difficult if there is insufficient space available. All cows are motivated to explore.

2.5. To have appropriate social interactions

Dairy cows need to have social contact with other cows or heifers on a regular basis. Cows separated from the herd, apart from when calving, show strong negative reactions, for example, they vocalise. Mixing of unfamiliar cows results in aggressive interactions so cows need to be able to retreat from aggressive animals. Moreover, a restriction in access to important resources, such as the number of feeding places, results in increased levels of aggression. Normally effective social behaviour may be rendered ineffectual by insufficient space availability. Cows recognise other individuals but there are limitations to the number that can be recognised. In very large herds more occasions arise when individuals are treated as strangers resulting in aggression.

2.6. To avoid fear and other negative experiences

As a prey species, cattle have evolved a number of mechanisms associated with predator detection and avoidance. As a consequence, the biological functioning of cows is strongly adapted to promote security and to maximise the chance of recognition of danger and escape from it. Cows respond to sudden events and approaches by humans or other animals perceived to be potentially dangerous with substantial sympathetic nervous system and hypothalamic-pituitary-adrenocortical (HPA) changes. These physiological changes are followed by rapid and often vigorous behavioural responses. Fear is a major factor in the life of cows and has a great effect on their welfare. In any circumstance in which the cow can predict that a negative experience is likely, welfare will be poor.

2.7. To perform maintenance and eliminatory behaviour

Cows need to groom in that they have to keep the body surface free of harmful substances or organisms. Hence they groom and scratch themselves. They select lying places that are dry and comfortable when possible and this behaviour tends to keep the body clean. Defecation and urination are carried out as the animal stands and as she moves around during feeding and other behaviour. Particular postures are adopted to carry out these actions.

2.8. To have an appropriate thermal environment

Cows need to maintain their body temperature within a tolerable range. If the ambient temperature is too high or too low, or the humidity is too high, welfare can be poor. Shade seeking is the main behaviour cattle use to avoid overheating. Over-heated, or potentially over-heated, cows adopt positions that maximise the surface area from which heat can be lost and will attempt to drink.

2.9. Reproduction and maternal functions

Cows which are sexually mature are motivated to show sexual behaviours which in dairy herds is often addressed to other cows. Females in a late stage of pregnancy also show clear signs of having specific needs at this time. Dairy cows try to separate at calving and it might be regarded as a need, because when they are calving in a group pen there may be disturbance from the other cows in the group. If the calf has been allowed to stay with the cow for some days after calving, the cow shows a strong negative reaction to the separation.

2.10. To avoid and minimise disease

At some times, all cows need to minimise contact with pathogens that might cause disease. They do this by various behaviours, anatomical adaptations and physiological responses. They also need to minimise the adverse impacts of pathogens, again using a range of responses. Some degree of exposure to pathogens is advantageous during the development of defence mechanisms. Since physiological stress responses, including those resulting from metabolic disorders, may give rise to immunosuppression cows need to minimise stressful experiences in order to have an effective immune system. Cows which are sick need an environment that may be different as regards temperature, food, good lying surfaces and possibilities for rest and avoidance of disturbance from that needed by healthy cows.

2.11. To avoid harmful chemical agents

Cows need to avoid ingesting toxic substances, even if they cannot recognise them all, and to react appropriately if harmful chemical agents are detected within their bodies or their environment. These substances can be in food, water, air, bedding, etc.

2.12. To avoid pain and injury

Cows need to avoid any environmental impact or pathological conditions that cause pain and injury. In practice, they often cannot do this. In cattle husbandry, dehorning, tail-docking, excessive aggression, udder disorders, leg and foot disorders are some examples of sources of pain.

3. Dairy cow farming systems

3.1. Introduction

From an analytical viewpoint the farming system can be seen as the primary condition determining the living circumstances and thereby the welfare, including the health, of livestock. Although it can be argued that the farmer, being the decision maker and representing the operational principal of the farming system is as important. Van der Ploeg

(1999) elucidates in an extended study that socio-technical variations or farming styles may have a substantial effect on the final outcome of farming. Also Norton et al. (2006) emphasise that both human and exogenous institutional factors are major determinants of a farming system at a given point of time. This chapter focuses on the technical conditions of farming systems that count directly for the animals. The human factor will be considered only by the role of the stockperson and caretaker with its direct effects on welfare and disease in the animals (Seabrook, 1972; Kilgour, 1983).

Worldwide there is a tremendous variation in ecological and socio-technical conditions of farming. Farming systems in which livestock are involved are also multiple (Seré and Steinfeld 1996; FAO, 2007), reflecting the nature of the agro-ecological complex that they represent. This report will only deal with settled agriculture, which represents a variety of agricultural systems, the dominant types being developed from tremendous amounts of human experimentation. The latter is evidently true for dairy farming in Europe during the last century (Oenema, 2007). In line with the more elaborate classification of Seré and Steinfeld (1996), Norton et al. (2006) distinguish three main types of settled production involving livestock: 1) Mixed farming, defined as an integration of crops and livestock production such that multiple commodities are grown at the same time and the same land; 2) Intensive livestock systems, including ruminants that produce milk, meat, and dung, and non-ruminants that are particularly important for their meat and eggs; 3) Extensive livestock systems, which include a variety of grazing systems. This scheme fits also with the actual division used by the World Bank between grazing systems, mixed crop-livestock systems and industrial systems (Livestock and Environment Toolbox, 2008). These three categories of farming system will be discussed in the next section, restricted to European dairy farming but including organic farming as a specific variant.

A crucial point is that the housing and management can affect cow welfare in both an additive and an interactive way. An example exists in the way of feeding cows. More space at the trough will lower aggression, as does ad-lib feeding versus restricted feeding. In case of ad-lib feeding, less space at the trough suffices but in case of restricted feeding more space is necessary (Metz, 1983; De Vries et al., 2004).

3.1.1. The European dairy cow population

Table 1 provides statistics on the living conditions of the European dairy cow population, with its variations between countries.

Geo/time	Number of dairy cows (x1000)			
	2001	2003	2004	2006
EU (25 countries)	na	24266.798	na	na
EU (15 countries)	20271.497	19480.699	na	na
Euro area	16847.571	na	na	na
Belgium	624.457	584.587	568.571	na
Bulgaria	na	366.388	na	352.501
Czech Republic	na	469.404	na	441.709
Denmark	623.359	596.033	563.453	557.869
Germany	4548.587	4371.958	na	4235.900
Estonia	na	119.820	na	na
Ireland	1147.950	1135.676	na	na
Greece	172.315	149.15	na	na
Spain	1158.938	1118.418	na	na
France	4191.324	4019.300	na	na

Italy	2238.900	2079.909	na	na
Cyprus	na	26.612	na	na
Latvia	na	184.268	na	185.175
Lithuania	na	448.100	na	416.500
Luxembourg	43.992	41.238	na	39.894
Hungaria	na	309.161	na	285.320
Malta	na	7.607	na	7.675
Netherlands	1605.932	1535.211	na	1494.570
Austria	597.981	583.810	na	na
Poland	na	2875.948	na	2751.670
Portugal	337.693	328.488	na	324.008
Romania	na	na	na	1626.000
Slovenia	na	130.712	na	na
Slovakia	na	214.467	na	na
Finland	351.817	327.983	na	312.949
Sweden	452.329	402.520	na	393.263
United Kingdom	2202.923	2206.373	na	na

na= Not available

Table 1 European dairy cow population.

3.2. Mixed, intensive, extensive and organic farming system.

The farming systems that are discussed below have their own agro-ecological and socio-technical setting. However, within each type the way of farming can still show substantial variation. It means that in practice the boundaries between types may appear very gradual.

3.2.1. Mixed (crop) livestock farming

Mixed farming is an integration of crops and livestock production such that multiple commodities are grown at the same time on the same land (Norton et al., 2006). In their classification Seré and Steinfeld (1996) define livestock systems as mixed farming, if more than 10 percent of the dry matter fed to animals comes from crop by-products and stubble, or more than 10 percent of the total value of production comes from non-livestock farming activities. Mixed farming is common in traditional agriculture because it produces relatively high returns while helping to manage risk, makes efficient use of labour and land, and helps maintaining soil fertility (Norton et al., 2006). Seré and Steinfeld (1996) add to this the sustainability advantages to the farmer of nutrient recycling at mixed livestock farms, adding economic value by grazing on crop residue, and providing an incentive to plant nitrogen-fixing crops or forages which serve to improve soil fertility and reduce soil erosion.

In spite of their potential environmental virtues (Van der Meer, 2008) and all the stages of modernization occurred in the past century (Oenema, 2007), the share of mixed livestock farming in European dairy production is currently low due to the change towards specialization and intensification throughout European agricultural production.

Dairy production on mixed farms involves housing structures for cattle and process technologies more or less like intensive production has (see below). However, the production scale may be smaller and specific investments lower. The lower density of animals could create an advantage with respect to the spread of infectious diseases.

The pros and cons of mixed farming change if mixed farming is effectuated in multifunctional mega-enterprises as discussed by De Wilt and Dobbelaar (2005). Extra ecological and environmental advantages can be obtained in that way. Nevertheless, dairy farming itself as part of such enterprises is likely to assimilate more or less similar technical solutions as on specialised dairy farms, either intensive or extensive.

According to Van der Ploeg et al. (2002) mixed livestock farming systems have a propensity to be the starting point of broadening or deepening of farming activities in EU rural development.

3.2.2. Intensive production systems

In their classification Seré and Steinfeld (1996) do not provide quantitative boundaries for intensive livestock systems, but the main principle of intensive systems is a relatively high and certain return per unit of effort (Norton et al., 2006). On dairy farms defined by Seré and Steinfeld (1996) as solely livestock systems, more than 90 percent of the dry matter fed to the animals should come from rangelands, pastures, annual forages and purchased feeds, and less than 10 percent of the total value of production could come from non-livestock farming activities.

The intensification in dairy production has been made possible through some major technical achievements:

- breeding and genetic improvement to increase the milk production per cow and the contents of valuable constituents in the milk;
- an intensive use of (chemical) fertilizers to boost the production of farm feeds, specifically grass and maize silage;
- a large-scale import of complementary feed ingredients from other continents for a comparatively low price;
- an almost full scale mechanization, advanced building designs and automated control to reach large scale, labour-saving operations that can produce very efficiently against low labour costs.

Alongside the role of these technical achievements in the process of intensification and specialization, Oenema (2007) points to the impact of exogenous institutional determinants such as the EU Common Agricultural Policy (CAP) and the increased opportunities in export markets, that surely enhanced the process of specialization and intensification. Seré and Steinfeld (1996) refers to the role of consumers, their increased *per capita* income and changes in their consumption patterns, that sets upward trends in the market and creates economic room for farmers to invest and produce.

Most of the dairy production in Europe is from this specialised, intensive farming, although the proportion may differ between regions. The majority of those farms provide loose housing to the cows in cubicle barns while average herd size is increasing steadily over the years in combination with the reduction of the number of farms. Cows are milked in walk-through parlours with a capacity on larger farms up to 32 milking stands and milking 120-130 cows per hour. Technical prescriptions for housing and management of dairy cows are made available in various countries by extensions services (e.g. in The Netherlands 'Handboek Melkveehouderij' 2006; in Denmark 'Housing and Design for Cattle - Danish

Recommendations' 2001). The information originates both from research and field experiences. Animal welfare considerations are a part of it.

Intensive dairy farming systems are land-based, but the area of land is mostly not sufficient to feed the cows. Complementary feed is bought, usually as dried product (e.g. ingredients for concentrates, hay, straw) and sometimes wet (e.g. by-products from the food industry, sugar beet pulp) if the production source is geographically nearby.

The available land is used for grassland, pasture, growing maize or sometimes other fodders. The intense use of the available pastures and grasslands is an important aim within intensive dairy farming but it has led to heavily nutrient surplus pastures in North-Western Europe countries (De Haan, 1997). Intensive dairy farming involves carefully managed grasslands and pastures. Generally it does not allow cows being on pasture at all times. Different regimes of restrictive pasturing are applied in practice, dependent on factors like climate and growing conditions of grass, physical condition of the grass mat, stocking density, nutritional needs of the cows, incidence of too hot weather, and distance to the cow barn and milking parlour. Due to growing herd size or geographic location of the fields, dairy farmers may decide to keep the cows inside throughout the year in spite of a long tradition of pasturing cows.

In Europe and North America dairy cows are often housed indoors or kept on outdoor dry-lots with little or no access to pasture. This so called "zero-grazing management", where cows never get out on pasture, is also increasing in some developing countries (Gitau et al., 1996). In a paper on the permanent indoor feeding of cows in Western European countries a presentation of the occurrence of grazing in eight European countries (Austria, Denmark, England, France, Germany, Italy, The Netherlands, Sweden) and the public opinion on this are presented (Beerda et al., manuscript). The percentage of farms with zero-grazing varied between 4-55% in Austria according to farming system (Kirner et al., 2001); unpublished surveys in Germany indicate that the percentage varies largely according to geographic regions e.g. 2% in one region (Niederrhein) and 99% in another (part of Bavaria); in the Netherlands 15% of farms use zero-grazing but none in Sweden. However, there was no available information from the other countries. Regulations to keep dairy cows on pasture were only reported from Sweden, where it has existed since 1988 (Ekesbo, 2006). Regulations to let dairy cows out on pasture during the summer time were introduced in Finland from 2006 (Ekesbo, 2006).

Intensive farming represents the majority of dairy farming in Europe. But the development of intensification of dairy farming is under pressure these days due to its negative impact on the environment. Through mineral leaching to ground water and run off to surface waters, through aerial emissions, precipitation of minerals and its role in environmental acidification, and its contribution to greenhouse gas emissions, dairy production causes ecological burdens in several areas in Europe. Oenema (2007) concludes that common livestock production in Europe moves and has to move from intensive, specialised farming to 'restricted' farming. Emissions control is needed and this requires a shift in feeding and manure management on farm and the adaptation of housing systems (Webb et al., 2005).

Since feed will have to be bought, the intensive farms regularly face transport of goods and products to and from the farm. Those farms face the need for specific hygienic measures, to prevent the intake of infectious materials.

Intensive dairy farms may also farm out their young stock in order to keep as many cows as possible for milking within the farm's capacity (i.e. milk quota; environmental permits; profit making). The exchange of animals with an outer central rearing centre for young stock for one

or two season can create extra infectious risks and should, as a principle, be evaluated on welfare effects.

3.2.3. Extensive production

In contrast to intensive systems, in extensive production systems the return per unit of input is relatively low (cf. Norton et al., 2006). In dairy farming production is linked to the genetic disposition of the cows deployed for milk production and the amount and quality of feed that is fed.

In the classifications, extensive dairy farming commonly includes livestock grazing systems (De Haan, 1997; Seré and Steinfeld, 1996). In grazing systems, the range or pasture is the primary feed resource. The quality of feed and breed of cows vary widely between grazing systems. Grazing systems in the Oceania region involve top-dressing with fertilizers, introduction of legumes and appropriate fencing to achieve highly productive legume-grass pastures. Even rainfall distributions allow for relatively high productivity levels using a minimum of hay and silage. According to Seré and Steinfeld (1996) the developments in New Zealand show the potential of highly competitive dairy production based on enhancing the productivity of the basic resource, a productive rangeland.

In the EU, dairy production with pasture or rangeland as the primary feed resource is mostly restricted to specific locations and linked with values like landscape conservation or rangeland management. All year grazing does occur in the EU, for example, in the Azores Islands (part of Portugal) more than 100,000 dairy cows are all year in pasture with some concentrate supplementation (INE, 2008). On the other hand, there are locations where pasture does not provide sufficient feed resource for dairy cows. Zervas (1998) discusses the optimization of grazing regimes in Greek mountain areas where small numbers of dairy cows are involved. In this system dairy cows and fattening calves are usually kept indoors and fed intensively. An example of a grazing system in an ecologically sensitive area is the Veenweide area in The Netherlands (Meulekamp et al, 2007). The area developed in past centuries into a successful dairy production region, famous for on-farm cheese making (“Gouda”). In the short run the region is bound to remain in dairy production as for ecological reasons. The (peat) soil with its high groundwater level and fine-maze canal structure hardly permits other land use than grassland. The lack of possibilities for intensification, however, maintains the cost of milk production substantially above the average level in the country. So in this case the grazing system is not economically sustainable unless the goals of farming are broadened (cf. Van de Ploeg et al., 2002) and for ecological/landscape reasons additional income sources are available.

Grazing systems are typically based on maximal grazing of the animals during the year, as long as climate and growing conditions permit. For the remainder period, conserved feed needs to be available.

3.2.4. Organic farming

Organic farming is a value-based method of agricultural production. The values are held in four principles that were recently articulated by the International Federation of Organic Movements (IFOAM) through a world-wide participatory stakeholder process, in order to bridge the values from the pioneers in organic agriculture to the present time of globalization and extended growth of the organic sector (Luttikholt, 2007). The four principles transferred in a statement are:

- the Principle of Health saying that organic agriculture should sustain and enhance the health of soil, plant, animal, human and planet as one and indivisible;
- the Principle of Ecology saying that organic agriculture should be based on living ecological systems and cycles, work with them, emulate them and help sustain them;
- the Principle of Fairness saying that organic agriculture should build on relationships that ensure fairness with regard to the common environment and life opportunities;
- the Principle of Care saying that organic agriculture should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment.

The principles are the basis for development of prescriptions and standards that hold for any farming operation or product that can legally be labeled “organic” (some countries use the term “biologic”). EU adopted specific regulations regarding organic production of agricultural products and foodstuffs to include in livestock production (Council Regulation (EC) No 1804/1999).

Dairy farming under the rules of organic farming will always be land-based due to the requirement that manure production should not exceed of 170 kg of nitrogen per year/ hectare of agricultural area. It implies a maximum stocking density of two dairy cows per hectare. Other requirements for care are: indoors cows should have available minimal 6 m² net area, cows should be allowed to go outside every day with a minimum exercise area of 4.5 m² per head and outside the winter season pasturing should be allowed. Medical treatment is restricted to specific rules and the feed stuff from external sources should be produced organically. Tethering of cows and dehorning are only permitted under certain conditions.

With the existing standards, organic dairy farming can be applied in a structure of “mixed” farming as well as “specialised” farming. However, various directions of intensification as seen in regular animal production are unable because of the four principle standards. But a trend towards specialization and increase of scale (within given standards) for a better economy is emerging. De Wit and Verhoog (2007) pointed to the risk of conventionalization of organic agriculture with such trend, especially on the Principles of Ecology and Health. The use of off-farm inputs is an important factor in conventionalization itself and has negative effects of the core organic values. The authors foresee the need of regulative action to secure that organic farming remains distinguishable to secure its value principles.

Within Europe organic dairy farming accounts only for a few percent of dairy production, with an upward trend in at least some countries (Oudshoorn et al., 2008).

3.3. Indoor and outdoor housing for dairy cows in different farming systems.

Due to unfavourable climatic conditions, lack of grass or other forage in the field or poor conditions of the sward, European dairy cattle are kept indoors for the main part of the year, roughly 5-7 months, during the winter season. The length of the period differs between regions in Europe, with the variations in climatic condition as the primary reason. In addition, dairy cows are likely to be indoors during a part of the day in the summer season, or even the whole year round in zero-grazing systems. This is because of milking, water supply, supplementary feeding or even protection against extreme weather such as hot sunshine or heavy rainfall. Only in full grazing systems (see section 8.2) cows are likely to be maximally

outdoors. In contrast, an increasing number of farms in the category of intensive dairy farming tend to keep their cows permanently indoors, during the winter as well as the summer season.

The presumption is that for the welfare of the cow the *full* range of indoor and outdoor conditions count. The effect on welfare of indoor and outdoor conditions can be cumulative as well as interactive. It is different regarding the seasonal effect on health. Improved claw health that results from the pasture period prevents the cow from early lameness and sensitivity to a hard floor surface in the next housing period (Bierma et al., 2006). It is a typical example of an interactive effect.

The cumulative and interactive effects on animal welfare of the indoor and outdoor environment have logical implications for the technical standards of indoor and outdoor housing. As some of the needs of dairy cattle are provided for more readily when they are at pasture, the conditions provided in indoor housing have to be carefully designed in order not to miss the key benefits from outdoor conditions. This is a crucial element in the evaluation and standardization of housing systems for dairy cattle (cf. Maton et al., 1985; CIGR, 1994; Housing Design, 2002; Waiblinger and Wechsler, 2008).

In this chapter main housing types and outdoor accommodations for dairy cows will be described according to their relevance in the current situation in Europe and for the future development.

3.3.1. Stanchion barns (Barns with “tie stalls” with or without possibilities to exercise).

The stanchion barn was in Europe (and worldwide) by far the most common type of dairy cow housing until milking parlours came and loose housing was introduced (period 1960-85). These days the share of stanchion barns in dairy farming is low (e.g. NL 10 percent) but there are exceptions, for instance in most of European mountainous regions and in Sweden (60 percent).

The typical feature of the stanchion barn is that the cows are tied to a stall. In a cowshed there are one or more rows of stalls available, with all equipments and installations around for an efficient and rational management. Design and construction details of a stanchion barn and its equipment are extensively described by Maton et al. (1985). Dimensions of the stalls are related to the anatomical measures of the cow and the ease of labour for the stockman. For stalls, Maton et al. (1985) indicate a minimum width of around 1.10 m and a length of 1.75 to 2.5 m dependent on the manure displacement system behind the cows. Given the increased size of dairy cows (see section 4.2.4.) larger sizes are currently required (cf. Waiblinger and Wechsler, 2008). Guidelines for dairy farmers are available in several countries with recommended measures, like the yearly updated *Handboek Melkveehouderij* in NL, *Housing Design for Cattle – Danish Recommendations* in DK, etc. Some countries also turned to legislative prescriptions (Waiblinger and Wechsler, 2008). The requirements can be empirical based or being derived from theory and available animal measures (CIGR, 1994).

In stanchion barns the tied cows have little freedom of movement. The feed is provided to them in a manger in front of the stall, with the bottom about 5 to 15 cm lifted above the stall floor. For each two cows a drinker is available in the front. Behind the cows is a dung plate or a swallow channel for collecting the faeces and urine. Next to that is the service passage used by the stockman for milking the cows if it is still done on the stand, and for cow observations and hygiene control.

While the housing principle is still the same, the stanchion barn has undergone many adjustments and modernizations over the past decades. In the original stanchion barns cows were provided with a straw bed, the stall length was 1.75 to 2.00 m (medium stall) or 2.00 to 2.50 m (long stall). In the dung channel the solids and liquids were separated. To avoid the use of straw, a change was made later towards a rubber matt on the floor and a metal grid covering the manure channel. For hygienic reasons the stall floor could be shortened to 1.45 m so that for sure the faeces and urine were deposited on the grid and turned into a mixture of slurry in the underlying channel. The slurry could easily be pumped and transported for spreading into the field. Cows were standing with their hind legs on the grid which for that reason was covered with rubber.

For hygiene control also electrified cow trainers were introduced. A metal wire was suspended above the cow wither so that she will step back during urinating or defecation, if it is, as usual, executed with a curved back. The use of cow trainers has been intensively disputed because of their impact on animal welfare (see section 6.11.1).

Systems of tying the cows to their stalls with a vertical chain and nylon strap or a chain with collar were common when the cows were still milked in their stall (Maton et al., 1985). But later techniques were applied for automatic de-attachment (e.g. the American yoke), so that the cows could move themselves to a milking parlour or, if required, to a paddock outside. Current stanchion barns mostly make use of a detachment technique. In combination with the use of a milking parlour, it allows the farmer with a stanchion barn to manage a larger herd.

The tethering in a stanchion barn restricts the freedom of movement of cows. Cows are almost completely deprived of exercise. Dependent on the tie system they are also more or less prevented from grooming their body and they lack freedom of motion in standing up and lying down. Cows in a stanchion barn do not have to compete for food and are largely prevented from aggression from herd mates in a crowded environment, but subdominant individuals are unable to move away from dominant individuals. In stanchion barns, cow are easy to monitor and to provide individual care if it is needed.

3.3.2. Barns with open cubicles (“free stalls” or “cubicle houses”).

Although stanchion barns exist in substantial numbers in some countries, loose housing of cows in cubicle houses is presently the most common housing in intensive dairy farming. The cubicle housing, developed as part of a process of rationalisation and intensification of agricultural production, focuses both on saving labour and on the increase of production.

The essence of a cubicle house is that the cows move themselves to the necessary commodities and facilities in the house, so that a substantial step in mechanisation and process automation could be made. It should be pointed out that this applies to all loose housing systems. Indeed in the case of cubicles, an increase in herd size with a minimum of labour input was the result.

The cubicle house consists of a number of specific facilities (e.g. Maton et al. 1985; CIGR 1994), whose technical design and operation has major impact on cow welfare.

a) Cubicles:

The cubicles or stalls for lying and resting are arranged in one or more rows within the available barn space. Each cubicle is a rectangle floor area made of concrete covered with a rubber mat or mattress, or soil covered with straw, wood chips or another bedding material. Various alternatives of cubicle flooring exist and/or are still under development (Zähner et al.,

2007), but in all cases the aim is to provide the cow with a stable and somewhat soft lying surface for comfortable resting (Irps, 1983). Mats and mattresses should be in any way technically durable and covered with some litter to absorb moisture (urine, sweat). Cubicles are around 1.15 to 1.20 m wide and separated from each other by metal, wooden or textile framework. The type of partition has undergone many changes in the course of time, with the aim to allow cows' maximum freedom of motion within the available space (Danish Recommendations, 2001). The cubicle length is considered to be around 2.30 m (Maton et al., 1985), but the positioning of the head rail and another lower bar (at about 0.50 m above the floor) in the front of the cubicle is more important for the actual space of the cow. They can both keep the cow in the right position when standing or lying in the cubicle. The dimensions of cubicles are not always adjusted to the body size or weight of the cows (CIGR, 1994; Danish Recommendations, 2001; Waiblinger and Wechsler, 2008). Formulae and tables are developed, to deal with variation in body size within a herd. Pelzer et al. (2007) point to the requirements of attractiveness and hygiene of cubicles. Commonly there are as many cubicles as cows and as many cows as cubicles in the barn, but, in practice, higher rates of occupation are applied, (Wierenga, 1983).

b) Feeding facilities.

The feeding facility in cubicle houses has various components. There is a feeding fence in the barn where cows can reach the feed by putting their head through a gate. Feed is presented in a manger or through an elevated floor of a feed passage in front of the feeding fence. The feeding fence is usually 65 cm per cow, and mostly self-closing gate systems are used so that cows can be restrained if necessary for the management (Konggaard, 1983; Zappavigna, 1983). The feeding fence is typically the location for supplying cows their roughage or roughage and concentrates in a mixture (so-called mix-ration feeding). The feed supply at the fence is mainly mechanised and at modern farms often even completely automated. Given the high yield of the cows, the feed is provided nearly or even entirely *ad libitum*.

Farmers may also supply the roughage by a system of self-feeding outdoors. The cows eat the feed (commonly silage) directly from the feed storage outside the barn, through a movable fence. As the feed is always freely accessible, the total feeding space for the cows is reduced by one third to avoid decrease in food quality.

Given their nutritional needs, high yielding cows will have an additional supply of concentrates, either in separate electronic concentrate dispensers, in the milking parlour or at both places, or at the feeding place when there is a locking barrier. The concentrate dispensers are one-cow stalls located in between the cubicles for resting. Concentrate dispensers are a common cause of increased aggression in the herd, given the fact that attractive feed is provided at one location with limited access space (Metz, 1983).

c) Milking facilities.

The milking of cows in a cubicle house is usually arranged in a milking parlour. A milking parlour is a specific arrangement consisting of individual milking stands to milk a number of cows at the same time. While originally it could be a number as low as four or six at once, Maton et al. (1985) suggested milking parlours with a capacity of 28 cows at once, as most-suited for a herd size in the range of 140 to 200 cows. The stands can be arranged in different patterns, for example as double row herringbone parlour or a carousel. Also other designs are available in the market (Maton et al., 1985; Danish Recommendations, 2001), and the newest model is the robotic milking system in which a robot controls the milking cluster attachment and removal.

With the standard milking parlour, cows to be milked are collected in a holding area, enter batch-wise the parlour and leave after milking leave through a return alley. The procedure occurs under control of the herdsman two or three times per day. In the case of automatic milking systems using milking robots, cows are expected to visit the milking unit voluntarily within a certain time interval after the previous milking. Otherwise the herdsman should fetch the cow or exert control over the cow traffic in another way (Ketelaar et al., 1999). By proper management, stress responses of cows in advance of and during milking should be avoided (Seabrook, 1972; Svennersten et al., 2000)

d) The floor.

The floor in a cubicle house is linked to three main functionalities in the cow house. Firstly, it is the area where the cow can stand, walk, and idle. Secondly, it is the system for collecting active or passive discharge of the cow manure. Thirdly, it should allow cows space for specific behaviours like grooming, defaecation and urination, and social spacing.

3.3.3. Loose housing in bedded pens, including straw yards.

Loose housing with a lying bed is practiced only by a small number of farms in Europe. In the original concept described by Maton et al. (1985), a littered area is situated 0.75 to 1.00 m under the level of the feeding passage. In this area a manure pack is allowed to develop and is removed one or two times per year. The feeding area can be a part of the resting area where the cows take the forage from a trough or crib through a fence. Also a paved feeding area may be available adjacent to the resting area. One modern version is a slatted concrete floor with a feeding gate like in cubicle houses next to the resting area with lying bed. Farm may also have a confined site outside the house with a concrete floor as an exercise area. But those areas require a lot of cleaning. Maton et al. (1985) indicate a space allowance for cows in bedded loose housing of about 10 m² per cow or 5 to 6 m² if an outside lot is available. The main restriction to the application of loose housing with straw bed is the large amount of straw that is needed: about 10 kg per cow for a full bed and in deep litter, or 5-6 kg per cow if a separated feeding and exercise area with a concrete floor are applied. It makes the system for several reasons unattractive in specialised dairy farming. On minor scale the testing of alternative bedding materials is currently going on (Endres and Barberg, 2007).

3.3.4. Loose housing in combination with corrals / drylots.

This type of housing system is practised if farmers want to let their cows outside but no pasture is available. Earthen corrals can actually be applied in combination with any type of housing system. The condition of earthen corrals may deteriorate fast under wet climate conditions. In the case of large herds a major manure problem could arise, also with non-permitted nutrient leaching to the ground water (Oenema, 2007). Therefore earthen corrals are primarily feasible for temporary use; for example for the exercise of cows during a part of the day or in a dry season as a feedlot for a small group of animals.

3.3.5. Pasture.

Pasturing of dairy cows during the summer season is very common in most of the EU countries, also in the circumstances of intensive farming. But several factors will limit the time that the cows are outside and can graze. Firstly, cows may need supplementary feeding indoors, to balance their N-rich grass diet and to provide them with extra energy. Secondly,

the growing herd size at a farm may exceed the required area of grassland available for grazing of all cows, and supplementary feeding indoors is necessary anyway. Thirdly, mineral legislation may prohibit the farmer to put as many cows in the field as the farmer otherwise would do (Luesink and Kruseman, 2007). Fourthly, farmers who apply automatic milking may prefer keeping their cows inside due to management reasons: for optimal timing of the individual cow's milking and higher milk yield (Ketelaar-de Lauwere et al., 1999). These and some other factors earlier mentioned result in a trend that on intensive dairy farms the cows are kept more and more indoors. Data available from The Netherlands indicate that the so-called 'limited grazing' is applied at 52 % of dairy farms in NL. The so-called 'summer feeding' which means that the cows are indoors all the year is estimated to be applied at 18 % of the dairy farms in NL (Luesink and Kruseman, 2007).

On the other hand, unrestricted pasturing during the summer period is obligatory in organic farming (Council Regulation, 1999). Also some countries have a legislation that requires having cows at pasture during some months in the summer (e.g. Sweden). For farmers, a positive factor of pasturing can be that it is a relatively cheap feeding system and that it provides the cows with very favourable circumstances for their health.

3.3.6. Environmental constraints and manure handling

Along with the requirements on animal health and welfare, livestock farming is facing main demands of environmental sustainability. It has major consequences for the way dairy farming is able to develop (Oenema, 2007). Moreover it has consequences for the way animal welfare goals can be implemented in dairy farming systems.

Dairy farming contributes significantly to three main environmental problems:

- acidification, through its ammonia emission
- eutrophication through the run-off and leaching of its nutrient surpluses
- greenhouse effect, through methane production from the rumen of cows and release of nitrous dioxide from grasslands.

The ammonia emission originates mainly from manure handling and storage in the animal house and from manure application in the field. Nutrient surpluses have a main cause in animal nutrition, type of manure, manure application in the field.

Results from Swensson and Gustafsson (2002) demonstrated a higher release of ammonia from a free stall cow barn with liquid manure than from the conventional tie stall barn with solid manure.

The environmental impact of mineral emissions and legislative environmental constraints at farm level may be a reason for farmers to keep the cows continuously inside (Groot Koerkamp et al., 1998).

3.4. Management in dairy cow farming systems

The management in dairy cow farming systems can affect the welfare of the animals in various ways. Basically management as well as many aspects of the health of the animals can affect all the needs of dairy cows. Inspection of the status of each individual animal and proper handling and treatment of sick animals is crucial for the welfare and security of cattle.

There are a many systems, which automatically or partly automatically can be used for different aspects of management of dairy cows, for instance automatic feeders for individual feeding of concentrate or pedometers for recording of the level of activity of individual cows. However, these systems do not always work properly, thus regular inspections and quality control of various management and control systems is important.

3.4.1. Daily events

Inspection of animals. Production diseases are common in dairy cattle, and can cause both pain and discomfort (Chapters 14-16). Furthermore, animals sometimes get injured for instance by slipping and falling on the floor. Punctual treatment of diseases and injuries can avoid development to more severe stages and decrease the severity and duration of pain and discomfort. Furthermore, punctual treatment may decrease spreading of infections. Monitoring of single animals for health deviance is one of the most important tasks in order to secure animal welfare.

The indoor climate and hygiene. The indoor climate in terms of temperature, humidity, wind speed and air quality can have an impact on animal welfare (sections 11.3 and 11.5). The indoor climate is to a large degree influenced by the building design, volume, insulation and heating, if any. However, daily regulation of ventilation can help to obtain high air quality and keep the climate within the limits that do not have negative effects on animal welfare. Automatic monitoring systems can be built-in to monitor the climate in order to regulate for instance ventilation.

Cattle defecate and urinate in all the areas where they are kept. Dirty and slippery floors both in the walking and lying area can lead to infections, for instance mastitis, and it is more likely that animals are slipping and falling and thus get injured on slippery floors. The frequency and efficiency of cleaning of floors both in the walking area and the lying area is therefore important in order to allow floors to be dry and non-slippery and to minimise injuries and infections. The floors can be cleaned automatically by scrapers, robots or manually at various frequencies. The frequency of cleaning, as well as the diurnal rhythm in cleaning in relation to the diurnal rhythm of the activity of the animals, may affect the hygiene as well as the indoor climate. Fixed or rotating brushes can be placed in loose housing systems to help the cow when performing grooming.

In most systems the lying area is provided with some bedding materials on a daily basis. The type and amount of bedding as well as the frequency of providing the bedding material can have great impact on the quality of the resting area (section 11.6).

Feeding and drinking. Roughage and total mixed ration (TMR), including concentrates, is most often offered on *ad libitum* basis while concentrate, when given separately, is provided in restricted amounts either in a concentrate feeder, in the milking parlour or in the automatic milking unit. However, sometimes feed is also offered in restricted amount on a shared feed trough. The feeding strategy can have a strong influence on how much time cows and heifers spend eating and ruminating, and can also have various effects on the health of the animals (see chapter 10). The choice of feeding strategies and control of feed intake is important to ensure that all animals get a balanced diet. However, in loose housing systems direct control of roughage or TMR intake on an individual animal level is very rare. Inspection of the animals is therefore necessary in order to avoid very thin cows especially in early lactation or overeating in late lactation or dry cows. Careful planning of the feeding, based on the actual status of the animals in the group as well as inspections of feeders and systems for mixing

rations and delivering water, is important in order to provide a balanced diet for each individual. When food is provided at a shared feed trough the distribution of feed as well as the distance to the feed have a great impact on whether or not the feed is within the reach of all the animals. Furthermore, the number of animals in relation to the available space for feeding can have severe impact on individual animals feed intake and the level of aggression (Huzzey et al., 2006).

Milking. In many milking systems cows are milked two or three times per day. In loose housing systems the cows commonly have to wait a certain amount of time before milking in a rather crowded area in front of the milking parlour. In larger herds the waiting time can be up to several hours a day depending on the capacity of the milking system and whether or not the herd is divided into groups for milking. In systems with robotic milking waiting for access to the robot will depend on whether it's a system with free traffic or some types of forced traffic. In systems with robot milking the routines used for fetching cows, which do not approach the robot voluntarily, may affect the welfare of the cows if the milking intervals become very long.

3.4.2. Non-daily events

Hoof care. Checking of the hoofs of cattle and hoof trimming whenever necessary is important in order to minimise hoof diseases and secure the cow ability to move with a normal pattern.

Reproduction. When cows and heifers are in heat they will typically show mounting of other animals, as well as an increased level of activity and more aggression. The management of animals in heat can thus affect the other cows in the group. Animals in heat can either stay in the group or be moved to a separate area. Animals are either artificially inseminated or naturally mated by a bull. The bull can either be in the group of cows or kept in a separate area. Furthermore, some farmers choose to inseminate all animals in heat while other farmers only inseminate animals they plan to keep in the herd for another calving. The later strategy means that some animals will stay in the herd for a period and repeatedly get into heat. Detection of animals in heat can be done by visual inspection or by use of one of the various commercial systems for heat detection, most of which is based on automatic measurement of the level of activity.

Calving. In many loose housing systems the cow will be moved to either an individual calving pen or a calving pen shared by more cows with or without their calves. In loose housing systems and at pasture the cows sometimes deliver the calf in the group of lactating animals. In tie-stalls the cow either gives birth to the calf in the stall or in a calving pen as above. The calf can be removed from the cow either immediately after birth or stay together with the cow for various time intervals, however usually only a few days (see chapter 18).

The cow will usually be introduced to the group of lactating cows when the calf is removed from the cow. Management procedures securing that the cow is moved to the calving facility in time as well as the position of the calving facilities and management procedures that secure regular inspection of the cow before and during calving are important in order to secure intervention when needed.

Drying off dairy cows.

The dry dairy cow is usually kept in a separate group away from the non-lactating cows in order to prevent her from overeating. Cows can be dried off either abruptly by taking away the

majority of the food and only giving the cows' access to straw and water for a few days until the milk production stops. Alternatively cows can be dried off by reducing the feed intake and only milking the cow once a day for a period. In loose housing systems regulation of the feed intake in the lactating group of cows is most often done by reducing the amount of concentrate allocated to cows, either in concentrate feeders or in the milking parlour. It is more complicated to make a stepwise reduction in the roughage or TMR ration since all cows typically have access to this type of feed in a shared manger. In tie-stalls, the reduction in feed intake can take place even though the cow is still kept in the same stall as during lactation. The method of drying off the cow properly can affect the welfare of the cows, particularly in cows with a high milk yield. The length of the dry period is typically 6-8 weeks, but can vary a lot.

Grouping and re-grouping. Grouping of heifers and cows can be done according to various strategies. However, heifers are often grouped according to age and whether or not they are pregnant. Dairy cows are most often grouped according to whether or not they are lactating. In larger herds the group of lactating animals may be split up into smaller groups either randomly or according to stage of lactation and/or level of milk yield. Sometimes cows may also be grouped according to whether or not the cows are pregnant. Grouping according to udder health is a way to reduce new infections (Ekman, 1998). Moving animals from one group to another can induce increased levels of aggression for a period and cattle often show stress responses when introduced to a new environment (Hasegawa et al., 1997).

Access to pasture or exercise yard. There is a large variety of different strategies for access to pasture or exercise yards. In one end of the scale both cows and heifers are kept indoors all year round and at the other end of the scale both heifers and cows are at pasture for 24 hours a day during the whole summer. Cows can be kept at pasture in various sorts of systems, for instance at pasture during daytime and inside during the night or outside during the night and not in the daytime. In a few countries regulations exist to let dairy cows out on pasture during the summer (see chapter 8.3.5). In between, all sorts of systems can occur, for instance at pasture between morning and evening milking and inside during the night. The amount of time per day spent at pasture very often also varies during the season depending on weather condition and the conditions of the pasture. Furthermore, the length of the season depends on the climate in the region. The effects on the welfare of the animal will thus vary a lot depending on both the indoor and outdoor conditions at the specific farm.

4. Genetic change for higher productivity and disease resistance in dairy cattle in relation to welfare

Most of the cow milk in EU these days is produced on specialised farms rather than on mixed farms where both dairy and beef cattle are kept (van Arendonk and Liinamo, 2003). Cows on those farms have been genetically selected over generations for milk production and not at all, or only as a secondary goal, on muscularity i.e. suitability for meat production. The major highly specialised breed for milk production is Holstein-Friesian. However, other breeds are used, for example in Finland over 60% of cattle are Ayrshires (Koivula et al, 2007), in Norway, over 90% of dairy cattle are Norwegian Red (Østerås et al., 2007), in Sweden 45% of dairy cows are Swedish Red and White Breed (Sandgren pers. comm.) and in Austria 75% of dairy cows are Simmental.

In this chapter, the effects of selection for increased production are discussed. This type of selection was prevalent in Holstein breed that represents about 80% of dairy cows. As mentioned above, other dairy cow breeds are used, but it was decided not to address them

individually, as there are too many breeds to deal with and because most of them were subjected to a different selection programme (less intense, more traits, etc.)

4.1. Genetic selection

For the most part of the 20th century the goals for animal agriculture were increased production and efficiency to satisfy a consumer market that demanded an abundance of animal products at low cost. Under these circumstances, it is not surprising that the main aim of dairy cattle breeding for the last 50 years was to improve production efficiency, with genetic selection focused on increasing milk yield. This goal has received wide support because, other things being equal, it should optimise the use of resources, increase farm profit and reduce cost for consumers. In many European countries, yield per cow has more than doubled in the last 40 years. The dramatic increase in yield per cow is due to rapid progress in genetics and management. The average ECM (Energy Corrected Milk) yield for Swedish dairy cows, shown in Figure 1, increased from 4200 kg to 9000 kg between 1957 and 2003 (Pryce and Veerkamp 2001). An average production per cow of over 10,000 kg of milk is not uncommon in the USA and increasingly common in Europe. Individual cows may produce twice as much. Data from National Milk Records in the UK show an increase in average yields of dairy cows of about 200 kg/year from 1996 to 2002 and 50% of the progress in milk yield is attributed to genetics (Pryce and Veerkamp 2001).

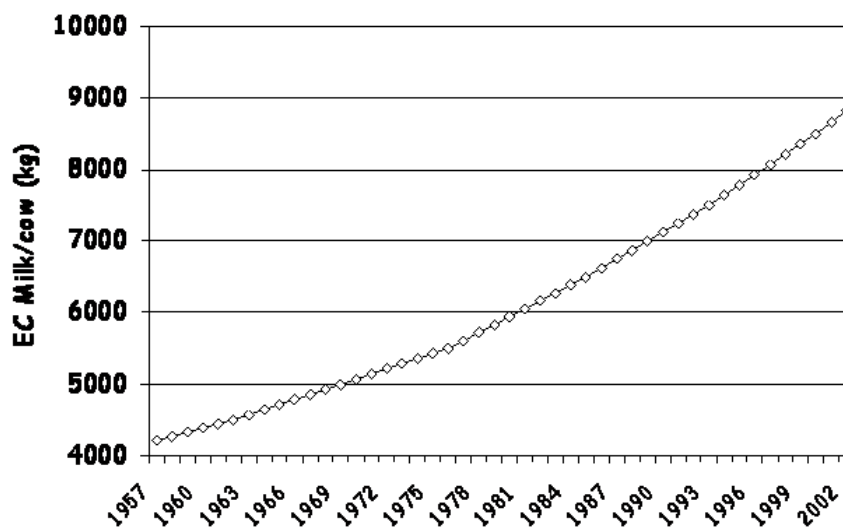


Figure 2 Average ECM (Energy Corrected Milk) yield for Swedish dairy cows over time.

The picture is similar in the US where, between 1993 and 2002, the average milk production per cow increased by 1287 kg and 708 kg of this increase, or 55%, was due to genetics (van Raden, 2004). It is interesting to note that, until the mid-1980s, most of the increase in milk yield was the result of improved management, in particular better application of nutritional standards and improved quality of roughage. Since then, genetics became the major factor as a result of effective use of artificial insemination (AI), intense selection based on progeny

testing of bulls and worldwide distribution of semen from bulls with high genetic merit for production.

The North American Holstein Breed began with imports from Northern Europe in the late 1800's. The breed stayed in North America until the early 1970's when large scale exports began of live animals, followed by semen and embryos. Over a 25-year span, US Holstein semen exports grew from about 400.000 units in 1973 to almost 8 million units in 1997. Early exports were mainly to EU member countries, particularly Italy, the Netherlands, Germany and France. In addition, several countries, such as the Netherlands, France and others, implemented an aggressive embryo import program as a source of breeding stock for their internal genetic improvement programs. The major factors responsible for this trend were:

- Worldwide awareness that Holsteins gave higher milk yields than most breeds;
- Dairy farmers' breeding objectives worldwide became increasingly focused on income from sale of milk;
- Technology existed to import Holsteins from USA into other countries.

The import of semen and embryos has resulted in the "Holsteinization" of much of Europe. If we take UK as an example, in the last 30 years from what was predominantly a Friesian dairy cattle population is now, on average, 90% North American Holstein (Brotherstone and Goddard, 2005).

The high input/high outputs are the most important dairy production systems and are used in most of the EU. These systems account for 83% of all EU dairy cows (with 95% of them being Holstein-Friesian breed) and 85% of all EU milk production (OECD, 1999). This chapter, unless otherwise specified, refers to Holstein dairy cows performing in a high input/high output dairy production system.

There are several practical reasons why one sided genetic selection for high production of milk, generally practiced since late 1990's, should be viewed with concern:

- a) the increase in milk yield has generally been accompanied by declining ability to reproduce (see chapter 6), increasing incidence of health problems, and declining longevity in modern dairy cows, all of which may be indicative of reduced animal welfare (although in Norway there has been a recent decline in the incidence of such health problems (Østeraås et al, 2007).
- b) substantial antagonistic genetic correlation exists between milk yield and fertility and between milk yield and several production diseases, indicating that a proportion of the observed decrease in reproductive performance and of the increase in incidence rate of production diseases are correlated responses associated with past one sided selection for increased yield;
- c) with increasing production cows need to spend more time eating and thus have less time available for other activities, and may not be able to allocate time enough to fulfill their need for important activities such as resting;
- d) the selection for high milk production has produced a cow that is dependent on a high level of management in order to maintain its health, and which requires certain management practices to maintain its high milk output, which may themselves reduce animal welfare e.g. high-starch grain-based diets, and minimal grazing;
- e) the success of the dairy industry depends upon public perception of its products and production methods and increased public concerns regarding modern animal agriculture,

particularly animal welfare (Vanhonacker et al, 2007), put the future of the dairy industry at risk.

One aim of this report is to document the changes in fertility and in health problems and, hence, the welfare associated with selection for increased production in dairy cattle.

A more detailed discussion of the biological reasons for decline in fertility associated with increased genetic ability to produce milk will be discussed later in this report. Briefly, excessive tissue mobilization early in lactation to support milk secretion has a negative impact on other biological functions, such as the ability to reproduce or maintain health. Lower fertility reflected by such reproductive measures as longer interval to onset of cyclicity postpartum and lower conception rate earlier in lactation, are indicative of the cows coping with metabolic stress. This may not be a welfare problem if the cows are allowed to cope normally with this stress through a longer calving interval. Unfortunately, intensive production systems seldom provide this allowance. In some countries hormonal and other invasive interventions are used to kick start the reproductive system postpartum, which increases the stress and leads to increase risk of health problems during the transition period of subsequent calving. The most serious welfare problem is substantial decrease in length of productive life of modern dairy cow due to high involuntary culling, and subfertility is the main reason for involuntary culling.

A conceptual framework linking the increase in genetic ability to produce milk with the decline in welfare is also presented to stimulate research aimed at developing breeding goals that would address the antagonistic genetic association between milk yield and fitness traits in order to jointly improve milk production and welfare in dairy cattle. For the purpose of risk analysis to evaluate the impact of increased genetic ability to produce milk on welfare, genetically high producing cows were defined as cows with estimated breeding value (EBV) for milk production in the top quartile for the breed and country.

4.2. Impact of selection and breeding on welfare

One definition of animal welfare put forward by Broom (Broom 1996) states that “The welfare of an individual is its state as regards its attempts to cope with its environment”. Animal welfare ranges from poor to good and an objective way to assess it is in terms of directly measurable biological functions such as reproductive success, disease incidence, survival and behavioural changes (Anonymous 2001). Duration, prevalence and severity are aspects that need to be considered to assess the importance of any welfare indicator. For dairy cattle, the major indicators of poor welfare that are associated with selection for high milk production are lameness, mastitis, other metabolic disorders, sub-fertility, and longevity. The impact of selection and breeding can be judged on the basis of its impacts on the welfare of individual offspring and future generations. As pointed out earlier, some of the most serious welfare problems in dairy cattle are the consequence of a lack of balance in genetic selection (Rauw et al., 1998; Sandoe et al., 1999). It is also important to recognise that rectifying welfare problems in commercial dairy herds that may have resulted from past breeding strategy might be difficult to do in a short time. Considerable efforts may be needed to encourage definition and adoption of more balanced breeding goals if such welfare problems are to be addressed.

A total of 22 scientists participated anonymously (Delphi method) to develop a conceptual framework for assessment of farm animal welfare, to identify the major welfare performance indicators and rank them in order of importance. For dairy cattle the major welfare indicators

in order of priority were: lameness, mastitis, other metabolic disorders, sub-fertility, and longevity (Anonymous 2001; Whay et al., 2003a).

4.2.1. Lameness and other production diseases

The incidence of production-related diseases has increased greatly over the last decades. A case in point is lameness. Its incidence increased in UK dairy herds from lactational incidence rate (LIR) <10% reported prior to 1980 (Russell et al., 1982) to >20% after 1990 (Clarkson et al., 1996). Many more countries are now reporting a high incidence of lameness (Barkerma et al., 1994, Philipot et al., 1994, Boettcher et al., 1998). For the US, Guard (1996) reported a 38% LIR whilst Espejo et al. (2006) reported a mean prevalence in the country of 25%. Lameness decreases milk yield and is an important cause of culling (Rajala-Schultz et al., 1999). Guard (Guard, 1999) estimated direct cost due to lameness in a 100-cow herd to be \$7,600.

Ingvartsen et al. (2003) reviewed the literature on the relationship between milk performance and health in dairy cattle. The review dealt with production diseases as defined by Kelton et al. (1998): dystocia, parturient paresis, ketosis, displaced abomasum, retained placenta, ovarian cyst, metritis, mastitis and lameness. The review of 11 epidemiological studies showed clear evidence that cows with high yield in the previous lactation are at increased risk of mastitis and ovarian cysts in the subsequent lactation, but for other diseases the phenotypic association was weak because of the large variability between studies. These results led Ingvartsen et al. (2003) to conclude that examining the relationship in terms of cause (level of milk production) and effect (disease incidence) is inadequate as cows producing more milk are also likely to eat more and make greater use of their body reserves in early lactation (Veerkamp, 1998).

Many published studies (Oltenucu et al. 1991, Dematawewa and Berger 1998, Royal et al. 2000, Pryce and Veerkamp 2001, Roxstrom 2001, Veerkamp et al. 2003) reported strong unfavourable genetic associations between milk yield and fertility measures, indicating that the decline in fertility observed on dairy farms is, at least in part, an unwanted consequence of past one-sided selection for higher yields.

Ingvartsen et al. (2003) reviewed 14 genetic studies on the relationship between milk performance and health in dairy cattle. These studies showed an unfavorable genetic correlation between milk yield and incidence of ketosis (0.26-0.65), ovarian cyst (0.23-0.42), mastitis (0.15-0.68) and lameness (0.24-0.48) indicating that continued selection for higher milk yield will increase LIR for these production diseases.

There has been a Swedish study investigating associations between welfare and farm economy, where large differences were found between the Swedish Red and White and Swedish Holstein Friesian Breed. The results show that although Swedish Holstein herds have higher milk yield, and therefore higher gross income from milk, Swedish Red and White Breed herds have the same overall profitability due to significant effects of breed for a large number of the welfare indicators, all in favour of the Swedish Red and White breed (Hallén Sandgren and Lindberg, 2007a, b). Pryce and Veerkamp (2001) showed that including fertility and mastitis in a selection programme will increase return per cow.

4.2.2. Mastitis

The genetic antagonism between mastitis resistance and production traits has been well established. In their review, Mrode and Swanson (1996) reported a weighted average genetic correlation between SCC and milk yield in first lactation of 0.14 0.04. Pryce and Brotherstone (1999) and Rupp and Boichard (1999) reported similar results.

The genetic antagonism between yields and clinical mastitis is more pronounced. Based on Scandinavian data, Emanuelson et al. (1988) indicated an average genetic correlation of 0.30 and, 12 years later, Heringstad et al. (2000) reported genetic correlations ranging from 0.24 to 0.55 with an average of 0.43. Pryce et al. (1998), Rupp and Boichard (1999), and Kadarmideen et al. (2000) reported genetic correlations in the same range, i.e., 0.29, 0.49 and 0.35, respectively.

Interesting to note that higher incidence of clinical mastitis is also associated with lower reproductive performance. Pryce et al. (1998) and Kadarmideen et al. (2000) reported genetic correlations with calving interval ranging from 0.16 to 0.41 and with conception rate to first service ranging from -0.21 to -0.58 . Castillo-Juarez et al. (2000) also reported that high somatic cell counts were correlated to reduced conception rate at first service and a longer calving interval with genetic correlation of -0.21 and 0.14, respectively.

As expected, mastitis resistance is found to be an important component of cow's longevity. Sander Nielsen et al. (1999) reported genetic correlations between udder health and survival from first calving to end of second lactation ranging from -0.37 to -0.75 differing according to the breed. Pryce and Brotherstone (1999) reported genetic correlations of lifespan with somatic cell counts and clinical mastitis ranging from -0.11 to -0.32 .

Up to the mid-90s, in most countries, the breeding objective included primarily production traits (mainly protein and fat yield), milk composition (protein and fat contents), and several morphological traits, particularly capacity and udder type. The Scandinavian countries were an exception with selection based on broader breeding objectives that included many functional traits and, particularly, mastitis resistance (Heringstad et al., 2000). Including resistance to mastitis in selection objectives proved to be effective. In Norway incidence of clinical mastitis increased from 0.15 cows treated per cow-year in 1975 to 0.44 in 1994, and then decreased to 0.23 in 2002 (Østerås et al., 2007).

In the last five years, the continuous and unfavourable trend for fertility and mastitis susceptibility led most European dairy populations to update their breeding objective and to increase the weight of non production trait. Evaluating some of the recently defined breeding objectives put forth by Colleau and Le Bilan-Duval (1995) and by Pedersen et al (2002) shows that mastitis resistance accounts for 10 to 30% of the total weight. This weight is large enough to substantially decrease SCC and to stop any deterioration of CM frequency, even if SCC information only is available.

There are some concerns that continuous selection for low SCC may influence the cow's capacity for leukocyte recruitment and, therefore, her ability to respond to intramammary infection. Further research is needed to clarify if this concern is indeed justified.

4.2.3. Fertility problems and decreased longevity

Decreased reproductive success may not in itself indicate reduced welfare (see chapter 6). However, it is clear that many of the reproductive problems associated with highly productive dairy cows result from disease, such as uterine infections or other disorders (Bell and Roberts,

2007; Dobson et al., 2007; Sheldon et al., 2008) or from metabolic stress associated with milk production. For these reasons, reduced reproductive performance of modern dairy breeds is a welfare concern.

Calving interval increased from < 13.0 months to > 14.5 months and number of inseminations per conception from 2.0 to > 3.5 from 1980 to 2000 in 143 US commercial herds (Lucy, 2001a). A decline in pregnancy rate to first service of 0.5% per year between 1975 and 1997 was reported in the US (Beam and Butler, 1999). Poor reproductive performance often leads to premature culling of dairy cows.

The decline in fertility, reflected in increased calving interval and in longevity (measured by proportion of cows alive at 48 mo of age) in Holstein cows in the Northeast US from 1957 to 2002 are shown in Figure 2. Average milk yield per cow over the same period increased from about 5000 kg to 11000 kg at a relatively steady rate of about 150 kg per year. It is interesting to note that average calving interval increased by only 0.5 months from 1960 to the late 1980s and by almost 2 months in the last 15 years, and the trend seems to reflect the pattern of rate of genetic gain. Proportion of cows still alive at 48 months of age decreased from 80% to 60% between 1957 and 2002 indicating a substantial decrease in length of productive life of the modern dairy cow.

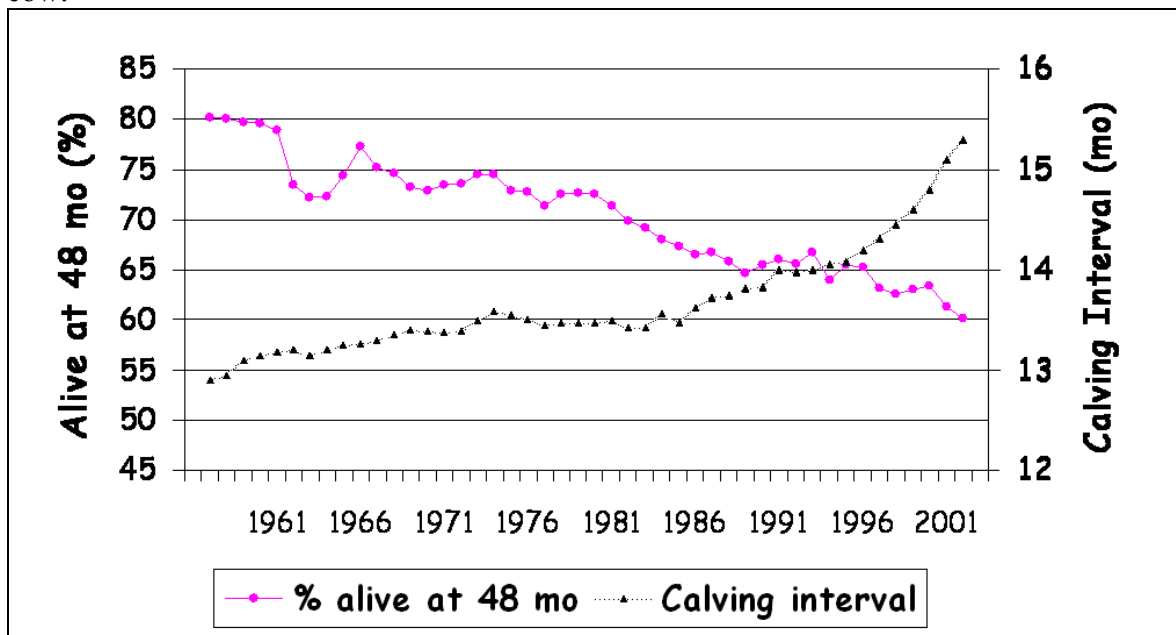


Figure 3 Average calving interval and proportion of cows alive at 48 mo of age over time for Holstein cows in Northeast United States.

Declining reproductive efficiency is not limited to the US. In the UK (Royal et al. 2000) pregnancy rate to first service decreased from 56% in 1975-82 to about 40% in 1995-98, a decrease of about 1% per year. Similar decreases in conception rate and other reproductive measures have been reported in Sweden (Roxstrom, 2001) and many other countries.

Behavior may also play a critical role in the declining reproductive performance of genetically high-producing cows. In a study of 17 commercial herds that used an electronic estrus-monitoring system, Dransfield et al. (1998) showed that a higher proportion of cows with

production above herd average exhibited estrus with only low intensity and short duration relative to lower-producing cows (24% vs. 16%). Lopez et al. (2004) also reported an unfavorable association between milk production and estrus behavior with shorter estrus periods (5.5 h vs. 11.1 h) in high relative to low producing cows (>40 kg /d versus <30 kg/d). Emanuelson and Oltenacu (1998) found extended interval to first breeding and prolonged days open with poorer estrus detection. The decline in fertility also has economic consequences and several studies reported increasing reproductive costs for dairy cattle (Lindhe and Philipsson 1999, Royal et al. 2000, Lucy 2001a).

4.2.4. Modification of body form and behaviour.

Variation between breeds and breeding lines provides first-hand evidence that breeding affects the body form and behaviour of dairy cattle. This section focuses on changes that obviously impair the physical health and welfare of dairy cows under the prevailing husbandry conditions.

Potential effects of breeding on body measurements and conformation traits of dairy cows are broadly supported by the estimated heritabilities and genetic correlations reported in various studies (e.g. Short and Lawlor, 1992; Koenen and Groen, 1998; Tsurata et al., 2005). Koenen and Groen (1998) calculated from data of 7344 lactating Holstein heifers of 560 herds heritabilities of 0.33 for body weight and from 0.32 to 0.54 for heart girth, hip height, and conformation traits. Genetic correlations of body weight with heart girth, hip height, body depth, rump width, and muscularity ranged from 0.48 to 0.77. Other studies yielded comparable results.

Genetic selection in dairy production is commonly based on multi-criteria selection indices. Those indices include production parameters, characteristics of longevity as well as conformation traits that refer to body size and shape of the cows. Which traits are used and their weight in the index depends on several factors (Klassen et al., 1992). These days much emphasis is put on the external factors such as economic determinants, the envisaged production environment and the applied feeding regime (cf. Buenger et al., 2001). Tsurata et al. (2005) and Macdonald et al. (2008) provide typical examples that show how important a thoughtful development and calibration of the selection indices is. It has principal consequences for the effect of breeding on the body measurements and conformation in due time (Hansen, 2000).

Apparently, breeding for milk production has caused an increase of body size of dairy cows, especially of the height, as is best noticed in specialised dairy breeds such as Holsteins and Holstein-Friesian crossbreds (Hansen, 2000). As an example, in the Dutch black and white dairy population average hip height of heifers increased from 130 cm in 1981 to 144 cm in 2007 while the 305- days milk yield of the pedigree cows in the population raised from 5765 kg in 1985 to 8720 kg in 2007 (NRS Statistics, 2007). Kertz et al. (1997) measured in a herd of 728 Holstein cows 3 cm increase of wither height from the first to the second parity while wither height peaked during the fifth or sixth parity with an additional 2 to 3 cm. Koenen and Groen (1998) registered in their study with heifers an average hip height of 141.7 cm, an average heart girth of 192.9 cm and an average body weight of 546 kg. Body weight is not a constant in the further production life of a dairy cow. In general, with the height also body weight increases. Koenen et al. (1999) measured average body weights of 553, 611 and 654 kg of Holstein-Friesian cows during the first, second and third lactation. These authors also

point to shorter term fluctuations in body weight, connected to the reproductive state and lactation cycle of the cow. After calving the mean maximum weight loss was 26, 22 and 22 kg for the first, second and third parity. The weeks of lactation when the cows had this maximum weight loss ranged from week 7 in the first lactation to week 13 in the third lactation. Estimated maximum effect of pregnancy on live weight during the lactation varied from 27 to 59 kg.

Numerous studies can be found that confirm the changes in body size, conformation and weight of dairy cows due to breeding on production. It is the result of ongoing adaptation to the human controlled production environment. The effect is likely to change the cows' environmental requirements for good health and welfare.

Changes in body form and specially an increase of size and weight affect the mechanics of movements of the cow at least in two aspects: a) the space that is needed for the cow to execute her movements freely and b) the scale of forces to be exerted for movement as standing up and lying down. In both respects the welfare of the bigger dairy cow may be at stake in the restraining environment of a cubicle house. Spatial dimensions of motions of cows are already studied extensively in relation to the ease of cows of standing up and lying down in cubicles and choosing their lying postures (CIGR Working Group, 1994). Publications on this subject are going back to the seventies (Schnitzer, 1971). These days such studies are still executed but supported by the use of 3-D kinematic techniques (Ceballos et al., 2004). It allows studying the use of space of cows during any activity in greater detail, including variations between breeds and lines, and individual variations. In their reviews on dairy cattle housing, Maton et al. (1985) and the CIGR Working Group (1994) refer to body dimensions and spatial movements of cows as a necessary basis of the proper dimensioning of their housing. Incompatibility between housing design and the mechanics of cow movement are a main impairment of cow welfare. It results in a decline of normal behaviour and in wounds and mutilations on the body surface of the cow (section 11.1).

The mechanical forces exerted or withstood by an animal in motion, standing or lying depend on the body weight of the animal. When standing or moving, the claws bear the whole weight of the cow. The weight bearing capacity of claws is determined among others by its size and surface profile and by the modulation capacity of the ground or floor surface on which the cow is standing or moving (Van der Tol et al., 2002; 2003; 2004; Telezhenko, 2007). Mechanical unbalances that occur between the claw and the floor surface will cause mechanical stress and pain (Van der Tol et al, 2003) and longer term claw disorders and lameness (Somers et al., 2003). Disorders are more likely on hard floor surfaces like concrete than on a natural ground surface and more likely when the floor surface is grooved, slatted or with a surface profile than evenly shaped (Bierma et al., 2006). Moreover, unbalances in unfavourable circumstances turn to negative effects easier when cows are large and heavy in comparison to their claw size, as seems the case in Holsteins breeding lines. Franck et al. (2006) show that claw tissue has indeed a limited capacity to resist mechanical stress without being damaged.

Mechanical stresses on limbs and rump surfaces of cows when lying on hard surfaces are known to distract cows from lying and may cause hairless patches and injuries on skin and joints. Body shape and weight determine the magnitude of the effect. Hypothetically, changing the lying posture would limit the effect, but those changes are unlikely to occur if the cubicle space is insufficient for free standing up and lying down or lying on different sides.

Another relevant aspect of the physical shape of dairy cows with an impact on animal welfare is the positioning and size of the udder. In high yielding cows, especially during the first part of lactation, the udder can be an extremely large extrusion of the body. The selection for udder shape is performed using linear type traits. Udder shape is defined by a number of single traits like fore and rear udder depths, fore and rear udder attachments, udder width, fore and rear teat placement, or a composite (Short and Lawlor, 1992; Klassens et al. 1992; Boelling and Pollott, 1998, Koenen and Groen, 1998; Tsuruta et al., 2005). Selection for increased milk production is likely to cause an increase of secretory tissue in the udder and therefore a tendency towards more voluminous udders will always exist. On the other hand by selection for better udder conformation, inconvenient depths or non-functional shapes (e.g. unbalance between fore and rear part) that may lead to early culling can be reduced (Hansen, 2000; Buenger et al., 2001). According to Buenger et al (2001) udder depth is negatively correlated with longevity of the dairy cow. The heritability of udder volume is less than for single anatomical features of the udder due to the fact that udder volume and weight are at any moment affected by several factors. Those factors are: daily milk yield, milking interval, likelihood of mastitis or oedema, and fat deposition in the udder.

Deep and voluminous udders affect cow welfare. Boelling and Pollot (1998) point to the negative effect of wide and deep udders on the locomotion of cows by saying: 'that it causes a splay-legged walk, uneven foot wear and could lead to lameness'. Also other researchers indicate that large size udders contribute to the likelihood of lameness on the rear feet (Bierma et al., 2006).

Deep and voluminous udders are a main cause of lying discomfort for cows when housed in tied stalls or in a cubicle house. It thwarts the cows from choosing an upright lying position with retracted hind legs and from easily changing from lying side. By lying more on its side more space can be given to the udder of the cow. The upper hind leg is likely to be stretched then, while the lower leg lies on the floor under rump, getting the pressures of the rump and risking to be injured over time. The upper leg is likely to be stretched into the fouled area behind the cubicles. The prevention of free changing of lying postures, including free stretching of the legs, is a significant restriction to welfare. The negative effect is amplified if the floor surface underscores in the quality of the natural surface - which is often the case- and is less hygienic. The kind of material on the lying bed, the remaining manure in the after-end of the cubicle as well as the shape and condition of the udder and teats affect the chances of mastitis. Whether the load of the milk in the udder has an effect on cow welfare is not known. However, cows seem to be sensitive to high milk pressures in the udder. Ipema et al. 1992 found that cows are standing more if the interval between milking is longer.

Behaviour genetics in cattle are in their early stages (Buchenauer, 1999). Effects of selection on the behaviour of dairy cows must initially be seen as an indirect effect, i.e. due to changes in specific physiological target functions resulting from genetic change for production and other traits, in combination with the prevailing living circumstances of the animals. As an example, selection for increased milk production causes an increase in incidence of mastitis, a disease that has behavioural consequences, such as fear of being milked (entering the parlor) and unfavorable behaviour during milking. The selection for high milk yield and a restricted living environment promote the lack of expression of behaviour as in the case of silent heat. Lack of space and insecurity on a concrete floor and increased body mass due to breeding may withhold cows from normal grooming behaviour. Natural tendencies of social facilitation and expression of social affinity are almost eliminated in dairy herds. But both are inherent to the natural, biological functioning of cows.

A marked increase of behavioural activity in dairy cows regards the feed intake. Dairy cows live mainly from prepared feeds with high energy density, so that their increased physiological needs can be met within the available time budget per day, restricting the time needed for resting and other occupations.

A consequence of elevated metabolic rate makes high yielding cows vulnerable to heat stress. During the summer it increases their need for shadow or other possibilities of cooling.

Little evidence is present in the literature addressing the inventory of behavioural expressions of dairy cows that are modified by genetic selection (Price, 2002). If behavioural extinction occurs, it likely regards changes of thresholds for response and swamped motivation. Cows domesticated for milk production are indeed much more docile and less reactive to environmental challenges than breeds in the wild (Price, 2002). Another particular adaptation of the dairy cows is its adaptation to being milked. Milk let-down and ejection are from nature released by stimuli imposed by the calf. In dairy production the milk release is triggered by simplified artificial stimuli successfully replacing the calf. Breeding has without a doubt brought about these changes. ‘Temperament’ and ‘milkability’ are behavioural traits that are consciously included in dairy breeding selection indices. Their genetic basis can be derived from variation that can be seen between breeds and breeding lines.

4.2.5. Inbreeding

From about 1800, breed societies with closed herd books started to form. This decreased or eliminated the flow of genes between populations that were regarded as different breeds. The loss of genetic variation caused by closed herd books has been exacerbated by modern breeding programs, especially in the last 30 years. This has come about because of the adoption by dairy cattle industry of two technologies. First, accurate methods for estimating the genetic merits of cattle have led to an intense selection for high profit and, second, reproductive technology has allowed individual bulls and, to a small extent cows, to contribute many genes to the next generation.

Inbreeding results from the mating of related individuals and is also increasing. Inbreeding in the UK currently stands at around 3% and has been rising at 0.17% per year (Brotherstone and Goddard, 2005). The Holstein and Jersey breeds in USA have rates of inbreeding of 0.2% per year (Thompson et al., 2000) corresponding to an “effective” population size (or N_e) of 50 and the picture is relatively similar in all Holstein populations across Europe. Movement of genes between countries and focus on similar breeding objectives has meant the selection of the same cattle everywhere. Low N_e causes inbreeding and loss of genetic variation in a population. The current N_e of 50 in the US Holstein is less than required to maximize long-term genetic improvement. Since it is a recent phenomenon, little genetic variance has been lost to date.

Although inbreeding is not currently considered a problem, if it continues to rise it will become a real problem in the future. Inbreeding has three major undesirable effects. It causes inbreeding depression (including an increase in the incidence of abnormalities caused by recessive alleles), loss of genetic variance and random drift in the population mean. Inbreeding depression reduces the value of many traits, particularly those related to fitness, such as fertility, ability to remain healthy, and other traits indirectly affecting welfare.

In the Danish Holstein population, an unfavorable additive genetic trend for both the direct and maternal effect of stillbirth was found when evaluating all records from 1985 to 2002

(Hansen et al., 2004). The increase in direct effects of stillbirth was associated with an increase in direct effects of calving difficulty and especially calf size.

A major reason for this was an intense use of Holstein sires (mainly from North America) as sires of sons in Denmark. In general, the sires of sons with large impact on the Danish Holstein population is similar to the sires of sons with large impact on the Holstein population in the US, shown by Hansen (2000), and most likely for other European dairy populations that underwent “Holsteinization” process. These Holstein genes have increased the direct effects of calf size, calving difficulty, and stillbirth. As a consequence, the stillbirth rate at first calving was 12% in 2002. Philipsson and Steinbock (2003) argue a stillbirth rate around 11 to 12% is alarming. Results from breeds other than Holstein, such as the Danish Red, Danish Jersey, and the Swedish Red and White have shown that it is possible to have a considerable lower stillbirth rates (5 to 6%) at first calving (Nielsen et al., 2002; Philipsson and Steinbock, 2003).

Considerable genetic variation of stillbirth is present in Holstein breed (Steinbock et al., 2003; Hansen et al., 2004) indicating that selection of sires can be effective in reducing the stillbirth rate.

Breeding organizations have the responsibility to maintain the genetic variability and prevent the increase of inbreeding in the dairy population. This can be accomplished by broadening the breeding objectives to include health, fertility and other fitness traits along with production traits, by considering the genotype by environment interactions, by implementing selection strategies that minimise the average relationship of selected individuals with the rest of the breeding population and by taking advantage of the molecular genetic tools already available or in the developmental phase. It should be acknowledged that several of these strategies are already adopted by many breeding organizations in EU and other countries.

Other factors that would contribute to conservation of within and between breeds genetic variance are a more realistic payment system for the meat value of cull dairy cows that would encourage more crossbreeding with beef breeds and better knowledge of breed differences that may decrease the dominance of the Holstein breed. For instance, breed differences in fertility, disease resistance and feed conversion have not always been known or considered when choosing Holstein over other breeds. Crossbreeding of dairy cattle should benefit from heterosis in many traits. For two breeds of similar profit, it is likely that crosses between them would be more profitable than either one. Until now crossbreeding has not been used much in dairy cattle but recently, it is receiving some attention. In New Zealand, an across-breed genetic evaluation for profit indicates that, under their conditions, Jerseys are at least as profitable as Holsteins (Montgomerie 2004). In the US, crossbreeding of Holstein cows with Montbeliard, Swedish and Norwegian Red as well as other dairy breeds is gaining in popularity and a three breeds crossing system is generally recommended. Use of crossbreeding automatically leads to a demand for cattle of more than one breed. Therefore, a rational use of crossbreeding should, in the long run, support the conservation of a variety of breeds.

Inbreeding may itself have direct negative effects on animal welfare e.g. an increased risk of retained placenta and dystocia in cattle with greater inbreeding (Adamec et al, 2006). Inbreeding is associated with reduced milk production and impaired health, fertility and survival (Weigel, 2001). Smith et al. (1998) reported a reduction in lifetime milk production of 177 kg per 1% increase in inbreeding.

4.2.6. Genotype by environment interaction.

It is clear that selection for production may lead to problems in health and fertility. As animals tend to adapt to the environment they are selected in, it is likely that selection for increased yield may also lead to environmental sensitivity expressed as genotype \times environment ($G \times E$) interaction. Castillo et al. (2000) and Kearney et al. (2004) showed that the magnitude of the antagonistic genetic correlations between milk yield and somatic cell score and between milk yield and conception rate were significantly higher in a poor environment relative to a good environment. Dairy producers in several grazing countries have expressed concern regarding the declining fertility of cows with an increased proportion of Holstein genes. Harris and Winkelmann (2000) and Verkerk et al. (2000) reported significant differences between cows of New Zealand origin and North American origin for conception rate, services per conception, and days to first service. These studies indicate that the negative genetic correlations between production, fertility and health in modern dairy cows, already large when producing in an intensive production environment, are even larger when cows are producing in a less intensive production environment. The increase in negative genetic correlation between production and fitness traits in less favorable environments is indicative of a decline in adaptability associated with selection for increased yield in the modern dairy cow.

4.3. Selection for high production and consequences for metabolic stress

As the genetic ability to produce milk increases, more cows have sub-fertility or production diseases. As more cows are culled for health or fertility reasons, the productive life of modern cows is rapidly declining. The associations between increased production and increased risk of production disease as well as decreased fertility are well documented, but less is known about the biological mechanisms behind these relationships. Are these consequences of production stress? Are all these dairy cows trying to tell us something?

One of the first attempts to explain the negative collateral consequences of selection for increased production was presented by Goddard and Beilharz (1997) who suggested the "Resource Allocation Theory". The resources an animal has are limited and as a result, if output is increased through one biological process, such as producing more milk, other functions such as fertility, maintenance, movement, immune defense, etc. will be affected. The resources that one process demands can be increased to a certain extent. Management factors, such as increasing access to feed and nutrients, could increase fitness of the animal until resources became limited again. Any further increase in fitness would imply a reallocation of resources and thus modify other outputs such as disease resistance or behavior (Beilharz et al. 1993). Reviewing the negative side effects of selection for high production, Rauw et al. (Rauw et al. 1998) concluded that "when a population is genetically driven towards high production"... less resources will be left to respond adequately to other demands like coping with stressors; i.e. buffer capacity is [negatively] affected". To address the growing perception that the pursuit of ever-increasing milk production is detrimental to cow welfare, Ingvarsen et al. (2003) developed a framework for future research. The framework links the genotype, nutritional environment and management of the cow through its metabolic status to fertility and disease susceptibility and suggests that mobilization of body reserves has the potential to be the key factor.

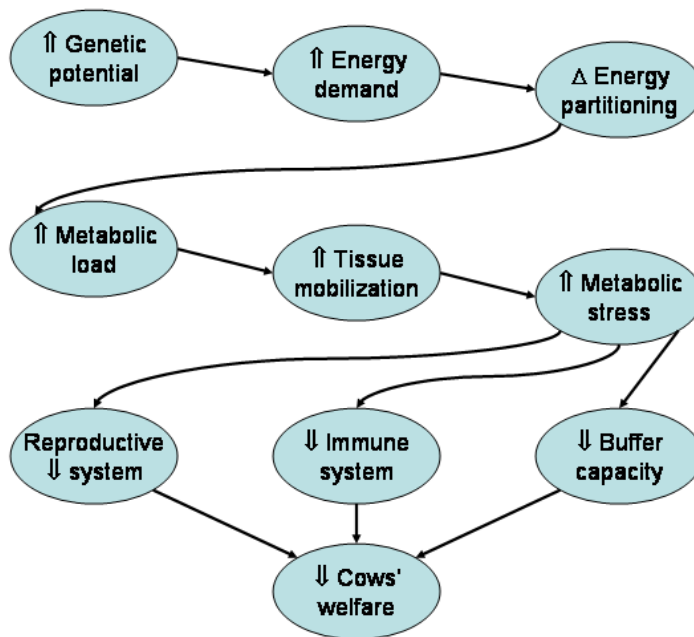


Figure 4 Likely biological pathways mediating the unfavorable consequences of selection for increased milk production on welfare and adaptability of dairy cows (based on Ingvarstsen et al., 2003).

A conceptual diagram, based on Ingvarstsen et al. (2003), describing a likely biological mechanism relating selection for increased production with the decline in animal welfare is presented in Figure 4. High producing dairy cows need to mobilise body reserve to support their milk production. In the early 1/3 of the lactation period, until energy intake catches up with the requirements, high producing cows enter a state of negative energy balance, losing excessive amounts of body condition. The terms “metabolic load” and “metabolic stress” are used (Clarkson et al. 1996) to describe the effects of high production on dairy cows. The metabolic load is defined as “the burden imposed by the synthesis and secretion of milk” and metabolic stress as “that amount of metabolic load which cannot be sustained, such that some energetic processes, including those that maintain good fertility and general health, must be down regulated.” The extent and type of down regulation would be indicative of the degree of metabolic stress. The term metabolic load is often used to describe only the part of the total energetic burden of lactation that is met by mobilization of body reserves, i.e., metabolic load is the same as negative energy balance.

Selection for production increases milk secretion and, therefore, the demand for energy. It also changes the partitioning of available energy by increasing the priority with which energy is allocated to support milk synthesis. Selection for production also increases feed intake but, with a genetic correlation between yield and feed intake ranging from 0.46 to 0.65 (Veerkamp 1998), the gap between energy input and output during early lactation is increasing. There is little evidence for more efficient digestion or utilization of metabolisable energy in high-genetic-merit cows. Consequently, the correlated response to selection for yield is increased body-tissue mobilization and increased metabolic load to bridge the gap between energy available through feed intake and energy needed to support increased milk production. Furthermore, an increasing demand for energy may lead to time constraints since cows like all

other living creatures only have a total of 24 hours per day to allocate to different activities including eating behaviour. There is some evidence suggesting that high producing cows may be under time constraints (Loevendahl & Munksgaard, 2004).

Unfavorable genetic correlations were reported between negative energy balance and interval to first luteal activity (Veerkamp et al. 2000), incidences of digestive (milk fever, ketosis, displaced abomasum, diarrhea and indigestion) and locomotive (laminitis, leg problems, hock problems, and inflamed thigh) problems (Collard et al. 2000), and average somatic cell count (Sondergaard et al. 2002). These reports suggest that a major part of the decline in health and fertility observed over time is the result of the increased metabolic stress associated with the success of the genetic selection for milk yield.

Management practices that may also increase the gap between energy input and output are expected to increase the metabolic stress and negatively affect fertility-health-welfare complex. Strategies, such as administration of Bovine Somatotropin (BST), should be carefully evaluated with respect to their impact on the welfare of the modern dairy cow before being widely implemented. The European Union, based on a report from its Scientific Committee on Animal Health and Animal Welfare (SCAHAW, 1999) and several published studies (Willenberg 1993, Kronfeld 2000), prohibits the marketing and use of BST because of its effect on cow welfare, in particular on lameness, mastitis and reproductive disorders.

A further impact of selection for high milk production is that it limits the ability to use pasture as a way of feeding lactating cattle (see section 10.1.2 on feeding practices).

Consideration of animal welfare in any livestock production system is a determining factor for its social acceptability and, therefore, its sustainability (McGlone, 2001). The double-edged sword of genetic yield improvement and associated metabolic-stress symptoms raises important challenges for sustainability of the dairy industry.

The necessity of broadening breeding goals to include animal welfare considerations has long been promoted by a number of geneticists and other animal scientists (Phillips, 1997). Need for action is fuelled by growing public concern for animal welfare and increasing demand for product labeling which assures the consumer of the adequate animal welfare origin of food.

4.4. Selection for improved welfare in dairy cattle

In regard to breeding programme, The United Kingdom's Farm Animal Welfare Council (1997) in its report on dairy cow welfare, recommended the following:

“Achievement of good welfare should be of paramount importance in breeding programme. Breeding companies should devote their efforts primarily to selection for health traits so as to reduce current levels of lameness, mastitis and infertility; selection for higher milk yield should follow only once these health issues have been addressed”.

Broom (2002), pointing out positive correlations between milk production and the major welfare problems in dairy cows (lameness, mastitis, impaired reproduction, inability to show normal behavior), stated:

“Genetic selection has not taken adequate account of the adaptability and welfare of cows. Current trends towards ever greater milk production should not be continued unless it can be insured that welfare is good. It is important to the dairy industry that welfare problems should be addressed before there is widespread condemnation of breeding and management practices.”

Breeding organizations are concerned with what type of dairy cows will populate our dairy farms in the future and, therefore, the ethical responsibility for the welfare of future populations of cows (Sandoe et al., 1999). The major advantages of genetic improvement for any trait are that changes are cumulative, permanent and cost-effective (Christensen, 1998, Simm, 1998). This is true for the selection trait as well as for correlated responses on other traits. As pointed out, these very advantages have facilitated a rapid increase in milk yield per cow and detrimental effects on the welfare of the animals when breeding objectives have centered on production, with little attention given to fitness traits, such as fertility and health.

The unfavorable genetic relationship between milk production and welfare indicators means that the most effective route to stop the decline or even improve welfare is by developing and adopting a selection index in which welfare related traits are included and appropriately weighted. With such an index, the genetic progress for any of the traits considered is smaller than a selection intended for a single trait. However, the overall economic response is greater than in single trait selection.

Animal welfare is often portrayed as opposed to animal production (Rushen and de Passille, 1998) and selecting for welfare traits is assumed to be uneconomical. This is not the case. The current breeding goal in the UK includes milk, fat and protein yields plus lifespan. These traits are combined into Profitable Lifetime Index, or £PLI. Calculations suggest that expansion of £PLI to include mastitis resistance and measures of fertility (calving interval) could increase economic response to selection by up to 80%, compared with selection for milk production alone (Pryce et al., 2000). Selection based on such an index could also halt the decline in fertility and mastitis resistance, compared with selection for milk production alone. Sandoe et al. (1999) evaluated the use of several selection indexes combining selection for production with selection for resistance to mastitis for the Danish situation. They showed that, after 10 years of selection with zero relative weight on resistance to mastitis (selection for milk alone) production per cow increased by 1179 kg and number of mastitis treatments/100 cows by 12.9. Using an index in which resistance to mastitis is given double weight relative to yield, production increased by 964 kg and number of mastitis treatments/100 cows decreased by 5.5. In a herd of 100 cows, this translates to 21,500 kg less milk and 18.4 fewer mastitis treatments compared to selection for milk yield only, i.e., the loss in milk yield gain is equal to 1168 kg per avoided treatment of mastitis. It is interesting to note that, as a function of the cost of mastitis relative to milk prices, the weighting of the two traits in the selection index can be chosen to maximise profit. These two examples illustrate that it should indeed be possible, through genetic selection, to address welfare without a reduction in profitability.

One example of successful multitrait selection comes from Sweden and other Nordic countries where breeding goals have been formulated to include not only production, but also fertility and health for the last 20 years. The average calving interval from 1987 to 2003 is shown in Figure 5 for the two major Swedish dairy breeds.

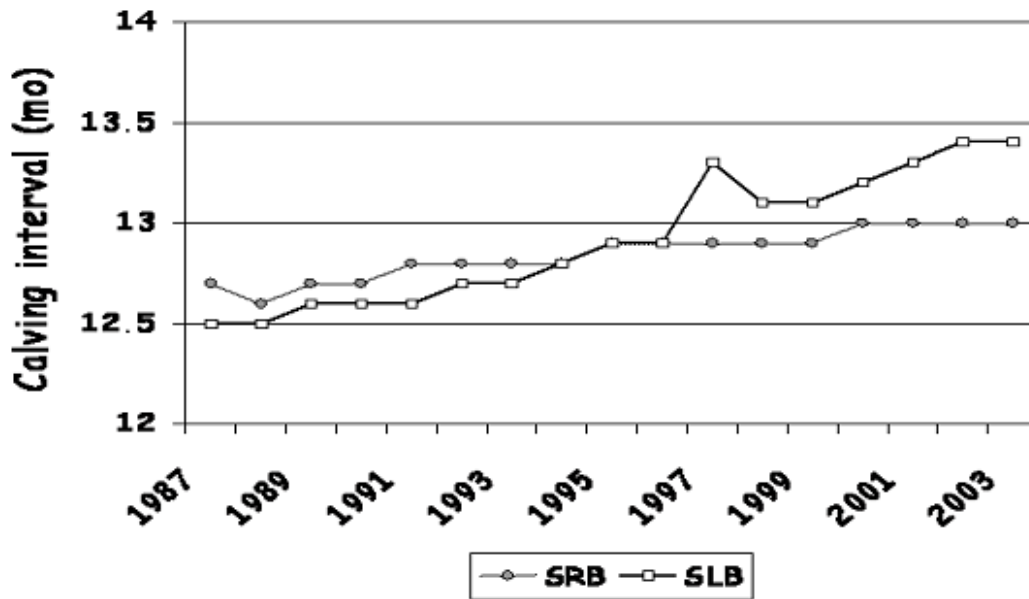


Figure 5: The average calving interval from 1987 to 2003 for the two major Swedish dairy breeds.

By implementing more balanced selection goals it has been possible to limit the decline of fertility in the SLB breed to about half of what has been observed in other Holstein populations and prevent it in the SRB breed which is much less influenced by germplasm from outside Scandinavia. Resistance to mastitis follows similar trends. There have also been recent improvements in the health of cows in Norway (Østeraas et al., 2007).

In Nordic countries, records are available to include fertility and health traits in selection. The progeny testing of bulls is performed with large progeny group size (>120 daughters/bull) to handle traits with low heritability. The program has a positive impact on smaller breeds, such as the red and white breeds in the Nordic countries (Philipsson and Lindhe, 2003). It is also clear that, as long as the majority of the black and white dairy bulls tested in the Nordic countries originate from sires outside Scandinavia, where no estimates for genetic merit for health and fertility traits are available, the Nordic effort to improve these traits will have only limited impact (Christensen, 1998). An active international germ plasm market makes breeding of dairy cattle truly global.

For the Holstein/Friesian breed, which is the dominant dairy breed in the world and accounts for about 80% of all dairy cows in Europe (Van Arendonk and Liinamo, 2003), increased emphasis on selection for fitness traits should occur in all countries, particularly those that dominate the international germplasm market. Since mid 1990's several breeding organizations in Europe as well as North America have included fertility and health (at least mastitis) in their breeding objectives. Recently several Nordic Countries included lameness in the breeding objectives and their lead should be followed by other breeding organizations. A multi-trait selection program in which health, fertility and welfare traits are included in the breeding objective is suggested. For multi-trait approach to be effective in improving welfare, higher weight should be given to fitness and welfare traits, a total merit should be calculated via selection index and selection should be based on total merit.

EU should urgently address the animal welfare issues in its breeding programmes to avoid public condemnation of breeding and management practices for dairy cows.

Management strategies to reduce the negative effect of metabolic stress should be developed and implemented. For example, reduced fertility resulting from long anestrus postpartum or low conception rate may be just consequences of cows coping with metabolic stress. Hormonal treatments used more and more, particularly in North America, to kick-start the reproductive cycle or to solve fertility problems may not be good solutions as they may further compromise cows' welfare by preventing them from using one of the few coping mechanisms left. Extended lactation is increasingly used to manage high yielding cows and it may represent a better strategy to manage low fertility in modern cows without additional welfare cost (see also chapter 16.2).

In order to improve the welfare and adaptability of dairy cows through long-term genetic selection, the cooperation of breeding experts, geneticists, epidemiologists, nutritionists, ethologists and others concerned with animal welfare problems is required. Sustainable breeding goals aimed at improving fitness and robustness are necessary to prevent the decrease in the quality of life of the animals and, perhaps, enhance it. The effectiveness of a selection program to improve welfare should be enhanced if selection acts directly on causes of poor welfare and not only on its symptoms. To implement such a program, research is needed to clarify the relationship between production, negative energy balance, metabolic stress and welfare indicators and to develop practical methods for measuring negative energy balance and metabolic stress. This research should identify traits directly related to welfare status, such as negative energy balance, body condition score, onset of cyclicity after calving, etc., and, ultimately, provide better selection tools to improve welfare status in dairy cows (Oltencu and Algers 2005).

4.5. Use of genetic engineering and novel breeding technologies in dairy cows

The different aspects of genetic engineering, cloning and transgenesis, and the impact that these technologies may have on the welfare of dairy cattle will be briefly discussed in this section.

4.5.1. Transgenesis

The first microinjection of genetic material in mammals was reported in 1966, but it took 15 years until Gordon et al. (1980) reported the first transgenic mice by microinjection. Two years later, Palmiter et al. (1982) produced the first transgenic mice growing twice than normal, and three years later the first transgenic livestock was reported (Hammer et al., 1985). This created enormous expectation about what could be done with transgenic animals, particularly in the field of animal production. In the last 25 years predictions about the future of transgenesis and genetic engineering have been invariably optimistic. However, few transgenic animals are now available. Quoting Maga et al. (2006) from the last World Congress on Genetics Applied to Animal Production, we have actually only two transgenic dairy cows currently available: Lysostaphin transgenic cows (Wall et al., 2005) with better resistance to mastitis and bovine κ - and β -casein transgenic cows (Brophy et al., 2003) with better milk composition.

For obtaining transgenic cows with better welfare, genes with major effects on the fitness traits should be found and transferred to animals with superior resistance to disease, tolerance to stress and other important functional traits. At least for now, transgenesis in dairy cattle is

inefficient, expensive, and risky, our knowledge of regulatory mechanisms is poor, few candidate genes with major effect are available for transferring, and much more knowledge about the genotype and gene interactions is needed before this technology can make a real and positive contribution to the welfare of dairy cows.

4.5.2. Cloning

Cloning has been practiced in dairy cattle in the last 30 years by splitting embryos. After the first animal cloned from somatic cells was produced, the popular sheep “Dolly” (Wilmut et al., 1997), new expectations appeared, since it was possible to generate clones of outstanding animals. However, nowadays there are no clones in the market, and somatic cloning is still restricted to experimental uses. Cloning from somatic cells can be used to repeat the genotype of valuable animals with the only exception of mitochondrial DNA. As transgenic animals have reproductive problems frequently, and they are often unique, cloning may also help in transferring the results of the expensive and inefficient transgenesis to the industry.

Commercial breeding companies see many potential benefits from cloning and have predicted that cloning will become a routine part of livestock breeding within 20 years. They suggest that cloning will serve a number of purposes such as the commercial development of disease resistant animals, improved feed conversion, greater muscle mass, and the production of milk of more consistent quality. Breed companies also see an application of cloning to evaluate the performance of animals of the same genetic make-up under different management systems and also in preserving the genome of both premium and rare breeds of animals.

It should be noted that the variability of most fitness traits relevant for welfare of dairy cows is mainly controlled by the environment. Heritabilities of traits associated with disease resistance, fertility or tolerance to stress are low, less than 20%, which means that more of the 80% of the variation is controlled by the environment. The consequence is that the excellence of a single animal in comparison with the other animals of the population is more probable due to environmental reasons than to genetic reasons, and the risk of having a clone with much lower welfare than the original animal is very high.

In 1998 the Farm Animals Welfare Council produced a “Report on the Implications of Cloning for the Welfare of Farmed Livestock” (FAWC, 1998) for the UK Government, which considered the welfare implications of the techniques involved and the regulatory controls which might be necessary. One overriding recommendation was that, until the problems of oversized offspring, embryonic and foetal losses and birth abnormalities, and the possibility of problems associated with aged DNA, have been satisfactorily resolved, there should be a moratorium on the use of cloning by nuclear transfer in commercial agricultural practice. It is sufficient to say that the main problems associated with cloning identified in 1998 report are still present.

The Scientific Committee of the European Food Safety Authority (EFSA) has recently adopted a Scientific Opinion about the cloning of food producing animals where welfare aspects have been also considered (EFSA, 2008).

4.5.3. Sexing of semen

This represents one technology that could have a significant positive impact on welfare of dairy cows. One undesirable consequence of selection for “dairy type” is a decreased economic value of bull calves. Provided that the technology is safe, sexed semen can be used

to reduce the number of unwanted dairy bull calves. A reasonable strategy might be to breed only as many cows in a herd with sexed semen as the number of replacements needed and breed the rest of the herd with semen from beef bulls of an appropriate size (see chapter 13).

5. Nutrition and major metabolic disorders in relation to welfare

5.1. Feed and feeding practices

Cows, like all adult cattle, are ruminants and have a digestive tract that is fundamentally different from that of omnivores. Their diet is composed mainly of plant stems and leaves that have high fibre (cell wall constituents) content. Fibre cannot be digested by mammalian enzymes. Ruminants overcome this problem through a symbiosis with protozoa, bacteria and fungi in their forestomachs and hindgut. The cows provide for the symbiosis the forestomach reticulorumen as a fermentation chamber with a carefully controlled microenvironment for the microbes. The host takes on the job of seeking feed, grinding it to increase the surface areas for microbial attack and maintaining acceptable pH conditions by volatile fatty acids (VFA) absorption and by a large production of buffering saliva. In return, microbes digest fibre by microbial fermentation and produce mainly short chain fatty acids (SCFA), such as acetate, propionate and butyrate, which can be used by the host. Lactic acid is produced only in small proportions, unless the pH of ruminal contents drops below 6.0.

In general, the diet of ruminants consists mainly of carbohydrates (> 70%) from fibre (hemicelluloses, celluloses and lignin) and non-fibre cell storage constituents (sugar and starch) (Figure 6). While microbial fermentation of carbohydrates from fibre is a relatively slow process, non fibre carbohydrates are easily and rapidly fermentable. During ruminal fermentation large amounts of SCFA are produced in particular when the diet contains high proportions of easily fermentable carbohydrates. Although SCFA are relatively weak acids there is a close correlation between the concentration of SCFA in ruminal fluid and the ruminal pH. To maintain an optimal pH in ruminal fluid for microbial fermentation SCFA are absorbed through the ruminal wall and leave the rumen into the intestinal tract via the reticulo-omasal orifice during normal digesta passage. Additionally the fibre content in the diet is a strong stimulus for rumination (regurgitation of digesta from the reticulorumen which is chewed and grinded and then re-swallowing). During rumination large amounts of saliva are produced, which have a high content of bicarbonate. The bicarbonate acts as a buffer in the ruminal fluid and contributes also essentially to maintenance of ruminal pH. A close correlation between chewing time during rumination and dietary fibre content is described.

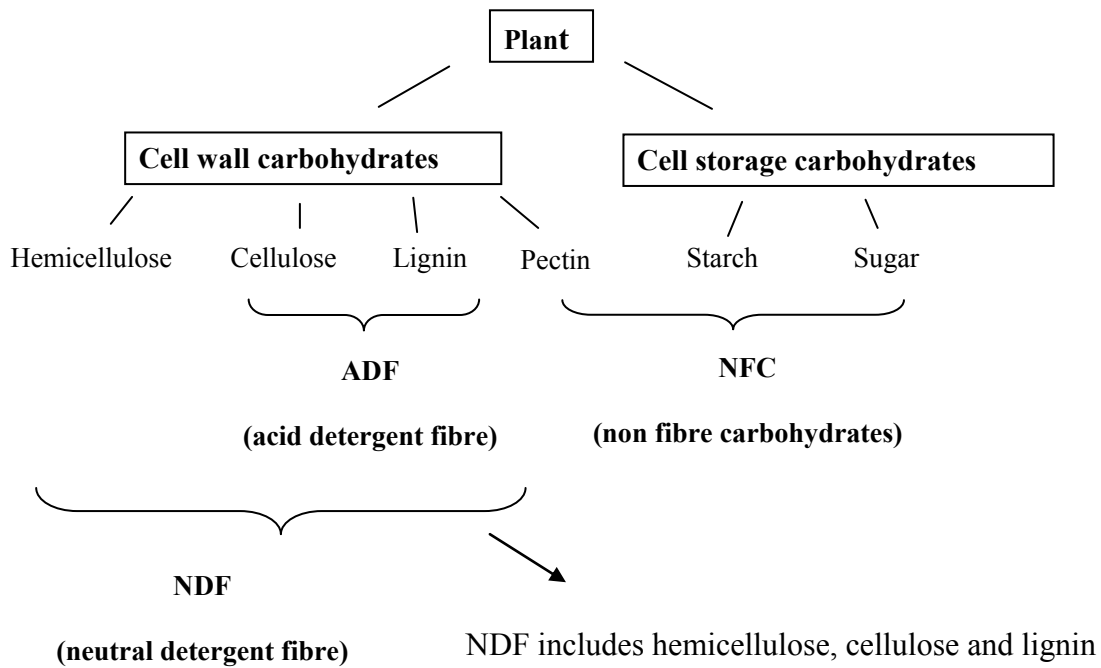


Figure 6 According to van Soest et al. (1991).

Microbial cells formed as a result of rumen digestion of carbohydrates under anaerobic conditions are a major source of proteins and vitamins for ruminants. Beside carbohydrates also protein is an important nutrient with a proportion of about 10-20% in the diet. The proportion of fat is mostly less than 3% in natural ruminant diets.

5.1.1. Feed stuffs used

Feeds are offered to ruminants either fresh or more commonly preserved after drying or as silage. Silage is material that is produced by controlled anaerobic fermentation of high moisture herbage. During fermentation lactic, acetic and few butyric acids are produced; thus the pH drops. Drying feed stuffs and the low pH in silage prevents the growth of harmful microorganisms in feed stuffs during storage.

5.1.2. Roughage

Forages and roughages are feed stuffs with a high proportion of neutral detergent fibre (NDF). Forages can be divided in two general categories: legumes and grasses. Legumes store also relatively high amounts of protein, in particular in their leaves, and can be a good source of vitamins. Grasses, however, have a wider geographical range than legumes. They can tolerate humid weather, severe cold weather, and poor soil better than legumes and can persist and maintain production with a low management level. Infrequently wheat and oats are used for production of cereal forages. Oat, barley and wheat straw are used to a small extent as high fibre roughages; rice straw is an important component of ruminant diets in many Asian areas.

The most important factor influencing nutritive value of forages is its stage of maturity at the harvest. As the plants mature, the relative amount of stem increases, and the relative amount of leaves decreases. Stems contain a higher percentage of fibre and a lower percentage of protein, soluble carbohydrates, vitamins, and minerals than do leaves.

A certain proportion of NDF in the diet of ruminants is of essential importance for normal ruminal function since the dietary fibre content is the strongest stimulus for rumination and thereby for saliva production and maintenance of ruminal pH. Different systems were developed for evaluation of the optimal fibre content in ruminant rations. Reviews on this subject were published recently (De Brabander et al., 2002; Plaizier et al., 2008).

Dietary NDF level

Dietary NDF level is an important component of ration formulation, both because it is generally associated with forages, which tend to have positive effects on rumen pH, and because its level is inversely related to the more fermentable NFC component of the diet. Dietary NDF alone, however, did not have a significant relationship with ruminal pH (Allen, 1997), probably due to variability in ruminal fermentability and particle size across forages and fibrous by-product feeds. A variety of systems have been proposed to estimate the minimum amount of fiber necessary in rations for lactating dairy cattle. These systems have generally attempted to guide ration formulation by predicting the amount of chewing that various feedstuffs would generate, or their relative effectiveness at maintaining milk fat percentage (Mertens, 2002). A new system, physically effective NDF (peNDF) attempts to relate the ability of a feedstuff to promote chewing relative to a hypothetical long grass hay corresponding to 100% physically effective NDF (4 hours of chewing activity per kg of hay) (Mertens, 1997). The peNDF system is of particular interest in this discussion since it more closely relates to ruminal pH than other proposed fiber systems. Indeed, the peNDF approach explained 71% of the variation in ruminal pH in published trials used to evaluate the system (Mertens, 1997). The peNDF of each feed is the product of the Physically Effective Fiber coefficient (pef) and NDF concentration. It was proposed (Mertens, 1997) that the pef of a given feedstuff could be either estimated from tabular values or determined by measuring the proportion of dried sample retained on vertically oscillating screens >1.18 mm. Ideally, the NDF concentration of this retained proportion would also be determined. The peNDF>1.18 of a feed would then be determined by either multiplying its tabular pef by the measured NDF level, or by multiplying the percent retained on screens greater than 1.18 mm by the NDF concentration of the sample or of this retained portion. The authors concluded that the diet should contain at least 22% peNDF>1.18 to maintain an average ruminal pH of 6.0 when using the wet sieving technique to determine pef values (Beauchemin et al., 2003).

Yang et al. (2001) determined peNDFps as the proportion of dry matter retained by the 8 and 19 mm screens of the Penn State Particle Separator, multiplied by total dietary NDF content. Absence of an effect of variation in peNDFps on rumen pH when this measure is >16.5% DM was demonstrated. However, feeding diets with a peNDFps of 12.5% dry matter or lower resulted in rumen pH indicative of sub acute ruminal acidosis (SARA) (Plaizier, 2004). These findings agree with Mertens (1997) who observed a curvilinear relationship between rumen pH and peNDF and the lack of an effect of dietary peNDF content on rumen pH in coarser diets. The limited relationship between peNDFps and rumen pH is also due to the multitude of animal and dietary factors other than peNDFps that affect rumen pH. Prominent among these

factors are forage source, concentrate source, acidogenic value of the feed, feeding frequency, and the inclusion of inorganic buffers (Mertens, 1997; Oetzel, 2003; Kleen et al., 2003; Stone, 2004; Rustomo et al., 2006c). Due to saliva contamination and diurnal variation in rumen pH, the monitoring of rumen pH by spot sampling is less accurate than continuous rumen pH measurement (Duffield et al., 2004; Alzahal et al., 2007). However, studies using continuous measurement of rumen pH have also not demonstrated significant effects of various measures of peNDF and forage particle size on rumen pH, despite increased chewing has been observed when peNDF was increased (Yang et al., 2001; Beauchemin et al., 2003; Bhandari et al., 2006; Rustomo et al., 2006; Yang and Beauchemin, 2006). Hence, peNDF might be a better indicator of chewing activity than of rumen pH (Yang and Beauchemin, 2006) and of acidogenic value of the feed (Rustomo et al., 2006a,b,c). This might be explained by the observation from Maekawa et al. (2002) that increased chewing did not sensibly increase daily saliva production, as increased chewing during eating and ruminating subsequently reduced saliva production during time periods when chewing activity was absent. Even when diets have been formulated to contain sufficient fiber and physically effective fiber, the feed eaten by the cows might not result in sufficient rumen buffering capacity due to sorting against long particles in favor of shorter particles (Calberry et al., 2003; Leonardi and Armentano, 2003). Furthermore, errors in mixing the diet, differences between the assumed and the real dry matter contents of the forages and excess mixing of the diet resulting in excessive chopping up the coarse feed particles, which can result in diets with a lower than expected peNDF contents (Kleen et al., 2003; Oetzel, 2003; Stone, 2004).

The clearance of acids from the rumen is affected by the size and density of the rumen papillae, as these determine how fast these acids can be absorbed (Van Soest, 1994). A reduction in absorption, e.g. by inflammation or parakeratosis of the rumen wall due to low rumen pH, puts cows at increased risk of SARA. Freshly calved cows are also at a higher risk of SARA compared to cows in mid and late lactation, as the ruminal absorption capacity for acids due to a reduction in the length and density of rumen papillae can decrease by 50% during the dry period (Dirksen et al., 1985). It will take several weeks for this capacity to be restored after high concentrate diets are reintroduced, possibly due to the increased concentration (and absorption) of VFA, especially butyrate (Dirksen et al., 1985). Reynolds et al. (2004) also found that the rumen papillae mass was greater at 10 and 22 days after calving compared to 7 and 21 days before calving, but observed that this mass did not differ between 10 and 22 days after calving. This increase in rumen papillae mass might explain why rumen pH can increase during the first 3 weeks after calving despite increased feed intake (Fairfield et al., 2007).

5.1.2.1. Concentrate

Concentrates are feed stuffs rich in non fibre storage carbohydrates (sugar and starch or NSC); their high energy content can be due to high digestible fibre (i.e. beet and citrus pulps, milling by products etc.), which are also rich in pectin

Concentrate can also be rich in protein (protein concentrates, >20% crude protein of plant or animal origin) or in protein and fats (i.e. oil seeds: whole cotton seeds, whole soybean seeds etc.). Their chemical and nutritional features can be obtained by Beyer et al. (2003) or Sauvart et al. (2004).

High energy concentrates are cereals and their by-products contain starch that is fermented in rumen. The fermentation rate can be quite different according to:

- chemical reasons: amilopectin more than amylose;
- physical conditions: less mature and moist more than mature and dry kernels;
- physic-thermo-mechanical treatments: extruded and steam-flaked more than flour, more than rolled.

This must be taken into account when the fermentation effects into the rumen have to be foreseen. In general, wheat is more fermentable than barley and barely more than maize and sorghum; the last two are more susceptible to the effects of treatments.

Other by-products are considered energy sources: such as almond hulls, apple pomace, citrus pulp, cocoa meal, dried bakery, beet pulp, brewers' and distillers' grain. They are generally well fermented, though at a slower rate. The final metabolites are VFA and not lactic acid (safer for rumen). Very few feed-stuffs are rich in sugars (molasses and milk whey) and their fermentation rate is extremely high.

Protein concentrates are derived from oil seeds (soybean meal, canola meal, sunflower meal, flax cake, cotton meal) or can be legume seed (faba bean, peas). Some cereal by-products can be rich in protein: brewers' dried grains, corn gluten meal, wheat or corn germ meal etc.. Before the BSE problem, some animal by-products were also used: meat meal, meat and bone meal, blood meal, fish meal etc.; nowadays they are only allowed for non ruminant nutrition.

For ruminants, some non-protein sources of nitrogen are also used (urea, ammonia salts) because they release ammonia and which can be utilised by rumen microbes for their amino acid and protein synthesis (if this release is gradual).

The true feed proteins can be characterised according to their rumen degradability (entity and rate) and, for the undegradable part, for their digestibility and aminoacid composition. The degradable part and its rate can be different according to:

- chemical composition: prolamins are less degradable than albumins and globulins;
- plant anatomy: proteins of fresh-green leaves are more degradable than protein of seeds;
- storage technique: silage more than hays;
- thermo-chemical treatments: heat (particularly above 130 °C) or some chemicals like formaldehyde tend to reduce rumen degradability.

In some cases, oil seeds are utilised as such (e.g. cottonseed) or simply thermo-mechanically treated (e.g. flaked soybean). They are both rich in protein (more than 20 and 30% respectively) and energy for the high fat content (approximately 20% and largely protected from rumen bio-hydrogenation, particularly the cottonseed). Some cottonseed (2-3 kg/d in dairy cows to avoid negative effects of gossypol) can be also useful for high yielding cows for his high content of fibre of good digestibility.

5.1.2.2. Feed supplements

Fat: Commonly the fat proportion is low in dairy rations. However small amounts of fats are often supplemented in order to increase the energy density of the diet or specific fatty acids are used as functional feed to modify metabolism, immune function or reproduction performance. Since dietary fats have a negative effect on ruminal fermentation when proportions of more than 5% are exceeded, fats need to be protected to allow ruminal bypass.

Unfortunately the processes of protection are found to be not very effective. Sources for fat supplements are animal products (e.g. tallow), marine products (algae, fish oil) or grains (e.g. linseed oil, cottonseed). While tallow contains mostly saturated fatty acids (C16, C18), unsaturated fatty acids are found in vegetable oils (e.g. linseed oil: C18:3n3; sunflower oil: C18:2n6) or marine products (rich in long chain poly unsaturated omega 3 fatty acids). However, since ruminal protection of dietary fats is mostly incomplete large proportions of unsaturated fatty acids are saturated during the normal ruminal biohydrogenation process and are only partly available for the animals.

5.1.2.3. Minerals and vitamins

The amount of macro minerals (calcium, magnesium, phosphorus and sodium), trace elements (e.g. selenium, copper, zinc, manganese, iron, iodine, cobalt) and vitamins (e.g. vitamin E, vitamin D, vitamin A or its precursor β -carotene) can vary substantially in dairy rations due to feed stuffs used for ration composition, time of harvesting, soil quality and preservation processes. Dairy rations commonly need supplementation of minerals, trace elements and vitamins in order to meet the minimum requirements. Dietary components can be analysed for minerals, trace elements and vitamins to allow a specific adjustment for these dietary components or they are supplemented on a general basis in fixed amounts which are commonly necessary. For monitoring trace element (namely Se, I, Cu, and Zn) and vitamin (namely E and A) status, blood and tissue samples can be taken from the cows. According to test results supplementation can be adjusted.

Macro minerals are supplemented commonly as inorganic minerals, while for trace elements inorganic or organic supplements are used. The supplementation of some macro-minerals: sodium as bicarbonate, calcium as carbonate and magnesium as oxide, can be utilised above specific requirements for their buffer capacity (rumen or intestine) when high fermentable diets are used.

There are many guidelines and recommendations for feeding dairy cows from national research councils (NRC 2001) to support farmers in the formulation of optimal dietary rations which meet requirements for fibre, energy and protein and also in minerals, trace elements and vitamins. This information is easily available for farmers in all member states.

5.1.3. Feeding practices

Since cows are commonly in negative energy balance during early lactation maximizing dry matter intake is one of the key issues in dairy cow feeding around calving and during early and mid lactation. Thus feed must be available and easy access is of essential importance at all times of the day to achieve maximal DMI. Diets need to be well balanced to provide enough energy and protein to meet requirements and sufficient physically effective fibre for maintaining good ruminal fermentation.

In the past, feeding different feed components of a ration separately to dairy cows (component feeding) was common. The major disadvantage of this feeding regime is that components are not necessarily fed simultaneously. When high yielding cows are fed forages with high amounts of NDF and concentrates with easily fermentable NFC, it is difficult to maintain a stable ruminal pH particularly if the number and size of concentrate meals is not properly established. The cows tend to introduce more concentrates under this feeding regime at the expense of forages. Thus, component feeding bears a very high risk of sub acute ruminal acidosis (SARA) and is therefore replaced nearly completely by so called mixed rations.

Component feeding is still exceptionally seen in small (often tie) farms where wagon is not convenient.

For mixed rations either all feed components (concentrates, roughages, feed supplements and mineral and vitamin mixes; total mixed ration) or all feed stuffs except the concentrates (partly mixed rations) are mixed. Mixing of feed components according to the dietary calculation can be done precisely with mixer-feeder wagons. In order to ensure complete mixing and a stable mixture of forages, concentrates and supplemental feeds, which vary substantially in particle size, forages need to be chopped to about 18mm. In particular when particle size of forages is too long feed components may separate again in the feed bunk and cows are able to select and sort out preferred feed stuffs predominantly concentrates of high palatability. Rations are mixed commonly from fresh feed stuffs and offered to cows up to three times a day. Good maintenance of feeder-mixing wagons is of crucial importance for a precise mixing of feed stuffs according to the formulation. A water content of 40-50% must be also ensured to optimise the mixture uniformity and to reduce sorting.

When some concentrate is fed separately to mixed ration, it is sometimes, with computer control, offered to cows in many small portions throughout the day in order to avoid considerable changes in ruminal pH, due to an overload with rapidly fermentable NFC. Cows are individually recognised at the concentrate feeding station by transponders which are carried either as ear tags or as a necklace. When transponder concentrate feeding is used a sufficient number of feeding stations is necessary to allow all cows easy access without stress or prolonged waiting periods. In high yielding cows offering concentrates only twice daily during milking is seen only exceptionally since ingestion of large amounts NFC from concentrates (more than 2.0-2.5 kg/meal) will lead to an immediate and considerable drop in ruminal pH and thus poses a high risk of SARA.

To maximise feed intake, feed must be available for dairy cows 24 hours a day. Before fresh feed is offered, the feeding trough is cleaned. Enough feeding places and sufficient space at the trough (not less than 60 cm/head as suggested by De Vries et al., 2004) is important to allow stress free access at all times of the day, in particular when fresh feed is offered. Since cows are kept in confinement during the day, feeds need to be pushed up several times over the day, otherwise the remainder of the diet might get out of their range (see also section 6.1.2 “feeding area”).

In recent years feeding cows only on pasture is getting increasingly uncommon for different reasons. One reason is to protect cows from adverse weather conditions (heat, cold, rain, storm). Another reason is that a second cost intensive mobile or stationary milking parlour is necessary on pasture when the distance between the stall with the milking parlour and the pasture is too long for daily walking. When the stall is within a walking distance to pasture, cows may have to walk several kilometers, in particular when in large dairy herds. Long walks on a hard or even rough surface may contribute to overload to claws and thereby to the development of claw diseases (see also chapter 9 “lameness”). But the main reason is that the nutritional value of grass is under constant change over the season and therefore difficult to evaluate. In particular for high yielding cows it is very difficult to calculate a well balanced ration when there is a high uncertainty about the nutritional value of one of the major feed components. Thus, many farmers prefer to feed cows with preserved feed stuffs which nutritional values are known from analysis or available feeding tables. This allows a more reliable ration calculation. In consequence many dairy cows are kept either year round indoors or have daily access to pasture for a restricted period of time (commonly a few hours) in order to allow cows some exercise and to expose cows to external stimuli (see also section 6.8). In other countries, e.g. Sweden, farmers with milking robots leave the door open between the

pasture and the barn so that cows can themselves choose to go indoors and eat the total mixed ration (and be milked) and then go out again and graze.

5.2. Water

5.2.1. Introduction

Water of sufficient amount and quality is very important for high producing dairy cows. At the same time it is known that water can be an important distributor of infectious diseases. More over it can carry chemical compounds and toxic substances. Presently there are no general legal regulations which define the quality of the drinking water for animals in EU. However, some rules and criteria exist in some countries which are designed to help to secure the water supply and quality of animals on farm level. When controlling the hygienic quality of water on the farm it is necessary to investigate not only the water itself but also the local facilities around the water well. If health problems occur in the stock the water tanks, the tubing system which distributes the water on the farm and in the animal houses and the drinkers has to be checked for leaks, and damages. Water samples for the analysis on microorganisms and chemical contaminants should be taken according to strict protocols. In Germany for example the regulations of the drinking water directive for humans is recommended as an orientation to characterise the drinking water quality for food delivering animals. In future it seems useful to elaborate animal species specific rules in order to avoid damage to the animals and contamination of the meat and milk. A proposal for some threshold values is reported below.

5.2.2. Amount of water needed for maintenance and production

The water consumption of dairy cows is influenced by a variety of factors such as season (temperature and humidity of the ambient air), production level and status of pregnancy, exercise and water and mineral content of the feed. Table 2 gives some figures on the amounts of drinking water which should be provided to dry and high yielding milking cows. The consumption can vary between 30 and 120 litres per day (Beede, 1999).

Table 2 Water intake (l/day) of dairy cows with a body weight of 630 kg in relation to milk production and ambient temperature (after Wurm and Pichler 2006).

Milk yield	Temperature		
kg/day	5 C	15 C	28 C
dry	37	46	62
9	46	55	68
27	84	99	94
36	103	121	147
45	122	143	174

5.2.3. Access to water (indoors and outdoors, summer and winter), water temperature

Cows prefer clean and tasty water. Water with strong odours and a high content of iron are avoided or the water uptake is reduced to a minimum which influences their well-being and milk production. Water with temperatures around 20 C° is preferred (Beede, 1999).

Permanent access to water has to be provided both in indoor as well as outdoor systems. Automatic regulated troughs and drinker cups should be installed in the animal houses and farm yards. On pasture tank wagons can make sure that the cows have access to water. This

water should be replaced at least every three days – particularly in summer – in order to avoid excessive microbial growth.

5.2.4. Water quality

Water quality is defined by its sensory, physical, chemical and microbiological properties. Useful limits for chemical compounds can be adopted from the drinking water regulations for humans. Water quality is classified on the basis of the “total dissolved solids” content, namely the combined content of all inorganic and organic substances contained in a liquid. In a document on water nutrition and quality, Beede (1993) reported a guide on the use of saline water for dairy cattle based on Total Dissolved solids values (Table 3). In addition, drinking water has to be free from toxic compounds and infectious agents, such as, various parasites (Dauguschies 2000, Karanis 2000), bacteria, fungi and viruses (Böhm, 2000).

Table 3: Guide to use of saline waters for dairy cattle; total dissolved solids equals TDS.

TDS (mg/l or PPM)	Comment
less than 1000 (fresh water)	Presents no serious burden to livestock.
1000-2999 (slightly saline)	Should not effect health or performance, but may cause temporary mild diarrhea.
3000-4999 (mod. saline)	Generally satisfactory, but may cause diarrhea especially upon initial consumption.
5000-6999 (saline)	Can be used with reasonable safety for adult ruminants. Should be avoided for pregnant animals and baby calves.
7000-10000 (very saline)	Should be avoided if possible. Pregnant, lactating, stressed or young animals can be affected negatively.
over 10000 (nearing brine)	Unsafe. Should not be used under any conditions.

5.3. Chemical and microbiological agents and toxic plants

Feedstuffs are not always as wholesome as supposed they are to be. For different reasons they could contain natural toxic compounds or could be joined by external toxic substances (chemical contamination or biological contamination). Furthermore, they could be contaminated by biological material potential cause of diseases: e.g. parasites, salmonella, *Listeria*, BSE prion etc.

Natural toxic compounds are alkaloids (*Datura stramonium*, larkspur, tall fescue), condensed tannins (blackbrush), glucosinolate (brassica crops), coumarins (fenugreek), anthraquinones (sacahuiste), cyanide glucoside like durrin in young sorghum plants and many others. In general, the whole plant, the leaves or the seeds (castor bean) which cause malaise or feelings of physical discomfort are not desirable. Animals may acquire aversion from mother and peers, and their own experience as well (Provenza, 1995). Therefore some

negative effect, and sometime death, can occur when animals are placed to graze in unfamiliar environments, if poisonous plants are present; furthermore in case of scarce pasture grass, sometime due to overstocking, the hungry animals are forced to consume “unusual” plants (Sundlof, 1999).

In case of intensive systems, some unintentional contamination of “processed” feeds can also occur: e.g. hay or silage contaminated of weeds like foxgloves (*Digitalis purpurea*) or ragwort (*Senecium*), grains of maize or soybean containing seeds of toxic plants if weed control was inadequate (i.e. *Datura stramonium* and *Crotalaria*).

A further aspect to be considered is the possibility of usually safe chemicals which can occur in plants at higher – sometime toxic – levels. This can occur with some peculiar soil (too high Se, Mo, Cu nitrates) or some physiological conditions of plants (durrin in young sorghum, saponins and phytoestrogens like ginsteine in young alfalfa). This suggests of course a proper management of their utilization, as needed in case of feedstuffs containing low levels of poisonous compounds, “safe” when the intake does not exceed a certain amount (i.e. cotton seeds for their gossypol content).

In order to limit the above mentioned risks for poisonous feeds causing discomfort, lower performance and fertility and sometimes even death, there is a need for proper care of pastures, of forage and crops cultivation, and grain utilization to avoid toxic inconveniences as much as possible (Sundlof, 1999).

Chemical contamination of plants or seeds is another possible cause of feed toxicity. The most common chemicals are pesticides utilised to protect the same plant-feeds or the surrounding trees (i.e. for fruits) where animals are grazing. Particularly in the past, some insecticides were utilised to protect grains from spoiling insects. Some contamination was observed in areas with high concentration of polluting industries (for instance, a case of fluoride poisoning in the animal feed forage coming from land close to tile factories). Apart from some unpredictable accidents, these kinds of poison risks are nowadays very rare or at least in EU.

A different type of chemical contamination, due to microorganisms growing on feedstuffs, is much more common and dangerous. These microorganisms are in general fungi or bacteria. Mycotoxins are secondary metabolites secreted by various molds such as *Aspergillus*, *Penicillium* and *Fusarium* (*Claviceps*, *Epichloe*, *Neotyphodium* and *Stachybotry* can also produce mycotoxins). They are synthesised during the production, transport and storage of feedstuffs in certain environmental conditions typical for different molds. 25 to 45% of the cereals and cereal products produced worldwide are contaminated by detectable levels of nearly 300 potentially toxic metabolites secreted by moulds. Mycotoxins can increase the incidence of disease and reduce production efficiency in cattle. Mycotoxins can be the primary agent causing acute health or production problems in a dairy herd, but more likely, mycotoxins are a factor contributing to chronic problems including a higher incidence of disease, poor reproductive performance or suboptimal milk production. They exert effects through four primary mechanisms: 1) intake reduction or feed refusal, 2) reduced nutrient absorption and impaired metabolism; 3) alterations in the endocrine and exocrine systems; and 4) suppression of the immune system. Recognition of the impact of mycotoxins on animal production has been limited by the difficulty of diagnosis. The difficulty of diagnosis is increased due to limited research, occurrence of multiple mycotoxins, non-uniform distribution, interactions with other factors and problem of sampling and analysis (Whitlow and Hagler, 1995).

Symptoms of a mycotoxicosis in dairy herd vary depending on the mycotoxins involved and their interactions with other stress factors. The more stressed cows, such as fresh cows, are most affected, perhaps because their immune systems are already suppressed. Symptoms of mycotoxins may be nonspecific and wide ranging. They may include: reduced production, reduced feed consumption, intermittent diarrhoea (sometimes with bloody or dark manure), reduced feed intake, unthriftiness, rough hair coat, reduced reproductive performance including irregular estrus cycles, embryonic mortalities, pregnant cows showing estrus, and decreased conception rates. There is generally an increase in incidence of disease, such as displaced abomasum, ketosis, retained placenta, metritis, mastitis, and fatty livers (Whitlow, 2005).

Grain for dairy nutrition is commonly preserved by drying (88% dry matter). Grass, lucerne or maize are preserved as silage thanks to lowering of pH levels below 4.5 by anaerobic fermentation. The environmental conditions in preserved feed stuffs allow considerable fungal growth when the drying process of grain is incomplete or the pH in wet silage is above 4.5. Fungal growth can also occur before harvesting of feed plants. Adverse effects of considerable fungal contamination are due to loss of nutritive value of feed stuffs, reduced palatability and thereby reduced feed intake or are related to produced mycotoxins (Radostits et al., 2007).

A quite recent review on toxicity and metabolism of the most common and dangerous mycotoxins has been given by Hussein and Brasel (2001) and by Whitlow and Hagler (2004). They are aflatoxin, deoxynivalenol (DON), Zearalenone, T₂ toxin, fumonisin and ochratoxin; their effects can be acute or chronic according to the dosage, but monogastrics are generally more susceptible (rumen is often a factor of their degradation). Unfortunately some animal products, particularly aflatoxin in milk but also meat (namely for ochratoxins), can contain dangerous levels of these mycotoxins. Particularly for aflatoxin (AFB₁, B₂, G₁ and G₂), the maximum allowed level in milk (50 ppt as M₁ in Europe) can be reached with feed contents (20 ppb) much lower than those risky for cow health (above 100 ppb).

To reduce the above mentioned problems, special care must be used and cows should receive the cleanest feed possible (Whitlow, 2005)

Aflatoxins are found on many spoiled feeds, e.g. peanuts, cottonseed meal, sorghum grain, corn, moldy bread or sometimes on standing crop. Aflatoxins are hepatotoxic and may also affect hemostasis. Also reduced feed intake and milk yield are observed. Calves at an age of 3 to 6 months are most susceptible (Robens and Richards, 1992; Pitt, 1994; Ramos and Hernandez, 1997; Park and Price, 2001).

Ochratoxin A is the most potent isocoumarin mycotoxin. It is a very powerful renal toxin associated with organellar damage, in particular epithelial cells. However, animal feeds should not be used when ochratoxin levels exceed 2ppb (Ewald et al., 1991; Marquardt and Fröhlich, 1992; Creppy et al., 1996).

It is important to remember that pasture plants can be affected as well. The “fescue toxicity” is more commonly known due to some alkaloids (ergovaline or ergotamine) contained in the sclerotia of *Neotyphodium* or of *Epichloe* which infect the plants of fescue. This mycotoxicoses cause nervous or gangrenous problems, but also lower performance and reproduction failure (Whitlow and Hagler, 2004). Another fungus causing ergotism is *Claviceps purpurea* which under natural conditions infests cereal rye, and less commonly other cereals and many grasses. Ingestion of large quantities of seed heads infested with sclerotia (ergots) is associated with ergotism. Ergotoxins include among others ergotamine, ergotoxine and ergometrine and their metabolites from ruminal fermentation. Ergotism occurs commonly

in stall fed cattle on heavily contaminated grain. Ergot contamination can be identified easily by macroscopical examination of fed grain. Ergot-infested pasture may be associated with the disease, and the toxicity is preserved through the ensiling process. Ergotoxins are potent vasoactive peptide alkaloids. Classical clinical signs of ergotism in cattle are gangrene of the extremities. Ergotism may also be expressed as the hyperthermia syndrome and by reproductive failure, abortion and increased post natal mortality. Also reduced feed intake and milk yield are seen (van Heeswijk et al., 1992; Rowan, 1993; Bourke 1994).

Not only cultivation, but also proper storage conditions are important: low moisture content or antimold treatments (i.e. propionic acid). Finally, the diet with “high” mycotoxin content can be safer with some chemical absorbants: active clays, activated carbon etc.

Besides fungi, toxic cyanobacteria, or blue-green algae are known; they arrive from dense blooms on still fresh water in lakes, ponds, billabongs and lagoons. The toxins produced can be classified as either hepato- or neurotoxic. Drinking from contaminated water will lead within a few minutes to severe clinical signs, such as sudden death, muscle tremor, stupor, increased salivation, staggering, and recumbency. In the less acute hepatotoxic cases jaundice, photosensitisation and recumbency are common (Chorus and Bartram, 1999).

Finally bacteria can be responsible of “chemical contamination” of feed-stuffs; it is the case of bad fermented silages, but a well known risk is that of botulism. Botulism is an intoxication caused by ingestion of feed or water contaminated with the toxin of *Clostridium botulinum*. In cattle, intoxication usually results from the ingestion of feed containing preformed type C or D toxin, either in feed which has been contaminated with toxin-containing carcasses (Galey et al., 2000) or in feed in which there has been primary multiplication of *C. botulinum* and toxin production (Hofmann, 1999; Livesey et al., 2004; Braun et al., 2005; Druce, 2006; Otter et al., 2006). In particular haylage or grass silage contaminated by the botulinum toxin appears to be of high risk when fermentation fails to produce enough acid to lower the pH to 4.5, the pH below which *C. botulinum* growth is inhibited (Kelch et al., 2000; Martin, 2003). Outbreaks of botulism have been reported repeatedly in cattle with contact to poultry litter. In affected herds death rates of 50% and more were observed (Jean et al., 1995; Ortolani et al., 1997; Livesey et al., 2004; Otter, et al., 2006; Sharpe et al., 2008). The mean toxic dose (MTD50) of botulinum toxin was calculated at 0.388 ng/kg body weight which is in comparison to the mouse lethal dose (3.88 mg/kg) extremely low (Moeller et al., 2003).

The initial signs of botulism are progressive difficulty in chewing and swallowing, caused by paralysis of the tongue and muscles of mastication. This results in slow prehension and chewing of feed, water and feed falling out of the mouth, excessive salivation and weakness of the tongue. After 1 to 3 days, generalised paralysis occurs followed by death due to respiratory paralysis. Intravenous fluid therapy is the recommended treatment. The administration of antiserum is of limited value in advanced stages and is used mainly as a prophylactic measure in cattle herds in which an outbreak has just started. Active immunisation of cattle in high-risk herds is also an option (Brown et al., 1999; Steinman et al., 2007). It is critical that cattle not be fed feed contaminated with soil or carcasses (Braun et al., 2005).

Although botulism is commonly seen as intoxication with severe clinical signs Boehnel et al. (2001) hypothesised that long-lasting absorption of low quantities of botulinum toxin may interfere with the neurological control of intestinal physiology. The authors concluded this assumption from a field study in northern parts of Germany. Observed symptoms were indigestion (constipation alternating with diarrhoea), non-infectious chronic laminitis,

engorged veins, oedemas, retracted abdomen, emaciation and apathy. Most cases occurred during the periparturient period and often resulted in unexpected death. In addition, there are findings of delayed growth and wasting in heifers, as well as decreasing milk yield. Bioassays for *Clostridium botulinum*, its spores and toxins in animals of affected farms revealed the presence of free botulinum toxin in the contents of the lower sections of the intestine. In two control farms without signs of the disease, the tests remained negative. The authors proposed to name this disease complex 'visceral botulism'.

Biological contamination. The most common situation of contaminated feeds – particularly for ruminant – can be the silage making; nevertheless, not for the usual and useful LAB, but for some undesirable bacteria: *Listeria monocytogenes*. *Listeria* is a gram+, non sporulating, aerobe-anaerobe, ubiquitous. It is present in the soil and can contaminate forage where it can grow in not well sealed and acidified silage. Optimal growth occurs at temperatures of 30 to 37°C, but the organism can grow and reproduce between -1 and 45°C. It can grow at pH 4.5 and 9. Commonly, listeriosis leads to encephalitis, with facialis paresis, salivation, disturbances of acid-base and electrolyte balance, walking in circles, and recumbency. Mostly only single or a few animals are affected, but incidence rates of 10 – 15% are also reported. Despite antibiotic treatment and correction of acid base alteration case fatality is about 30 to 50%. Less commonly abortion, mastitis, septicaemia, uveitis, or conjunctivitis are seen (Farber and Peterkin, 1991; Low and Donachie, 1997; Fenlon and Wilson, 1998).

Other bacteria causing diseases, particularly in young ruminants and coming from contaminated feeds, are Salmonellae, etc.

Finally, some parasites can be also uptaken with contaminated pastures; for example *Fasciola hepatica*, cause of liver damages.

5.4. Metabolic disorders in relation to production pressure

5.4.1. Lipomobilisation Syndrome

Over the last decade's intense genetic selection, improved nutrition and better cow management increased significantly annual milk yield of Holstein-Friesian (HF) dairy cows. Unfortunately, the increase in the genetic merit for milk yield is only partly compensated by an increase in maximal feed intake (Veerkamp et al., 2000). Thus, a prolonged negative energy balance (NEB) is a common feature in high yielding fresh cows due to a high initial milk yield in face of slow increase of dry matter intake. In order to adjust to the imbalance in nutritional energy intake and energy expenditure for maintenance and milk yield, low plasma concentrations of insulin, IGF-1 and thyroxin and high plasma levels of glucagon, growth hormone and cortisol allow increased hepatic gluconeogenesis and mobilization of lipids and protein from adipose and muscular tissues, respectively. In consequence high plasma levels of nonesterified fatty acids (NEFA) released from adipose tissue are measured in cows during early lactation (Baumann and Currie, 1980; Hart, 1983; Vernon and Sasaki, 1991; Ingvarthsen and Andersen, 2000).

During episodes of excessive lipomobilisation fatty liver and ketosis develop when the hepatic availability of lipogenic and glucogenic products is imbalanced. Thereby the hepatic capacity for complete oxidation of fatty acids is exceeded and hepatic metabolism of NEFA is directed alternatively towards formation of ketone bodies (beta-hydroxybutyrate, acet-acetate, and acetone) or re-esterification of NEFA to triacylglycerol (TAG) (Drackley, 1998). Excess hepatic lipids are stored as TAG in the liver tissue (fatty liver; Katoh, 2002; van Knegsel et

al., 2005). Fatty liver peaks immediately after delivery, remain more or less constant in the first weeks post partum and start to decline at about six weeks of lactation when energy balance is about zero or starts to become positive (Grummer et al., 1993; Drackley, 1999). Ketosis occurs predominately in the first month of lactation and has the highest incidence in about the third week of lactation.

Subclinical ketosis is assumed when beta-hydroxybutyrate level in plasma exceed 1,200 $\mu\text{mol/l}$. Lactational incidence rates of subclinical ketosis vary between 10 and 25% between herds. During episodes of subclinical ketosis milk yield and fertility is reduced. Subclinical ketosis may change into clinical ketosis. In case of clinical ketosis cows are off feed and appear depressed or in some cases show nervous symptoms. About 5% of dairy cows develop signs of clinical ketosis (Herdt, 2000).

Approximately 25% of dairy cows develop severe ($> 100\text{mg TAG/g FW}$) and 35% moderate ($50 - 100\text{mg TAG/g FW}$) fatty liver (Jorritsma et al., 2002).

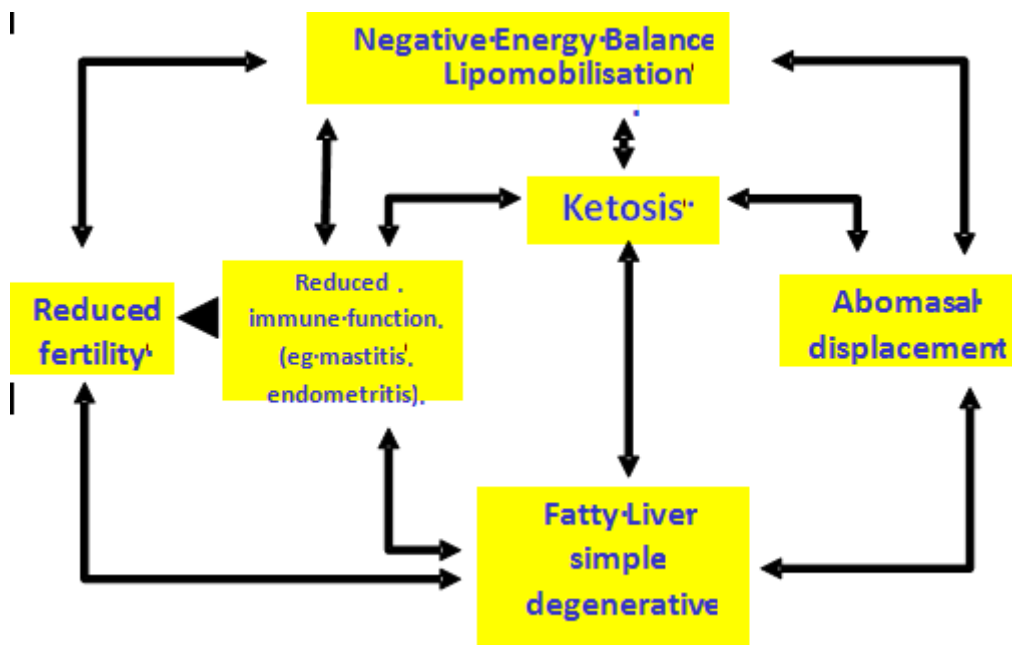


Figure 7 Causes and effects of the Lipomobilisation Syndrome (adapted from: Dohoo & Martin, 1984; Grohn et al, 1989; Correa et al, 1993 Duffield, 1997)

Negative energy balance, excessive lipomobilisation, ketosis, and fatty liver are associated with reduced reproductive performance, increased risk for abomasal displacement, and reduced immune competence and thereby with increased susceptibility for infectious diseases (Gerloff et al., 1986; Geishauser et al., 1996; Wensing et al., 1997; Zerbe et al., 2000; Bobe et al., 2004). The accumulation of fat in liver tissue is the major risk factor for acute liver failure. However, acute liver failure seems to occur only infrequently. Other factors such as increased oxidative stress in hepatic tissue due to low dietary Vitamin E and Selenium content in combination with high proportions of polyunsaturated fatty acids in the diet or concurrent septicaemic diseases (mastitis, endometritis) may also contribute to the development of acute hepatic failure (Mudron et al., 1999). Since negative energy balance and excessive

lipomobilisation are closely related to each other and to the above mentioned health disorders, the whole complex is also called lipomobilisation syndrome. The lipomobilisation syndrome during early lactation is one of the major risk factors for decreased average life time in cows (Drackley, 1999; Bobe et al., 2004).

During the dry period appropriate restriction of energy intake is the most important prevention measure in order to avoid overconditioning and obesity at the time of delivery. Obesity is associated with insulin resistance and will make cows prone to excessive lipomobilisation. Additionally, milk fever, dystocia, retained placenta, endometritis and abomasal displacement are seen frequently in obese cows, leading to reduced feed intake and enhanced negative energy balance. Obesity may also provoke reduced rumen capacity due to fat accumulation (Garnsworthy and Topps, 1982).

In contrast to dry cow rations, lactation diets are considerably higher in energy density and contain commonly high amounts of easily fermentable carbohydrates. Abrupt changes in diet formulation from the dry to the lactation period need to be avoided to minimise rumen disorders and the drop of feed intake around calving, which will already enhance lipomobilisation. Thus, the ration in the close-up dry period (last 8-10 days) should already contain the same feed stuffs as the future lactation diet (but much lower energy concentration). This will prepare the ruminal environment for optimal fermentation during lactation. The efficacy of this steam feeding during the few days prior to calving is discussed controversially in terms of prevention of lipomobilization post calving. Instead of steam feeding it appears more important to prevent the drop in feed intake around calving by optimizing housing and feeding conditions, such as, sufficient bunk space, ad lib feeding, high quality diet of excellent acceptance, avoidance of social and heat stress and overcrowding of dry lot pens, easily accessible water; etc. (Grummer, 2007).

Feeding early lactating cows balanced rations which meet energy requirements and provide sufficient amounts of fiber in order to avoid subclinical ruminal acidosis is an essential precondition in the prevention of the lipomobilisation syndrome, and is currently the greatest challenge in dairy cow management. Since formulation of well balanced diets limit energy density to about 7.4 MJ NEL/kg DM energy requirements of fresh dairy cows can only be met when all management tools available are used to maximise feed intake. Thus, only feed stuffs of excellent quality and palatability should be offered and enough bunk space and intensive bunk management will allow cows to maximise feed intake and thereby to minimise negative energy balance during early lactation (Drackley, 1999; Kleen et al., 2003; Vernon, 2005).

Effective prevention of milk fever and early and resolute treatment of all diseases which commonly go along with ketosis and fatty liver, such as abomasal displacement, mastitis, metritis, and lameness are required (Bobe et al., 2004). Reduction of inflammatory conditions seems also important to attenuate DMI reduction at calving and to accelerate its increase in early lactation (Bertoni et al., 2008). Thus, an intensive health monitoring system must be available on dairy farm. Avoiding social and environmental stress and provision of clean and comfortable housing conditions, regular exercise opportunities and good microclimate conditions are also important disease prevention measures (Drackley, 1999). Drenching propylenglycol, oral administration of glycerol or sodium or calcium propionate and provision of sufficient amounts of antioxidative substances in the diet reduce the frequency of disorders (Grummer, 1993, Abd Ellah et al., 2004, Bobe et al., 2004).

Efficacy of fat supplements to the ration of dry or lactating cows is controversially discussed (Grummer, 1993, Drackley, 1999, Bobe et al., 2004, Vernon, 2005, Van Knegsel et al., 2005).

Some studies suggest that fat supplementation could reduce NEFA concentration and help to prevent ketosis (Kronfeld, 1982). Some other studies indicate that fat supplementation increases NEFA and liver lipid content (Grummer, 1993), perhaps because fat administration in periparturient period tend to decrease DMI and milk production (Pickett et al., 2003). Other studies have showed that the addition of animal fat (tallow) at the end of the pregnancy led to an improvement in lipid metabolism in the early stages of lactation which could account for a series of positive effects: a lower incidence of disease in the puerperium and hence greater milk production and feed intake (Bertoni et al., 1989). Similar results have been obtained by Grum et al. (1996); thus Drackley (1998) have suggested that triglyceride accumulation in liver immediately after calving was extremely low in cow fed fat supplemented diets during dry period. These contradictory results are not surprising because high amounts (above 5% of total DMI), particularly in case of unsaturated fatty acids, can cause digestive problems for their negative effects on rumen bacteria cell wall (Garnsworthy, 2002). To avoid this, fats supplemented above 3,5-4,0% of DM, would be “by pass fats” because protected from rumen microbes for their natural traits (e.g. whole oilseeds), for chemical treatments (encapsulated in formaldehyde-casein, as calcium soaps), for physical treatments (e.g. small particle size of high melting point fatty acids) (Garnsworthy, 2002). Some calcium soaps, particularly after calving and for some weeks, are moreover less palatable and could contribute to the above mentioned reduction of DMI.

Providing antibiotic ionophores such as monensin as feed additives appears to be effective in particular in obese cows for the higher availability of ghecogenic substrates (C3) (Duffield, 2000; Duffield et al., 2003; 2008). However, monensin is not approved as a legal drug in the European Union in dairy cows.

Reviews on the lipomobilisation syndrome were published in recent years (Drackley, 1999; Bobe et al., 2004; Grummer, 2008)

5.4.2. Ruminal acidosis

5.4.2.1. Excessive carbohydrate engorgement (Lactic ruminal acidosis)

The sudden ingestion of high amounts of easily fermentable carbohydrates is the most common cause of lactic ruminal acidosis. It occurs in dairy cows only accidentally, when e.g. cows escape confinement and have uncontrolled access to concentrates or transponder stations. Ruminal fermentation of easily digestible carbohydrates will produce large amounts of SCFA (short chain fatty acids: acetic, propionic, butyric acids) with a drop in ruminal pH below 5.0. Since such low pH values will prevent growth of most ruminal bacteriae and protozoens the fermentation pattern is dominated by acidophilic lactic bacteria towards the production of lactic acid which will lead to a further drop in ruminal pH. Severe ruminitis, disturbance of the gastro-intestinal barrier, bacteraemia or septicaemia, liver abscesses and vena cava thrombosis, dehydration, metabolic acidosis and acute laminitis may result from lactic acidosis. The majority of affected cows will die despite treatment from lactic acidosis (Dirksen, 1970; Nocek, 1997).

5.4.2.2. Subacute ruminal acidosis (SARA)

SARA is a condition, which has been reviewed recently (Kleen et al., 2003; Oetzel, 2004; Plaizier et al., 2008; Enemark, 2008). The transient acidosis of the ruminal environment occurs due to the feeding of a large proportion of concentrate feed, high in rapidly fermentable

carbohydrate, or a diet relatively deficient in long fibre. Maladaptation of the ruminal environment or mistakes in feeding management and preparation of the ration may then lead to the rise of ruminal SCFA concentrations which are too slowly absorbed by the ruminal mucosa. The recurrent acidosis may eventually lead to ruminitis; abscesses in the liver and other tissues. Moreover, SARA has been linked to other signs of poor animal welfare such as loss of body condition, suboptimal appetite or cyclic feed intake, diarrhoea, milk fat depression (MFD), low milk fat/protein ratios, laminitis, immunosuppression, Pneumonia - Posterior Vena Cava Syndrome and high herd culling rates (Garrett, 1996; Nocek, 1997; Oetzel, 2000; Enemark 2008). It has been pointed out recently that the pathogenic mechanism of SARA might consist in activation of systemic inflammatory response due to lysis of gram-negative bacteria (Gozho et al. 2007, Gozho et al. 2006) and absorption of endotoxins.

Current definitions of SARA are based on ruminal pH. Ruminal fluid can be collected by oral ruminal probes or by ruminocentesis (Kleen et al., 2003), but samples obtained by ruminocentesis will deliver more reliable pH results (Duffield et al., 2004; Plaizier et al., 2008). Ruminal pH in ruminal fluid samples obtained by ruminal probes are commonly about 0.3 to 0.4 pH units higher than those obtained by ruminocentesis (and less reliable). Thus, Duffield suggested a threshold pH of 5.5 for samples collected by ruminocentesis and of 5.9 for those gained by oral ruminal probes of 5.9. Unfortunately the definition of ruminal pH for diagnoses of SARA varies between different studies. While some authors used threshold values for ruminal pH at or below 5.5 (Garrett et al., 1999; Oetzel, 2000; Kleen et al., 2009, Cooper et al. (1999) used values between 5.2 and 5.5 and Beauchemin et al. (2003) used 5.8. Gozho et al. (2005) used a threshold of a rumen pH depression between pH 5.2 and 5.6 for at least 3 h/day, and feed intake was only reduced and inflammation only occurred at equal or greater rumen pH depressions. In a study comparing a group of cows with induced SARA with a control group, Garrett et al. (1999) found the difference in proportion of cows at or below a certain cut-off point between the groups greatest at pH 5.5.

SARA has been reported to occur predominantly in two situations. First, in the freshly lactating animal that has not yet developed a ruminal environment capable of metabolising the lactating cow diet (maladaptation) due to inadequate dry cow feeding management; second, the high-producing dairy cow, which is confronted with a ration insufficient in structure and a larger proportion of concentrate, respectively (Nordlund et al., 1995). The buffer compounds, active in rumen and hindgut, are also important in the above situation (Meschy et al., 2004).

The prevalence of SARA is not well researched. Garrett et al. (1999) proposed a scheme of estimating the prevalence of SARA in dairy herds on the basis of rumen fluid samples taken from cows in the herd. They recommended a sample size of 12 or more cows, which would deliver a reasonable accuracy in correctly differentiating between herds experiencing low ruminal pH in a higher proportion (>30%) or lower level proportion (<15%) of cows (Garrett et al., 1999, Oetzel, 2000). So far, a study from the U.S. showed a prevalence of 19% in early lactating cows and 26% in cows further into lactation. Single herds with SARA-prevalence up to 40% had been observed in this field study (Garrett et al., 1997). Another survey on 14 dairy farms in Wisconsin detected SARA in 20.1% of early and peak lactation cows (Oetzel et al., 1999). An Italian study (Morgante et al., 2007) investigated the prevalence of SARA in ten intensive dairy herds. They found 3 herds experiencing SARA (>33% of cows tested with rumen pH \leq 5.5) and five herds with a critical level (>33% of tested cows \leq 5.8). Nevertheless, blood indices were better in lower pH cows suggesting higher DMI of the latter cows, maybe because 5.5 is a pH value still acceptable (Minuti, 2008). Recently Kleen et al. (2009) studied 197 cows from 18 dairy herds in the Netherlands by means of ruminocentesis.

Of eleven herds with ten or more animals in the study, four were diagnosed as having evidence of SARA, on only one farm no cow with a ruminal pH ≤ 5.5 was found. The overall prevalence in all animals sampled was 13.8%. The stage of lactation did not influence the occurrence of SARA. The proportion of cows with low ruminal pH in the different herds ranged between 8% and 38%. Ruminal pH was correlated significantly with body condition score at time of clinical examination ($r^2 = 0.25$) and individual cows experiencing SARA tended to lose more body condition post-partum.

5.4.3. Parturient paresis (Milk fever)

Recently excellent reviews and meta-analysis on the etiology, pathogenesis, treatment and prevention of milk fever were published (Lean et al., 2006; DeGarris and Lean, 2008; Goff, 2008; Mulligan and Doherty, 2008).

A depression of the levels of total and ionised calcium in tissue fluids (hypocalcaemia) is the basic biochemical defect in parturient paresis. A transient period of subclinical hypocalcaemia (total plasma < 1.9 mmol/l) occurs at the onset of lactation caused by an imbalance between calcium output in the colostrum and influx of calcium to the extracellular pool from intestines and bone. Adult cows in second or higher lactations are more susceptible to milk fever. Commonly about 4 – 9% of cows are affected. Case fatality is about 10 - 20% when adequately treated but it is considerably higher without treatment. Most cases occur a few days until or during delivery, only few cases occur earlier during the dry period or later in the lactation period.

Paresis due to hypocalcaemia may lead to the Downer cow syndrome due to muscular and nerve traumas, in particular in obese cows. Also acute mastitis, skin injuries and ulcers, injuries to the skeletal apparatus, retained placenta, endometritis, ketosis, and abomasal displacement are seen as secondary to hypocalcaemia.

Early detection and immediate treatment of clinical hypocalcaemia is essential for a good treatment prognosis underlining the demand for an optimal health monitoring programme on dairy farms. Additionally measures need to be taken immediately to avoid the development of the downer cow syndrome or other secondary diseases (e.g. move from hard surfaces to soft bedding, providing feed and water ad lib for the recumbent cow, turning cows every 4 hours, providing adequate support to get up). See Chapter 18 for further information on Downer Cow management.

Since parturient paresis affect animal welfare and health considerably, the dry cow management include either feeding or management strategies for the prevention of milk fever (diets low in calcium and phosphorus, but with a good content of magnesium (0.25-0.30 % D.M), manipulation of dietary cation-anion balance (DCAB), Vitamin D administration prior to calving, calcium applications around calving).

5.4.4. Abomasal displacement (AD)

In recent years excellent reviews on the etiology and pathogenesis of abomasal displacement (AD) were published (Geishauser, 1996; Doll et al., 2008).

In recent studies in North America, the mean lactation incidence of AD was estimated to range between 3% and 5% (Gröhn et al., 1998; Zwald et al., 2004a; LeBlanc et al., 2005) although an incidence rate of 10%, even up to 20%, has been observed in individual herds (Dawson et al., 1992; Pehrson and Stengärde, 2000). In Germany, the mean lactation

incidence in German Holstein herds has been estimated at 1.6% (Wolf et al., 2001) and up to 7.5% in individual herds (Poike and Fuerll, 2000). In contrast to left-side displacements, which occur primarily within the first 4 weeks after calving, only 50–70% of right-side displacements are found in this period, while the rest occur independent of the stage of gestation or lactation (Hof, 1999; Dirksen, 2002).

Pehrson and Stengärde (2000) analysed 71 dairy herds in Wisconsin and found that 54% of the animals with AD were first calf heifers which is in good agreement with results obtained in German dairy herds (Poike and Füll, 2000).

Evidence from epidemiological and experimental studies over the last 50 years have identified a variety of risk factors associated with the occurrence of AD. However, the primary cause of the disease remains unknown.

AD occurs primarily in the classical dairy breeds, such as the Holstein Friesian and German Swedish or Holstein (Martin et al., 1978; Geishauser et al., 1996; Wolf et al., 2001a,b, Stengärde and Pehrson 2002) as well as on Simmental–Red-Holstein crossbreeds (Eicher et al., 1999), Brown Swiss, Ayrshires, Guernseys (Constable et al., 1992) and Jerseys (Jubb et al., 1991). Dual-purpose breeds are less frequently affected.

Studies have suggested that selection for a tall stature and deep body depth in breeding herds may explain this observed breed predisposition (Stöber and Saratsis, 1974; Mahoney et al., 1986; Wittek et al., 2007). These traits may increase the risk of AD because the higher vertical distance between the abomasum and the descending duodenum will impair abomasal emptying.

The relationship between high milk yield as assumed predisposing factor and AD is discussed controversially. While some authors found a positive correlation between milk and the occurrence of abomasal displacement (Dirksen, 1961; Grymer et al., 1982; Kuiper, 1991; Lotthammer, 1992, Zwald et al., 2004) other authors have been unable to verify this finding (Cameron et al., 1998; Rohrbach et al., 1999; Wolf et al., 2001). Ricken et al. (2004) identified a significant additive genetic correlation of the trait ‘milk yield’ and left but not right AD. However, analysis of both abomasal disorders as one factor revealed a correlation close to zero.

It is generally accepted that genetic predisposition is an important risk factor for the occurrence of AD (Jubb et al., 1991; Lyons et al., 1991; Constable et al., 1992; Uribe et al., 1995; Geishauser et al., 1996; Wolf et al., 2001a,b; Ricken et al., 2004; Zwald et al., 2004a). The heritability (h^2) is estimated to range between 0.11 and 0.41, with only few researchers disagreeing with this correlation (Van Dorp et al., 1998). According to Wolf et al. (2001a), both left and right AD are highly genetically correlated and they concluded that both forms of the disease are determined by the same genes.

Epidemiological studies have shown a correlation of high-concentrate and low-fibre diets with the incidence of AD (Grymer et al., 1981; Jacobsen and Riddell, 1995; Shaver, 1997; Füll and Krüger, 1999; Van Winden, 2002). In experimental studies, an increase in the fraction of concentrates resulted in a dramatic decrease in abomasal motility (Svendsen, 1969; Neu-Zuber, 2005), as well as an increase in AD (Coppock et al., 1972; Van Winden et al., 2003, 2004). Also feeding highly digestible diets with low neutral detergent fibre (NDF) content may be a more important risk factor than the amount of concentrate in the ration (Stengärde and Pehrson, 2002).

Several studies have shown also that peripartum cows with a marked negative energy balance (increased NEFA and bhydroxybutyrate values; Geishauser et al., 1997; Cameron et al., 1998; LeBlanc et al., 2005) or obese cows (Kuiper, 1991; Smith et al., 1997; Van Winden et al., 2003, Pravettoni et al., 2004) have an increased risk for left AD. Furthermore, a significant positive genetic correlation between ketosis and AD has been observed (Uribe et al., 1995; Shaver, 1997; Zwald et al., 2004b). Insulin resistance which is a characteristic of ketotic and obese cows has been discussed as one possible pathogenic explanation for these findings.

In a dairy farm survey (Trevisi et al., 2006) blood samples were taken weekly before and after calving of 314 cows. Only 23 cows had DA (78% left side); for 22 cows, AD occurred after calving (12 ± 8 DIM). Since the AD diagnosis does not always occur readily, the probable beginning was been retrospectively hypothesised only for 3 cows, daily monitored for milk yield and dry matter intake. According to this, blood changes observed for all cows suggesting to predict AD in advance, are few: a reduction of Mg, an increase of bilirubin and GGT, and an AST/GOT raise. Glucose is also increased in cows with previous inflammatory disorders, as a consequence of insulin-resistance (insulin is abnormally high). The inflammatory phenomena do not seem directly responsible of AD, but they could increase the risk to develop AD, particularly when accompanied by high oxidative stress conditions (Trevisi et al., 2006).

While some studies showed that feeding total mixed ration (TMR) rations increase the incidence of AD (Poike and Füll, 2000; Stengärde and Pehrson, 2002), Østergaard and Gröhn (2000) reported that TMR diets reduced the risk of developing this disease.

Massey et al. (1993) demonstrated that during parturition hypocalcemic cows had a 4.8 times greater risk of developing the disease than normocalcemic animals.

Retention of the fetal membranes, endometritis, mastitis or lameness, are common concomitant diseases in cows with AD (Wallace, 1975; Markusfeld, 1986; Schmidt et al., 1996; Rohrbach et al., 1999; Zwald et al., 2004a, b). Animals suffering from these diseases had a significantly higher risk of developing AD in comparison to healthy controls (Detilleux et al., 1997; Poike and Füll, 2000; Wolf et al., 2001a, b; Stengärde and Pehrson, 2002; LeBlanc et al., 2005).

Several recent studies have suggested that development of AD may be related to an increased concentration of endotoxins from bacterial infections or from the gastrointestinal tract (Füll and Krüger, 1999; Poike and Füll, 2000). Endotoxins can inhibit abomasal motility (Vlaminck et al. 1985; Sustronck, 2000; Kaze et al., 2004). However, recently Wittek et al. (2004) showed that endotoxaemia does not occur more often in cows with AD than in healthy controls during the postpartum period.

AD is seen as a kind of indicator disease for good farm management, since common risk factors are negative energy balance and ketotic metabolic states, development of obesity during the dry period, dietary compositions leading to ruminal fermentation patterns similar to those found in SARA and the occurrence of other production diseases such as milk fever, dystocia, retained placenta or endometritis.

Providing well balanced diets and good control or at least early and rigorous treatment of production diseases are effective prevention measures for AD.

6. Housing conditions in relation to welfare

6.1. Building design

6.1.1. Introduction

The design of buildings for dairy cows varies considerably (see chapter 8) and can have a huge impact on the welfare of the animals.

Cows kept in tie-stalls always have access to a resting area and competition for feed is rather limited. However, tie-stalls impair cow welfare by preventing the cow from moving freely and locomotion is usually limited for a long period often during the whole winter season or longer. Furthermore, tethering restricts cows in their activity of self-maintenance by making self-grooming difficult and prevents them from performing most social behaviours. From the viewpoint of environmental sustainability stanchion barns provide easier solutions than loose housing systems (Jongebreur and Metz, 1999). In contrast, cows kept in loose housing systems can move around and engage in social behaviour. However, this also includes aggression and most often there will be some competition for resources such as feed and resting areas. A direct comparison of the welfare in different housing systems is complicated because a large number of specific features of the housing, such as for instance bedding material and design of the resting and feeding areas, can affect the welfare. Therefore the following part of this chapter mainly focuses on specific features of the building design rather than on comparison between the welfare in different housing systems.

6.1.2. Feeding area

Under natural conditions the cow will stand with its front legs slightly apart, which lowers the front of the body and makes it easier for the cow to reach the grass. However, when fed in the barn, both in loose housing systems and in tie-stalls, the cow usually stands with both front legs together. Therefore it is easier for the cow to reach the feed if the trough is elevated above the floor level, and the risk of a cow falling as well as the risk of getting injuries on the front knees and the shoulder is reduced (Rom, 1989; Munksgaard and Krohn, 1990; Waiblinger et al., 2001b). The risk of getting injuries at the shoulder is also reduced due to reduced load on the shoulder and forelegs (Waiblinger et al., 2001b). It has been recommended to raise the feed trough 15-20 cm above the bedding level in loose housing and 12-15 cm in tie-stalls (Waiblinger et al., 2001b; Housing Design for Cattle – Danish Recommendation, 2001). However, the optimal level depends on the size of the animals. Furthermore, there is some evidence that a narrower feed trough, which ensures that the cow can reach the feed, reduces the risk of traumatic injuries (Munksgaard and Krohn, 1990). However, when cows are kept in tie-stalls, the stall is also used for resting. Thus the separation between the trough and the stall should not be too high in order to avoid thwarting of the forward movement of the body of the cow when changing position from lying to standing. Also the level of feed trough should not be lower than it is in loose housing so that the head lunge movement is not hindered. Furthermore, it is also necessary to have some separation between the trough and the stall to avoid feed coming into the stall. In tie-stalls compromises between giving the cow easy access to the feed without dragging feed into the stall and easy access to change position from lying to standing is necessary. In loose housing systems, where the feeding area is only used for feed intake, the area can be designed to optimise feeding behaviour.

In loose housing systems there are different designs of the barrier that separates the feed and the cows. The barrier can be a simple neck bar or a barrier that provides some separation between the animals. The latter type may also provide the possibility to restrain the cows. The headlock type reduces aggression and protects the subordinate cows better than the neckbar during peak feeding periods (Endres et al., 2005; Huzzey et al., 2006). During feeding with restricted amounts of feed restraining can limit displacement and provide protection for subordinate cows, and thus to a larger degree ensure that all cows can eat without disturbance. However, cows tied for four hours showed more aggression, increased grooming and lying behaviour when released compared to control cows indicating that tying for four hours may lead to discomfort and increased motivation for lying down (Bolinger et al., 1997). However, shorter duration of fixation may not have these negative consequences, and the effects of duration of fixation also seem to depend on the type of food and availability of water at the feed trough (Menke et al., 2000). If there is less than one eating place per cow during feeding with restricted amounts of feed, some cows may not get access to the feed at all (Konggaard and Krohn, 1975).

When feed is provided *ad libitum*, stocking density with less than one eating-place per cow may not affect feed intake or even lead to a weak increase in feed intake (Henneberg et al., 1986; Olofsson, 1999). This, however, will depend on the degree of synchronization between the cows when they eat. For example, in an automated milking system there is less synchrony and so there should be less need for one feeding space per cow. However, if feed is delivered only once a day, there will be more synchronization when cows visit the feed bunk and so the effect of feeding space will be greater. One problem with TMR is that cows sort through the diet so that the cows that are able to have first access to the TMR are not eating the same diet as those that have later access. Increased stocking density can decrease duration of eating and lead to increased displacement from the feed trough (Albright and Timmons, 1984; Henneberg et al., 1986; Olofsson, 1999; DeVries et al., 2004). When the stocking density increased from one to three or four cows per eating place the level of aggression increased (Henneberg et al., 1986; Olofsson 1999), and in agreement, DeVries et al. (2004) found that the level of displacement was more than doubled when there was 0.5 m per cow compared to 1.0 m per cow at the feed manger. When the stocking density increased both when using headlocks (1.33, 1.0, 0.67 and 0.33 headlocks/cow) and when using a neck bar (0.81, 0.61, 0.41 and 0.21 m/cow) the level of displacement increased and the eating time decreased with increasing stocking density. Furthermore, availability of feed for all cows may also depend on number of feedings per day, speed of milking, cow traffic and the degree of synchronization between the cows when they eat. If there is less synchrony, for instance in an automated milking system, it is likely that there is less need for one feeding space per cow. However, even when the food is provided *ad libitum*, sorting of feed can cause huge variation in the diet of those cows that are able to have first access to the TMR compared to cows with later access.

In some cases, feed stalls consisting of partitions at the feed bunk are used. These can reduce displacements of low-ranking cows from the feeders, especially when less feeder space is provided (DeVries and von Keyserlingk, 2006).

Besides the amount of resources, the distribution or placement is important. When several resources are clumped together (e.g. drinkers and concentrate feeders in close proximity), the encounters and aggression increase while spatial separation can relax the situation. Not only the placement of special equipment is important, also the general design of the housing is influential. For example, feeding behaviour showed a different daily pattern in two and three

row cubicle houses. The amount and placement of alleys connecting cubicle rows and feed alley impact on behaviour such as cow locomotion and accessibility of the different resources for individual cows.

6.1.3. Automatic feeding stations

In loose housing systems concentrates and grain can either be provided as part of a total mixed ration in the feed trough, or separately either in the milking parlour or in automatic feeding stations. The design of the automatic feeders can affect the level of aggression and displacement at the feeders. Gates that protect the cow when the cow is standing in the feeder decreased the aggression by 65% and the number of displacements by 67% (Herlin and Frank, 2007). It is mainly cows that only get a limited amount or no concentrate in the feeder that perform the aggression and displacement (Katainen et al., 2005). However, the speed of delivering the concentrate also affects the level of displacement. If the speed of delivering the concentrate is above the speed of eating, aggressive cows have a greater chance of finding leftover feed by displacing other cows in the feeder (Krohn and Konggard, 1980).

6.1.4. Walking areas

Limited space is an important factor affecting the level of aggression. If the space is limited the cows will more often be at a closer distance and possibilities for avoidance will be more limited. There is only very limited information about the effects of the dimensions of the walking areas in loose housing systems. However, it is likely that too narrow alleys can restrain the cows' freedom of movement from one area in the barn to another as well as increase the level of aggression. Metz and Mekking (1984) found a higher level of aggression and subordinate cows spend more time standing in cubicles when the width of the alley behind the cubicles was 2 m versus 11 m. Furthermore, Henneberg et al. (1986) also found increased level of aggression when the width of the alley between the cubicles was reduced from 2.0 m to 1.2 m. Blind alleys properly increase the risk of cows not being able to avoid aggressive interactions with other cows. The effects of flooring are discussed in paragraph 12.9.

6.1.5. Resting areas

Cattle can either rest in stalls (tie-stalls or cubicles) or in more open bedded areas. Both the design and dimensions of tie-stalls and cubicles can vary as well as the flooring and provision of bedding material.

It is important there is sufficient amount of space for forward motion not to hamper cows' movement when changing position from standing to lying and vice versa. Restrictions in the space in front of the cow for instance rails in the area of the head lunge can lead to interrupted attempts to lying down or getting up and abnormal behaviour. Cubicles that are too long may lead to more dung in the cubicles. Furthermore, if the dimension of the cubicles is not adjusted to the size of the animal, it can be difficult for the cow to rest in natural positions and her movement may be restricted. Cermak (1987) suggested that the optimal size of cubicles is a function of the size of the cow. A cow weighing 600 kg needs a length of 2.18 m and a width of 1.20 m. Boxberger (1983) suggested that the head lunge that cattle use to get up takes up to 1.5 m, measured from the carpus to the tip of the muzzle. There is only a limited amount of research on the effects of dimensions of cubicles. Tucker et al. (2004) found in two experiments with dry and lactating cows that lying time increased when the width of the

cubicles increased from 1.12 m to 1.32 m and from 1.06 to 1.26 m respectively. However, the optimal size of cubicles is dependent on the size of the cow.

A neck rail is most often placed perpendicular to the divisions between the cubicles in order to force the cow to stand with her hind leg close to the edge of the cubicle. The position of the neck rail, both the height and the distance from the front of the stall, can affect the time cows spend standing with all four legs in the cubicle (Tucker et al., 2005; Weary and Tucker, 2003; Veissier et al., 2004). There is some evidence that dairy cows try to stand in their cubicles because they do not have a comfortable place to stand outside their cubicles. The effect of the neck rail on welfare will therefore depend on the quality of the flooring outside the cubicles. If the flooring is poor quality wet concrete, then a neck rail position that forces the cow to stand outside the cubicle may increase the risk of lameness (Tucker et al., 2006a). Mülleder and Waiblinger et al., (2004) found that a neck rail diagonal greater than 1.94 m was associated with a lower percentage of lame cows. Hitting against the neck rail during rising is negatively correlated with neck rail length. There is hitting against parturitions during lying down with smaller width, horselike rising and sitting give hint on flexible parturitions and neck “rail” to avoid negative consequences (injuries, pain, fear) (Hörning, 2003). The position of brisket boards can also influence stall usage (Tucker et al., 2006b). Flexible neck rails and parturitions may reduce injuries, pain and fear. The effects of different bedding materials are described in 11.7.

A number of studies have shown that lying time decreases, the level of aggression increases and the risk of low ranking cows lying on the walking alleys increases when the stocking is increased to more than one cow per cubicle (Friend et al., 1979; Krohn and Konggard, 1987; Winckler et al., 2003; Fregonesi and Leaver, 2002; Fregonesi et al., 2007b).

6.2. Space allowance

6.2.1. Introduction

Space allowance can be considered from two points of view. Firstly, the individual’s physical space requirements for performing appropriate individual behaviour apart from social interactions (e.g. head lunge when lying down or standing up, self-grooming) are especially important for design of individually used equipment such as cubicle dimensions. Secondly, social space is the space needed to have appropriate social interactions and avoid social stress. Of course in practice physical space and social space often influence the same aspect, overlap or have to be added, for example regarding space at the feeding rack or cubicle width. Space allowance is associated to the amount of manure per m² and thus can reduce cows’ cleanliness. Given the same height of building, the space allowance also contributes to air quality and thus welfare by its association with air volume (section 11.5).

The physical space requirements depend on the animal’s size, for example recommendations by CIGR that are based on animal’s dimensions (CIGR Working Group, 1994). Because cows were bred larger over the last decades the space requirements increased. However, the most important housing systems (cubicle loose housing, tie-stall) are hardly flexible in dimensions of equipment and thus older buildings often bear severe welfare problems even if they were large enough when built. It is difficult to offer optimal conditions to growing animals. Another problem of size-dependent equipment is a large variation in cow size within herds, so that equipment may be appropriate for some animals, but may impact negatively the welfare of larger or smaller individuals. For instance, even in cubicles of 125 cm inner width, larger

cows (height at withers >1,45 cm) rarely show comfortable lying positions with outstretched hind legs compared with smaller cows (Keil et al., 2004). Physical space requirements and optimal design of equipment may differ for hornless (dehorned and polled) and horned animals because horns enlarge the head and thus horns may hit against partitions, e.g. in cubicles against the nose rail, or make it more difficult for the animals to enter or leave a feeding place or head gates (Menke, 1996). The negative effects of insufficient physical space and space requirements are reviewed below.

The need for social space arise because animals attempt to keep individual distance from conspecifics (Wilson, 2000). The individual distance depends on the affiliative and dominance relationships among the animals, bonded animals keep and accept closer distance (Bouissou et al., 2001), but also on the total space available. On pasture (Bennett and Holmes, 1987) observed an individual distance between 0.5 and 10m. (Kondo et al., 1989) found in adult dairy and beef cattle that the distance to the nearest neighbour increased gradually up to a space of 360m²/animal. Above 360m²/animal the animals maintained an individual distance of approximately 10-12 m. The distance between neighbouring cows ranged from 0.15 to 2.10 m when 0.5 m feeding space/cow were available and from 0.30 to 4.20 m for 1,0 m of feeding space, and the average distance between cows was at least 60% greater in the high relative to the low space treatment (DeVries et al., 2004). In a study on 35 dairy farms, space per cow was correlated with the number of displacements following horn butts and the number of injuries (Menke et al. 1999) suggesting a linear association as found by Kondo et al., 1989). If possible, subordinate animals avoid intruding on the individual distance of a dominant animal and withdraw from approaching dominants that may or may not show overt aggression or threats (Bouissou et al., 2001). The aggression is therefore reduced.

6.2.2. Effects of space allowance on welfare

Once a dominance relationship is established, agonistic interactions with body contact are rare on pasture, where sufficient space and resources allow the subordinate animals to avoid intruding the individual distance of other animals. In contrast, in housing conditions agonistic interactions, especially with physical contact, increase considerably (Wierenga, 1984; Miller and Wood-Gush, 1991) due to the limitation of space and resources like lying or feeding places. Injuries due to horn butts are higher indoors compared with pasture (Baars and Brands, 2000). In loose housing, the amount of total space is negatively related to the frequency of agonistic interactions and injuries in dairy cows and heifers (Wierenga, 1984; Metz and Mekking, 1984; Andreae et al., 1985; Metz and Wierenga, 1987; Menke et al., 1999; Fregonesi and Leaver, 2002) as is the amount of feeding space alone (DeVries et al., 2004; Huzzey et al., 2006). The type of interaction differs: in high-space vs. low-space the number of threats is higher, but number of displacements including physical contact (butts) is much lower (Wierenga, 1984). In practice different aspects contribute to the total space allowance and are often associated with each other: width and length of the different alleys, number of resources (especially cubicles, feeding places) per animal as well as possible additional space such as an additional running (idling) area inside or outside the barn. In a given indoor situation additional space in an outside area reduces agonistic interactions: cow herds showed less agonistic interactions when having access to an outdoor yard during the night compared with a closed yard (Menke et al., 2000). Reducing only feeding space (length or available feed bunk or number of feeding places) leads to increased aggression (DeVries et al., 2004; Huzzey et al., 2006). There are also effects of space allowance on other behaviours, health and production. With a larger idling area (alley width behind the cubicles 11 m) more locomotion

was observed and non-oestrus cows initiated mountings almost as often as the oestrous cows which was not the case in the small idling area (width of 2m) (Metz and Mekking, 1984). Existence of an outside run, associated with more space allowance, as well as higher total space allowance ($\geq 8.6\text{m}^2/\text{cow}$) was associated with lower prevalence of lameness (Mülleder and Waiblinger, 2004). Especially when there are few other possibilities to retreat from herd members, i.e. low space allowance, cows stand in cubicles to avoid encounters with others (Potter and Broom, 1987) and such behaviour seems to relate to lameness (Galindo and Broom, 2000). Lameness and hoof lesions were more among cows that spent more time standing half in the cubicle. Reduced space allowance reduces the availability of resources for low-ranking individuals, especially in case of small alleys in cubicle houses (Konggaard, 1983). Small alleys ($< 1.6\text{ m}$ between cubicles) were associated with production losses in dairy cows (Ostergaard et al., 1986). However, studies investigating alley width are scarce. Considering the requirement that at least two cows should be able to pass each other without (major) social disturbance, both physical space and social space interplay and show dependence on cow size. For example, the alley behind the feeding place would need to be at least as wide as a cow length plus 2 times cow width to theoretically enable cows during feeding time (when many cows are standing in the feeding place) to pass each other. For today's cow size, this would mean at least 360 cm alley width behind the feeding place. However the cows' need for social individual distance is not yet considered in this calculation.

The design of the given space is very important. Very small alleys behind the feeding place or in passageways can only partially be compensated by a larger space allowance elsewhere, e.g. an outside run. Furthermore, the frequency of crossways, i.e. the alley length in between crossways, influences the effects of alley width because crossways may offer alternative ways for low ranking animals to reach specific resources.

Overcrowding (feeding places, lying places and walking area), besides causing an increase in agonistic interactions, also results in a higher amount of contradictory displacements and unsuccessful buttings. These interactions seem to be a result of subordinate animals trying to get access to resources (Wierenga, 1990). A number of studies have shown that, when the stocking is increased to more than one cow per cubicle, lying time decreases. The time of lying down shifts, especially for low ranking animals, the level of aggression increases and the occurrence of low ranking cows lying in the walking alleys increases (Friend et al. 1979; Wierenga, 1983, Krohn & Konggaard, 1987; Winckler et al. 2003; Fregonesi & Leaver, 2002; Fregonesi et al. 2007). Wierenga (1983) found an average reduction of lying time for all cows in the herd of 20 or 30 min with 10% or 20% overstocking, respectively. Low ranking animals again were more affected: lying time was reduced on average by 30 min to 80 min for this group. Similarly, Leonard et al. (1996) found that the average resting time when cows were housed at a cow/cubicle ratio of 2 was 7.5 hours but that this varied between 2.7 hours/day and 11.9 hours / day for individual cows. The low resting times were associated with an increase in the incidence of sole haemorrhages and lameness. Fregonesi et al. (2007) showed that the linear decline in lying times with overstocking was paralleled by a linear increase in time spent standing outside the cubicle. It seems likely that even moderate levels of overstocking can increase the risk of lameness. This is supported by results where a cubicle : cow ratio of less than 1,06 : 1 was associated with higher prevalence of lameness in multivariate analysis including 80 dairy herds (Mülleder and Waiblinger, 2004). Howell et al. (2003) found a negative correlation ($r = -0.51$) between ratio of cubicles to cows and locomotion score in 22 herds. Additionally, overstocked cows are more likely to lie down immediately after returning from the parlour; when stocked at 1:1 ration cows feed for on

average 40 min before lying down (Fregonesi et al., 2007a); this extra time standing is thought to allow for teat end closure reducing the risk of intramammary infection when cows to lie down. Further, overstocking may lead to low-ranking animals lying down in the alleys (Wierenga 1983). Understocking has positive effects with respect to those welfare aspects (lying duration, lying time, lameness); additionally the cows more often can adopt more comfortable lying positions more often (Wierenga et al., 1985; Keil et al., 2004). Time spent lying was higher, cows lay down more synchronously, time spent standing in cubicles and in the walking areas was lower in a largely understocked situation (23 cubicles for 12 cows; Wierenga et al. 1985). In the already mentioned epidemiological study of 80 cubicle housed dairy herds, understocking of cubicles (at least 6% more cubicles than cows) was associated with reduced prevalence of lameness (Mülleder and Waiblinger 2004).

In dairy heifers, more space (3 m²/animal compared to 1.5m²) caused longer lying and higher liveweight gain by 174g/day or 31% and 23% reduced net energy intake (Hindhede et al., 1996; Beneke, 1985; Mogensen et al, 1999; Hindhede et al, 1999). At a resting area (deep bedding) of 1,8 m² per animal, heifers (weighing 315 kg at the start of the experiment) were unable to synchronise their resting behaviour, variance in lying time was higher, heifers showed more aggression (butting and chasing up), more leaning against another animal, and prevalence of heel horn erosion were higher. Daily gain and feed intake were lower compared to heifers having access to 2,7 or 3,6 m² resting area (Mogensen et al. 1997, Nielsen et al. 1997). Regarding synchronicity, half of the total lying time was synchronised in the larger space allowance, while only one quarter in the small resting area. Only one animal in the small resting area lied down on the slatted floor.

Comparing two groups in low (total space 6,7m², lying area 4,5m²/ cow) and high (13,5 and 9 m²/cow) space allowance in straw yards, Fregonesi and Leaver (2002) did not find a significant difference in lying time, synchronicity of lying, feeding or agonistic interactions in four groups of 6 Holstein Friesian cows (approximately 660 kg live weight). However, cows were dirtier in the low space condition and milk lactose and somatic cell count pointed at a higher incidence of mastitis in high yielding cows.

In principle, every limited resource can cause competition and thus aggression, stress, injuries and lameness. This applies for brushes, concentrate feeders and milking box in case of milking robots.

6.2.3. Feeding space / feeding place to animal ratio / drinker space

The highest amount of aggressive interaction among loose-housed cattle occurs in the areas around the feeding places (Miller and Wood-Gush, 1991) and they increase with restricted access to preferred feed or reduced feeding space for review (Boe and Faerevik, 2003). The amount of social agonistic interactions as well as feeding behaviour is related to both housing (feeding space per cow, design of the feed barrier) and feeding management (frequency and amount of food; restricted/ad libitum feeding) (Olofsson, 2000; Huzzey et al., 2006). A reduced ratio of feeding places to animals or feeding space per animal increases agonistic behaviour in dairy cows, also when fed ad libitum (Stumpf et al., 2000; Schrader et al., 2002; Mülleder et al., 2003; DeVries et al., 2004; Huzzey et al., 2006) and in feedlot steers (Corkum et al., 1994). The increase of agonistic interactions during this enhanced competition is not equally distributed, but depends on the social strategy of the individual (Mülleder et al., 2003). Further, reduction in feeding space / places per cow causes shorter feeding times and longer times standing as well as changes in daily rhythm with increased time feeding during night

(Olofsson, 1999; Schrader et al., 2002; Huzzey et al., 2006). Cows are highly motivated to feed after a relatively short period of food deprivation (Schütz et al., 2006). More feeding space (1 m compared to 0.5 m) did not only reduce aggressive interactions (57% less) but also allowed dairy cows, especially subordinate animals, to increase feeding activity throughout the day, especially during the 90 min after providing fresh feed (increase of 24%) (DeVries et al., 2004) and thus providing also low ranking cows access to the best quality food. With reduction in feed trough space (0.81, 0.61, 0.41, 0.21 m/ cow or 1.33, 1.0, 0.66, 0.33 headlocks per cow) a linear decrease in time standing inactively in the feeding area, a curvilinear increase in displacement from the feeding area and curvilinear decrease in time feeding is observed (Huzzey et al. 2006). The competition at the feed trough in general depends on the whole system and thus on how synchronised the animals are in feeding, e.g. in automatic milking systems with (partially) forced cow traffic, competition may be relaxed. However, cows are highly motivated to start feeding after fresh food is supplied and even partially forced cow traffic seems to impair welfare compared with conventional systems (Hagen et al. 2005). The effect of feeder space per animal will depend on how synchronised the animals are in feeding. In a robotic milker, there is little feeding synchrony and so competition for access to roughage is lower than when fresh TMR is delivered once a day. The effects of too little feeder space will also be greater if there are too few lying stalls or if the time taken for milking is long and there is less time available to feed and rest. As mentioned above, parallel overstocking in the lying area may enhance the problem as may long duration of milking so that cows have less time left for resting and feeding.

The drinker also can be a place for high competition and thus a source for aggressive interactions. Aggressive interactions were higher when cows were restrained longer in the feed rack without access to water and dry food compared with shorter restraint time (Menke et al., 2000). The number of drinkers as well as the water trough length influence aggression around drinker and the individual cow's possibility to have sufficient access to water. Because high ranking cows can block access to drinkers, problems arise unless there are at least two per group even in small herds. Problems also arise unless there is: for open water troughs, 1m for 15 to 20 and for water bowls 1 / 7 animals and good functioning, i.e. water flow is 20l/min. Low water flow, by increasing drinking time per animal, enhances the risk of aggression. High temperatures increase competition due to higher water intake.

6.3. Thermoregulation

6.3.1. Main definitions

There is a bulk of literature defining various thermal zones, thermoregulation and adaptation processes for animals. Because of the intensive and controversial discussions on these terms, definitions of the most frequently used terms are given to facilitate the understanding of the complex animal environment relationship.

As dairy cows are homeothermic, they are, within certain limits, able to maintain a relatively constant deep body temperature, different from the environmental temperature. A relatively constant deep body temperature means that heat production and heat loss are equal. An increased difference between deep body temperature and environmental temperature leads to higher heat losses to be compensated by a higher heat production. Body temperature will increase when heat loss is not sufficient (heat stress). Heat may be dissipated through conduction, convection, radiation and evaporation. Figure 8 presents a basic scheme of body core temperature control (Yousef, 1985). The heat production of the animal is minimum

within the thermoneutral zone. The body core temperature is kept constant in the zone of homeothermia. For temperatures lower or higher than the thermoneutral zone, the heat production of the animal increases or decreases. When the loss of heat is higher than the heat production, it causes hypothermia and eventually death. Conversely, when the loss of heat is lower than heat production, e.g. by too high ambient temperature and humidity, it causes hyperthermia. The animal will die when body temperature continues to stay too low or too high.

This concept is in principle valid for dairy cows both kept indoors and outdoors.

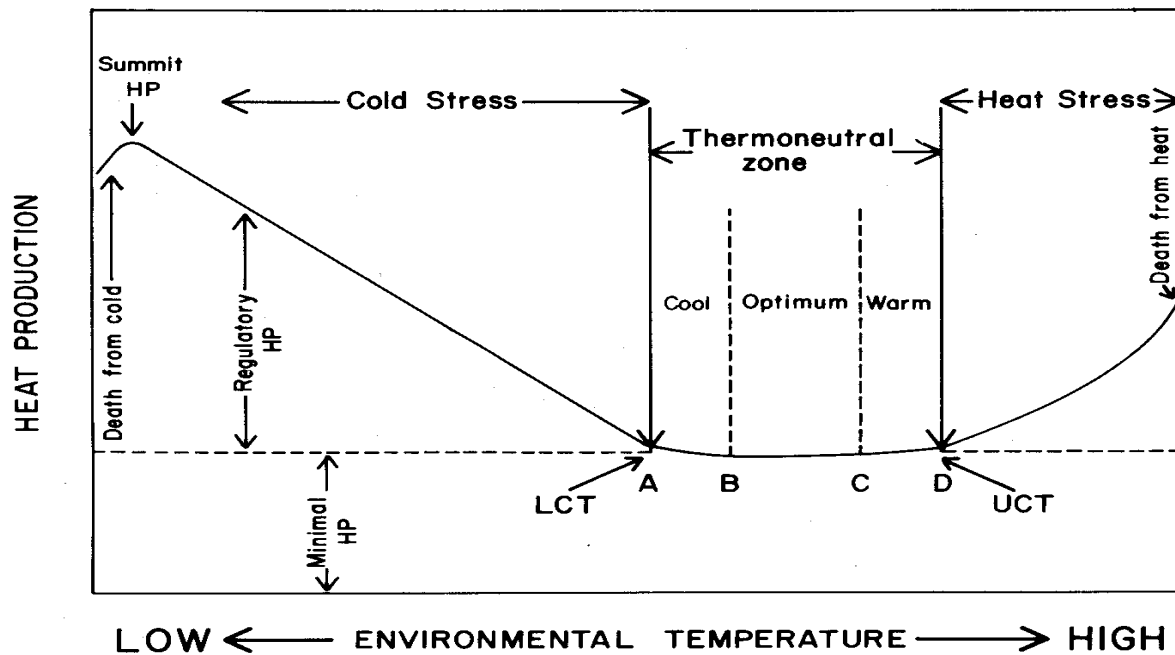


Figure 8 Scheme of the thermoneutral zone of animals (Yousef, 1985). LCT: Lower critical temperature, UCT: Upper critical temperature. This Figure should not be taken to imply that welfare is good close to UCT and close to LCT as these points were described with reference to production.

6.3.1.1. Indoor climate / Micro-climate

The indoor or micro-climate in animal houses is the sum of all physical, chemical and biological qualities of the air inside buildings (Hilliger, 1990). It is influenced by ventilation and insulation of the surrounding walls, floor, and roof. The most important components of the indoor climate in animal houses are temperature and relative humidity of the air, air velocity and air quality (gaseous and viable and non-viable particulate pollutants). They can significantly influence welfare and disease prevalence in the animals. High concentrations of ammonia, dust and bacteria can damage the respiratory tract of the animals, enhance the development of respiratory disorders and support transmission of infectious agents (Wathes, 1994; Hartung, 1994).

6.3.1.2. Effective environmental temperature (EET)

The EET theoretically expresses the total effect of a particular environment on an animal's heat balance. An animal perceives temperature (thermal environment) as a combined result of dry air temperature, air humidity (measured as wet bulb or expressed as RH (relative humidity)), air velocity, irradiative and may be conductive heat loss. For example, the effect of a higher ambient temperature or a higher relative humidity of the ambient air on the animal can be compensated for by a higher air velocity that maintains the same or equivalent effective temperature (Curtis, 1983).

6.3.1.3. Thermo-neutral zone (TNZ)

Within the thermoneutral zone, metabolic heat production and energy expenditure are minimal, most productive processes are at their most efficient level and an animal is thermally comfortable without the need to change heat production (Ewing *et al.*, 1999). The zone is limited by the lower critical temperature (LCT) and the upper critical temperature (UCT). Within the zone the regulation of body temperature is physical, e.g. by adjustment of insulation or behavioural, but below LCT and above UCT, there are energy costs of thermoregulation (Charles, 1994; Richards, 1973).

6.3.1.4. Lower critical Temperature (LCT)

LCT is the point in effective ambient temperature below which an animal must increase its rate of metabolic heat production to maintain homeothermy. Processes related to conservation of heat, including vasoconstriction in the periphery, piloerection, and behavioural adjustments to reduce heat loss from body surfaces, are at their maximum at this temperature and below (Ewing *et al.*, 1999).

6.3.1.5. Upper critical Temperature (UCT)

There is no absolute definition of UCT (Webster, 1981; McArthur, 1987). UCT is described as the point above which an animal must engage physiological mechanisms to stop the rise in body temperatures above normal. These processes are related to cooling by evaporation (through increased perspiration and respiration), and behavioural activities such as wetting the skin and vasodilatation in the periphery, to enhance heat loss from body surfaces through convection, radiation, conduction and behaviour (Ewing *et al.*, 1999). UCT can also be defined by an increase of evaporative heat loss (CIGR, 2002).

6.3.1.6. Thermal comfort zone (TCZ)

TCZ is the range of EET where an animal has thermal comfort (i.e. keeping deep body temperature constant is within the broader homeothermic zone) with the least effort through behavioural and physical thermoregulation by changing exposed body surface, tissue insulation (sensible heat loss) and latent (evaporative) heat loss without panting. The respiration rate may vary according to age, weight, activity, resting, feeding which makes it difficult to define what a "normal" respiration frequency is.

6.3.1.7. Homeothermic zone

That range of EET where an animal is able to keep deep body temperature by all available means at the normal level, which includes normal variability depending on species, age, physiological state, etc.

6.3.1.8. Survival zone

That range of EET where an animal is able to survive despite being hypo- or hyperthermic and having poor welfare.

6.3.1.9. Thermoregulation

Actions undertaken by an animal to meet its thermal needs, i.e. keeping body temperature constant (hypo- and hyperthermia also includes thermoregulation) forced by the physical conditions in the thermal environment, i.e. the EET and influenced by the emotional perception of the surroundings. Consequently, animal temperature regulation starts with change of sensible and latent heat loss (e.g. through the skin) and, if necessary, due to higher environmental temperature more of the total heat must be lost as latent. When ambient temperatures exceed deep body temperatures all heat must be dissipated as latent. For example, this enables cattle to survive to temperatures higher than 40°C, if the relative humidity is about 60 % (Mount, 1968 and 1974).

6.3.1.10. Adaptation

It is nearly impossible for an animal to be continuously in balance or in harmony with its environment. At some point the animal may react or make adjustments to the environmental stimuli (Lindley and Whitacker, 1996). Such an environmental adaptation refers to any functional, structural, or behavioural trait that favours an animal's survival or reproduction in a given environment, e.g. changing of the reference temperature and/or band width of the regulation mechanisms in the hypothalamus for behavioural, physical and chemical thermoregulation (Curtis, 1983). The adaptation does not necessarily imply good welfare as an individual may adapt only with great difficulty (Broom 2006b) can be acclimation, acclimatisation or habituation.

a) Acclimation

Acclimation refers to an animal's compensatory alterations due to a single stressor acting alone, usually in an experimental situation, over days or weeks. It is similar to conditioning (Mount, 1979).

b) Acclimatisation

Acclimatisation refers to reactions over days or weeks to environments where many environmental factors vary at the same time, e.g. seasonal variations. Acclimatisation to heat and cold may involve changes in thermoneutral heat production, coat depth and blood flow through the superficial tissues of the body. In extreme cases this has been shown to reduce the LCT of cattle by much as 20°C (Charles, 1994). Long term responses to thermal environment include adaptation of feed and water intake, change of metabolism, and fur or coat insulation.

c) Habituation

Habituation results when certain stimuli are repeated many times and the animal becomes “used” to it (behavioural adaptation) and the response to the stimulus decreases (Mount, 1979). Broom (1981) describes it as the waning of a response to a repeated stimulus. This is different from fatigue (Broom and Fraser, 2007).

d) Minimum and maximum temperatures, air velocity and ventilation rates

There are ranges of recommended and critical temperatures (LCT, UCT) for different types of animals usually related to optimal housing and production. The most important interacting animal related factors are age, body weight, adaptation level, coping capacity, thermal insulation, body cover (structure, colour), sweating capacity, feeding level, production level, previous experience, health status, group size, stocking density and social behaviour. Animals may be able to cope with extremes of temperatures for short periods but may be unable to cope for long periods. In such extreme conditions, their welfare would be poor if coping is difficult.

Some literature results are reported below in order to describe suitable ranges of temperatures for dairy cows in comparison to other animals and the interactions of temperature, air velocity, relative humidity of the air and ventilation rate.

The Temperature Humidity Index (THI)

Adult cattle can much better cope with cold stress when sufficiently fed than with heat stress. An approach to assess the general heat stress level caused by temperature and relative humidity in dairy cattle is the Temperature Humidity Index (THI). It is also called Livestock Weather Safety Index (Esmay and Dixon, 1986) and was used by the U.S. National Weather Service for advisory bodies. The basic formula reads:

$$THI = t_{db} + 1.36t_{dp} + 11.2$$

t_{db} = dry bulb temperature (C)

t_{dp} = dew point C

There are also other THI reported in the literature which use slightly different values and figures like the THI for cattle of Bianca (1965) ($0.35 \times$ dry bulb temperature C) + ($0.65 \times$ wet bulb temperature C). It is convenient to use is the graph of Armstrong (1994) shown in Figure 9. The stress threshold is expected to initiate at 75THI, below this value, no thermal stress is anticipated. The other zones are mild distress (< 78), moderate distress (< 83), severe distress (< 84) and fatal many deaths from heat stress (> 84).

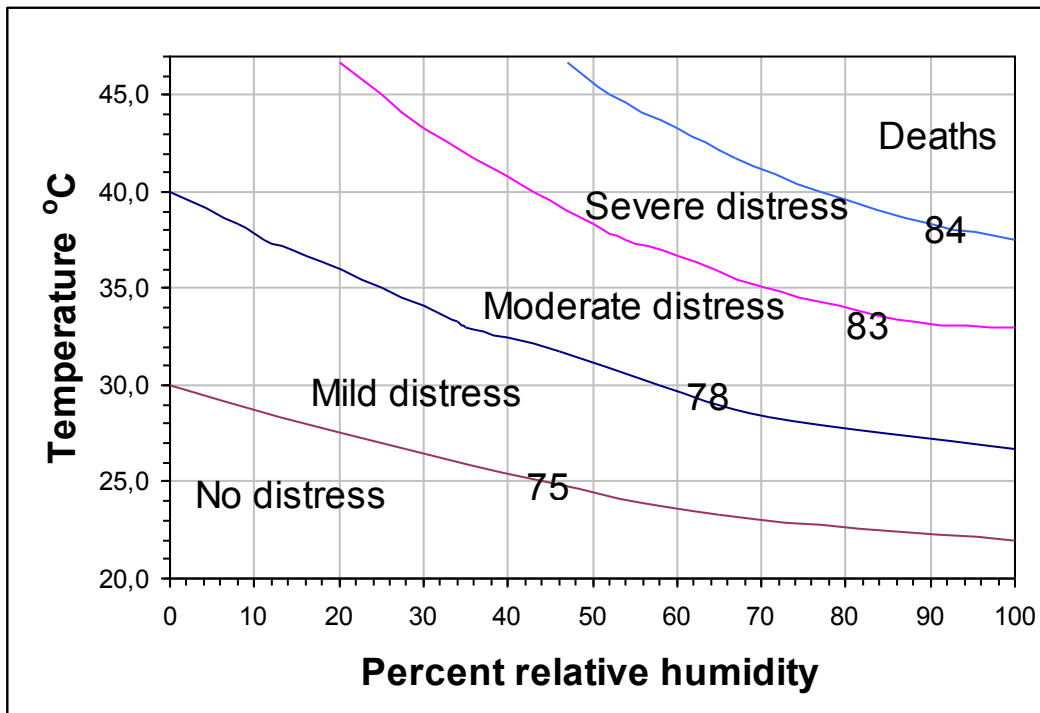


Figure 9 Relationship between temperature and relative humidity with THI-zones of heat stress levels in cattle (modified after Armstrong, 1994).

Some combinations are given below which are suitable for cattle when if mild heat distress is accepted:

35 C and 25 % RH

30 C and 58 % RH

28 C and 80 % RH

27 C and 100 % RH

Air movement around the animals can influence the THI considerably. A few examples from Baeta (1985) are shown below. He used slightly different assessment thresholds which makes detailed comparisons difficult:

Wind velocity 0.5 m/s:

Safe: e.g. 26 C + 90% RH or 32 C + 20% RH

Caution: e.g. 28 C + 90% RH or 36 C + 20% RH

Danger: e.g. 30 C + 90% RH or 42 C + 20% RH

Wind velocity 6 m/s:

Safe: e.g. 28 C + 90% RH or 41 C + 20% RH

Caution: e.g. 30 C + 90% RH or 42 C + 20% RH

Danger: e.g. 34 C + 90% RH or 43 C + 20% RH

Wind speeds below 0.5 m/s have little effect on heat loads on the animals. Recommendations for wind speeds around housed animals in summer should therefore be at least 0.6 m/s and more (DIN, 1992). A wind speed of 6 m/s increases the heat dissipation distinctly.

These figures can be influenced by various factors such as different feeding intensities, coat depth of the animals and type of breed and wet skin. If cattle are fed below the maintenance level, LCT rises sharply. Wind and rain influence LCT additionally. An example of Charles (1994) illustrates the impact of these factors. For a 400 kg beef cattle (fed barley, gaining 0.75 kg/day) kept in dry, draught free conditions the LCT is at -9 C. At 4 m/s draught and rain (coat 50% wet), LCT rise to 17 C. Indoors the animals are usually protected against rain. The skin of the animal can become also wet when for longer periods without sufficient ventilation and the relative humidity is high.

6.4. Protection from adverse weather condition

The thermoneutral zone refers to the temperature interval within which the animal's heat production is independent of the temperature in its environment. When the environmental temperature is lower than the thermoneutral zone, a lower critical temperature (LCT) is attained. The animal must increase its heat production in order to maintain constant body temperature and ruminants then must redistribute their energy to heat regulation (Senft and Rittenhouse, 1985). Similarly, when the environmental temperature exceeds the upper critical temperature (UCT) the animal must decrease its heat production. LCT is partly dependent on the animal's insulation, coat, subcutaneous fat etc., and partly on the animal's heat production in the thermoneutral zone. The heat production for lactating dairy cattle is considerably higher than for non-lactating or low lactating beef breed cattle. The higher metabolic rate of the lactating dairy cow implies that it can withstand lower temperatures better than dry cattle or low lactating beef type cattle.

6.4.1. Cold climate

Most studies on cold climate refer to beef cattle. Webster (1974) states LCT for an adult beef cow to be -13°C at cloudy and calm weather and -3°C at cloudy weather and wind velocity of 4,5 m/s provided that the animals have dry lying area. LCT for beef cattle with summer coat, or wet winter coat, is estimated to be 15°C, with autumn coat 7.2°C, with winter coat 0°C and with thick winter coat -7.8°C (Wagner, 1988).

The lower critical temperature for a cow at peak lactation is estimated to -25 degrees Celsius and to -14 for a dry cow (Collier et al., 1982).

Cattle undergo habituation to cold temperatures depending on how long they were exposed to it. Cattle must be exposed to cold during at least one week before the habituation process will start (Christopherson and Young, 1986). Habituation does not occur after a short exposure to cold or by intermittent exposures during short periods (Kennedy et al., 2005).

Cattle habituate to cold from summer to winter through growth of coat and the establishing of a subcutaneous fat layer whereby the insulation increases, thus making it possible to maintain the body temperature unchanged. Experimental studies in climate chambers have shown that beef cattle shiver when exposed to - 20°C in September but not in December which indicates that the coat has adapted to cold during the autumn (Gonyou et al., 1979).

Acute cold stress is met with shivering, muscle trembling with a frequency of 10 per second, whereby heat energy is released (Andersson and Jonasson, 1993).

The coat structure differs between Aberdeen Angus and Hereford. However, the two coat types have the same insulation capacity (Gilbert and Bailey, 1991).

Experimental studies of dry and wet coat show that wet coat substantially increases the heat loss (Hillman et al., 1989; Jiang et al., 2005). While the heat losses from a dry coat are negligible those from a wet can amount to 200-300 W/m² (Cena and Monteith, 1975). Studies of the insulating capacity of reindeer coat at different coat humidity and different wind velocities show that the impact by humidity from mist or easy rains did not change the insulating capacity. However, heavy rains significantly reduce the insulating capacity of the coat through evaporation and by heat-conducting water replacing the insulating layer of air in the coat (Cuyler and Øritsland, 1993; 2004).

New-born calves are noticeably tolerant towards cold at dry and calm weather provided they are given dry bedded lying areas (Ekesbo, 1963; Radostits et al., 1999). Calves kept in hutches cope with temperatures between -8°C and -30°C on condition that the straw bedding is dry (Rawson et al., 1988; 1989a, b).

Adult cattle with experience of being kept outdoors the year around seek shelter to a greater extent than younger against adverse weather conditions (Beaver and Olson 1997). This seems to be at least partly acquired behaviour explaining the observation that only cattle which have learnt to use sheds, seek shelter in those against adverse weather. Preference tests show that cattle prefer sheds to forests during winter and to lie on straw bedding to the bare ground (Wassmuth et al., 1999). Cattle offered free choice between resting and seeking shelter outdoors or in sheds with dry straw bedding choose in winter the shed and in the summer to lie down outdoors (Krohn et al., 1992).

Adult cattle on pasture rest lying 10,1 - 11,6 hours per day, calves longer (Krohn and Munksgaard, 1993; Albright and Arave, 1997; Phillips, 2002). Experimental studies show that cattle are inclined to invest a lot of work in order to get a possibility to lie down (Jensen et al., 2005). Preference tests show that cattle offered wet lying areas have substantially shorter resting period than if offered dry lying areas (Keys et al., 1976). At cold and wet weather cattle also seek dry lying areas (Wassmuth et al., 1999).

Comparison between different bedding materials shows that cattle prefer straw to other materials (Jensen et al., 1988). Straw as bedding gives better protection against cold than e.g. wood shavings (Rawson et al., 1989a). Ambient temperatures can affect cows preferences for alternative bedding materials. Manninen et al. (2002) found that cows showed a stronger preference for rubber mats (that provide some thermal insulation) over sand in winter compared to summer.

Thyroxines are secreted when animals have been exposed to cold for a long period. This increases their appetite and feed requirement (Westra and Christopherson, 1976; Young, 1981). However, the time grazing per day decreases with falling temperature (Malechek and Smith 1976; Christopherson, 1983; Adam's et al., 1986; Dunn et al., 1988; Beverlin et al., 1989; Prescott et al., 1994). If no supplementary feed is given in winter, when grazing time per day will be reduced, or when the feed supply is insufficient, the animals therefore must use their energy reserves for maintaining heat balance.

Cattle without sufficient protection against unfavourable weather show increased feed consumption and decreased daily growth (Hoffman and Self, 1970; Leu et al., 1977). Cattle with access to sheds show better daily growth in winter time than those provided only with wind shields (Hoffman and Self., 1970; Milligan and Christison, 1974; Leu et al., 1977).

However the quality of dry, and thereby heat insulating, or moist and thereby heat-conducting, the laying area has a greater influence on the ability to maintain growth during unfavourable weather than shelter from wind or low temperature (Christopherson, 1981; Mossberg, 1992).

Preference tests show that cattle in winter choose to rest in sheds with dry straw bedding while in summer they choose to rest outdoors (Krohn et al., 1992).

Problems with animal losses and inappropriately designed sheds gave rise to experimental wind tunnel studies in Canada aiming at learning how to design sheds in order to give optimum shelter against wind and precipitation (Theakston, 1960; 1962). These questions have been addressed later (Charles 1991).

6.4.2. Hot climate

Heat stress is considered to be the level of temperature where the cow can no longer cool herself adequately and is for dairy cows it is considered to be at temperature levels above 25 °C (Roefeldt, 1998). The changes in physical and genetic constitution of the modern dairy cow may have affected their capacity to cope with heat stress. Coppock et al. (1982) concluded that high producing cows are more affected by heat stress than low producing cows as the thermoneutral zone shifts to lower temperatures as a result of the increase in feed intake, milk production and metabolic heat production.

Thermal stress has primarily been assessed by measuring body temperature which shows susceptibility to hot weather (Akari et al., 1984) and the increase in rectal temperature has been suggested as a valid indicator to assess the adversity of a hot thermal environment (Silanikove, 2000). Other measures include increased respiration rate (Omar et al., 1996), panting, drooling, reduced heart rate and profuse sweating (Blazquez et al., 1994), decreased feed intake (National Research Council, 1989) as well as reduced milk production (Abdel-Bary et al., 1992) and breeding performance (Roman-Ponce et al., 1977; De Rensis and Scaramuzzi, 2003). Sweating capabilities vary among breeds but the measurement of sweating rate is difficult (Kadzere et al., 2002).

Physical responses are breed specific where tropical breeds such as *B. indicus* are less sensitive to thermal heat stress than *B. taurus* cattle (Finch, 1986). Within the *B. taurus* breeds, the Jersey has been shown to be less sensitive than the Holstein-Friesian (Sharma et al., 1983). The mean rectal temperature is higher in *B. taurus* than in *B. indicus* (Finch, 1986) because *B. taurus* is more sensitive to heat stress. The use of *B. indicus* sires has been shown to result in higher conception rates than with the use of *B. taurus* sires in lactating Holstein cows during summer heat stress (Pegorer et al., 2007). The pH in blood has been shown to be higher during hours of heat stress than to hours in a thermoneutral zone (Schneider et al., 1988) probably due to a respiratory alkalosis. Cattle with dark coats are more susceptible to heat stress from radiant heat than cattle with light coats (Brown-Brandl et al., 2006).

The exposure to a high ambient temperature induces a higher respiration rate (Coppock et al., 1982) with changes from 20 breaths/min in cool conditions to over 100 at temperatures of 32 °C and above (Johnston et al., 1959). Cattle heart rate may increase during short-term exposure to heat stress as a part of a classical stress response but may decrease as a result of long-term exposure and adaptive physiological processes (Kadzere et al., 2002). Cattle metabolism rate is lowered during heat stress. Plasma growth hormone concentration decreases with hot temperatures (Mitra et al., 1972; Igono et al., 1988; McGuire et al., 1991) and Johnson et al. (1988) found a decline in thyroid hormone production in response to heat exposure.

Temperature-humidity index (THI) has been used to indicate climatic conditions and values of 70 or less are considered to be comfortable for the dairy cow and values of more than 75 stressful (Kadzere et al., 2002). Rectal temperature has been shown to increase at THI levels above 80 whereas respiration rate began to increase at values above 73 indicating that compensatory mechanisms using increased evaporation through breathing starts before body temperature increase (Lemerle and Goddard, 1986).

Ambient temperatures above 25 degrees Celsius have been reported to be associated with lower feed intake, reduced milk production and a reduction in the metabolic rate (Berman, 1968) and a decrease in conception rate (McDowell et al., 1976). Also, cows under heat stress eat less fiber (especially long fibre) and this increases the risk for ruminal acidosis. In chamber experiments, heat stressed dairy cows consumed less feed, more water and had a lower milk production than cows kept in a thermal neutral environment (Schneider et al., 1988).

From a health point of view, cows are subject to increased exposure to vectors and other agents for disease in warm and humid conditions. The incidence of retained placenta was twice as high during the warm season of May to September compared to the rest of the year in a study of dairy herds by DuBois and Williams (1980). Further, they found an increase in gestation length of 6 days which might have been a result of the heat stress during the period. Several studies indicate that there is an effect of heat stress on breeding efficiency (Kadzere et al., 2002) and in a study conducted in the northeast of Spain (López-Gatius et al., 2005), the risk of ovulation failure in high yielding dairy cows showing oestrus and being kept under standard conditions was 3.9 times higher during the warm period (May-September) than during the cold. The likelihood of pregnancy loss in Holstein-Friesian dairy cows was shown to increase by a factor of 1.05 for each additional unit of the mean maximum temperature-humidity index from days 21 to 30 of gestation (García-Ispuerto et al., 2006). Housing of cows with cooling systems such as water spray and fans in areas with hot climate has been shown to improve milk production and reproductive performance postpartum in comparison to housing without such facilities (e.g. Avendano-Reyes et al., 2006).

Dairy cattle prefer to use shade when exposed to solar radiation and the use of shade increases with increasing solar radiation (Tucker et al., 2008) which highlights the importance of the provision of shade for all cows at high ambient solar radiation. Cows with more protection from solar radiation have been shown to have lower minimum body temperature than cows with less shade or no shade. The use of the shade was found to occur also on days with relatively low levels of solar radiation during summer (Tucker et al., 2008). Also, after being deprived of lying for 12h, dairy cows choose to stand in shade at high air temperature rather than lying (Schütz et al., 2008).

6.5. Adequate ventilation, air quality, climate control, manure gases and light

Intensive milk production with high-yielding cows is increasingly carried out indoors through the whole year. Adequate climate of housing systems for dairy cows is a basic requirement for animal welfare (Pelzer, 1998).

The predominant housing type in the modern dairy industry in Europe is a barn with natural ventilation. The air usually enters the animal house under the eaves by natural influx and leaves through an open ridge or slots in the roof. The driving forces are the wind speed and direction of the outside air putting pressure on the inlet openings and the heat produced by the animal which warms up the ambient indoor air. These warmer parts of the air are lighter than

the incoming air and rise up towards the roof. The higher the temperature difference between inside and outside the more efficient does this type of ventilation work. This implies that the ventilation rate is higher in winter than in summer time when higher ventilation is needed because of high temperatures. Therefore, in those barns without the option of a paddock or access to grazing during the day or in the summer season, additional ventilators are installed in order to provide sufficient air exchange and higher wind speeds around the animals when necessary. During grazing periods in summer cows should have access to sufficient water supply and adequate shelter from sun, wind and rain (Keck and Zähler, 2004).

6.5.1. Ventilation

The indoor climate is important for the good welfare and minimal disease in dairy cows and for good productivity (Novak et al., 2005). The higher the temperatures the higher is the risk for lower milk production. Ambient temperatures above 26 °C reduce the daily milk production of Holstein-Frisian cows significantly. Daily milk yield can decrease by 25% in summer if housing and ventilation are inadequate (Bucklin et al., 2000). In winter time, insufficient ventilation leads to high humidity of the animal house air, moist stall conditions, wet skin, uncomfortable conditions such as draught and poor surface and air hygiene. When the air exchange is too low, the concentration of airborne micro-organisms including pathogens, dust and manure gases are rising in a building. Unsatisfactory ventilation increases the likelihood of mastitis and even the spread of respiratory disorders causing poor health and loss of production (Wathes, 1992; FAWC, 2003; Novak et al., 2001). The ideal ventilation depends on the type of barn, the size, the number of animals to be housed and the season.

The maximum ventilation rate in hot weather is the slowest rate limiting the rise of building air temperature to 2-3 °C above ambient (Wathes, 1992). The minimum ventilation rate under cold conditions is in fact a misnomer since the rate is the fastest which can be permitted without lowering air temperature below a set point (Wathes, 1992). As a general rule for dairy cows, the ventilation rate should not be lower than 60 m³/h per 500 kg live weight in winter and at least 300 m³/h in summer when the temperatures rise above 28 °C, e. g. for a dairy cow of 600 kg yielding between 15-30 kg of milk the ventilation rate should range between 235 and 322 m³/h in summer at temperatures above 26 °C and between 176 and 241 m³/h between 20 and 26 °C, in winter the ventilation rate should be between 62 and 82 m³/h (DIN 18910, 2004). Insulated roofing helps to reduce the heat impact of sun shine in summer and the loss of heat in winter and prevents water condensation on the ceiling (Herkner et al., 2002).

6.5.2. Temperature and air humidity

The temperature and humidity of the air in naturally ventilated dairy cow buildings are affected by the outside thermal conditions, the heat and water vapour production of the animals (and some regular wet cleaning periods) and the ventilation rate (Keck and Zähler, 2004). When the outside temperature is between 0-25 °C, the inside temperature of such barns is usually 1-3 °C higher. The inside temperature and moisture content were found to increase approximately 0.8 °C and 1000 mg/m³, respectively for every 1 °C increase in outside temperature (Li-Bao Ming et al., 2004).

Dairy cows can compensate for quite a wide range of temperatures. The comfort area for dairy cows is between 0 and 20 °C (Sambraus, 1997). The optimal production temperature for dairy cows (10 - 20 kg milk yield/day) is given between 0 and 15 °C (BVET, 2002). Low temperatures are easily compensated by the considerable metabolic heat of digestion whereas

heat stress can only be reduced by reducing feed intake, drinking water and resting in shade (Albright, 2000; Phillips, 2002; Keck and Zähler, 2004; Bucklin et al., 2000). Sambras (1997) gives -10 °C as lower critical temperature, but short-term temperatures as low as -20 °C do not negatively affect health and performance (Müller and Schlenker, 2003). Even minimal housing and cold winter conditions do not have any negative effects on the Body Condition Score of dairy cows (Keck and Zähler, 2004).

The humidity of animal house air is mainly influenced by the water vapour content of the incoming air and the moisture produced by the animals deriving from respiration, transpiration and from urine and faeces. A 500 kg cow produces about 400 g water vapour per hour by respiration and transpiration (Pelzer, 1998). High moisture content of air and surfaces favours the production and release of noxious gases from manure and soiled surfaces and supports bacterial growth including species such as *Staphylococcus aureus*, *Streptococcus dysgalactiae*, *Escherichia coli* and *Streptococcus uberis* which increase the risk for infections and disease transmission (Pelzer, 1998, Müller and Schlenker, 2003).

The relative humidity in dairy housing should not vary more than between 40 and 80 % (DIN 18910, 2004).

6.5.3. Airflow

The air flow around an animal can have positive and negative effects. It removes heat and water vapour and supports thermoregulation particularly in summer, supplies fresh air or can transport noxious gases and cause uncomfortable draught (TVT, 2006). This is particularly important for cows in tie-stalls where they cannot escape to a more comfortable area of the animal house (Pelzer, 1998). Airflow directly around the animal should be about 0.2 m/s in winter and 0.6 m/s in summer, depending on the ambient temperature not causing draught or overheating (Wathes, 1992; Randall and Armsby, 1983).

6.5.4. Gases

The most important noxious gases found in livestock buildings are ammonia (NH₃) and hydrogen sulphide (H₂S). Carbon dioxide (CO₂) is a useful indicator for ventilation intensity. Methane (CH₄) and nitrogen oxide (N₂O) (Jungbluth et al., 1997; Pelzer, 1998) have environmental importance.

Table 4 Thresholds for air pollutants and in animal house atmosphere.

Pollutant	Thresholds for animal ¹⁾	Thresholds for man ²⁾
Ammonia	20 ppm	20 ppm
Hydrogen sulphide	0,5 ppm	10 ppm
Methane	-	-
Carbon monoxide	10 ppm	30 ppm
Carbon dioxide	3000 ppm	5000 ppm
Inhalable dust	-	4 mg/m ³

Microorganism	-	-
Endotoxins	-	50 EU/m ³ ³⁾

¹⁾CIGR, International Commission for Agricultural Engineering, Climatization of animal housing, 1984.

²⁾MAK-Werte-Liste Maximale Arbeitsplatzkonzentration.

³⁾Berufsgenossenschaftliches Institut für Arbeitssicherheit (BIA) des Hauptverbands der gewerblichen Berufsgenossenschaften 1998.

Ammonia

Ammonia originates from urine and faecal material produced by the animals and as a result of chemical/biological breakdown of the waste material (Groot Koerkamp et al., 1998).

Ammonia is a water-soluble gas, which can travel over great distance in the atmosphere and deposit as rain (Hultgren, 2004). Ammonia paralyses the cilia of the upper respiratory tract and presumably increases the risk of respiratory diseases (Heinrichs et al., 1994; TVT, 2006).

Investigations in laboratories (Anderson, 1995) and in livestock buildings (Oldenburg, 1989; Hartung et al., 1994; NI et al., 1999) have reported increase of ammonia release with increasing air temperature.

NH₃ concentrations in naturally ventilated houses normally are low (Amon et al., 2001). The mean ammonia concentrations were about 8 ppm in cattle housing (Koerkamp et al., 1998, Simensen, 1981; Hultgren, 2004). Concentrations of 10 or more ppm of NH₃ are generally regarded as likely to cause problems for calves (Scientific Veterinary Committee, 1997).

The level of atmospheric ammonia depends on specific climatic conditions, ventilation rate, housing design features and management procedures. Frequent removal of manure by flushing with slurry may result in temporary peak ammonia concentrations above the legal threshold.

The individual role of ammonia in the development of respiratory disease remains unclear, though it acts synergistically with other pollutants (especially with dust) and may influence the incidence and severity of biological agent-induced respiratory diseases. Ammonia is highly soluble in water and is supposed to be largely absorbed by the distal airway mucous. Ammonia can favour bacterial contamination of the lungs by reducing pulmonary clearance and by inducing airway mucosal inflammation. Ammonia can also affect cellular necrosis of alveolar tissues and lead to respiratory stress and edema.

The most common inflammatory pathway involves the induction of cytokines (e.g. TNF- α , IL-1, IL-4, IL-6), which are regulatory proteins secreted by cells in response to tissue damage. They can mediate a variety of local and systemic biological functions involved in the control of acute phase protein expression (Kataranovski et al., 1999). Ammonia causes the release of cytokines by alveolar macrophages and neutrophils, constituting a potent inflammatory response (Murata and Horino, 1999). Harding et al. (1997) found correlations of the first phase protein haptoglobin and plasma TNF with prolonged stress. Besides cytokines and acute phase proteins, total white blood cell count, macrophages, neutrophils, and lymphocytes, are seen as indicators of immunological responses to respiratory stress (Asmar et al., 2001).

Methane and N₂O

Methane emissions from the animal housing are mainly caused by enteric fermentation (Amon et al., 2001) and play an important role in the decline of contribute to global warming (greenhouse gas) together with N₂O.

Carbon dioxide

Generally, the concentration of CO₂ was highly correlated to outdoor temperature (Simensen, 1981). The level in barns increases with respiratory functions of animals and it is also harmful for them. But insufficient ventilation with high CO₂ ratio indoor stimulates respiration and circulation functions of animals and has a delay effect on milk production (Sabuncuoglu et al., 2007).

There is some scientific evidence for adverse effects on farm animals when the concentration of carbon dioxide is 3000 ppm or higher (SVC, 1997) and this may apply to dairy cows.

6.5.5. Light

Light is a primary condition of life and as such is an important environmental factor for dairy cows. In nature, two types of light cycle are imposed on living creatures, daily light cycle and annual light cycle. Through evolution, animals are adapted to these light cycles, which affect profoundly their activity patterns both over the day and the year. Cyclic patterns in behaviour and physiology resulting from adaptation to the natural light cycles are well established in cattle, and also easily recognizable, as can be seen from the diurnal rhythmicity of feeding and rumination of cows kept alone under controlled light.

Human control of light for cows on a dairy farm was in the past and still is at present mainly restricted to 'illumination', the supply of additional light for human orientation and care and handling of the cows. But a wider perspective should be considered. From reviewing literature, Biewenga and Winkel (2003) concluded that by exposing young female cattle to a light regime of 16 light L: 8 dark (D) instead of shorter natural daylight, would induce puberty at an earlier age. An increase of day length to a 16L: 8D regime would also increase milk production of adult dairy cows, by 6 to 15 percent, if the light intensity is at least 150 to 200 lux. In both cases the effects are mediated by endocrine responses to duration and intensity of light, and not the result of increased feed intake (Dahl et al., 2000). These effects are similar to seasonal effects on reproduction and lactation, as seen at different latitudes of the Northern and Southern hemisphere. Switching to periods of longer darkness each day, 8L: 16D cycle, in the period of dryness of cows was found to result in a higher milk production after calving of about 3 percent (Biewenga and Winkel, 2003).

Phillips et al. (2000) studied the effect of light intensity of moving dairy cows to the concrete passageways of a barn. Cows changed to shorter step length and higher step rate at low light intensities. This effect was interpreted as less motion confidence of cows. The authors suggest that to avoid such effects on locomotion, the optimum illumination may be approximately between 32 and 119 lux. A light intensity of 32 lux would be an optimum level in terms of cow's comfort in locomotion, and 119 lux optimum for object discrimination, if the floor surface is not safe. Within this range of light intensities the acuity of vision of cows would gradually increase.

Some countries developed guidelines to provide cows' sufficient illumination for orientation in the barn. These were set at 25 lux for the resting, feeding and walking area in the Danish Recommendations (2001) and at 20 lux for the entire barn by ADAS (2006) for the UK. Visibility of objects by cattle starts already at light intensities of 1-2 lux (Phillips et al., 2000; Biewenga and Winkel, 2003).

A further question is the light intensity required in automatic milking barns where milking of the herd is a 24 hours operation. Individual cows are supposed to visit the milking robot

voluntarily, at least two times per day, during the day or the night period. Pettersson and Wiktorsen (2004) studied the return of cows in the night to the resting area after being milked by the robot, while there was a choice between a full illuminated resting area (about 200 lux) and a resting area with only guiding light (5-7 lux). On average, cows did not show a preference between these two light intensities, but individual cows did. Some cows moved significantly more to the fully lit barn section while some others showed the reverse preference. The authors conclude that apparently a lower light intensity during the night is not aversive to cows which are milked by the robot at night time.

Automatic milking has introduced a 24 hour management practice on the dairy farm, with a tendency to provide continuous and even constant illumination in the barn for 24 hours. Dahl et al. (2000) indicate that constant light would have a refractory influence on photoperiodic effects in the cow. By consequence, enhancing effects on reproductive functions and milk yield of the cow of an increase of day length would disappear.

The importance of the photoperiod on cow welfare is little documented. But from Dahl et al. (2000) it is obvious that it is beneficial for cow welfare that the daily light–dark cycle is maintained.

6.6. Resting

Dairy cows mainly rest while lying down, and then they carry out most of the rumination, drowse and sleep. However, cows may also rest while standing inactive. In order to lie down they have to perform a movement pattern of lying down and getting up. In the following text, these aspects of resting behaviour are discussed in relation to housing and management of dairy cows.

6.6.1. Lying

The amount of time that cows spend lying down is influenced by the type of housing, comfort of the stall, cubicle or lying area, type of diet, pregnancy, climatic factors and presence of cows in heat (Sambraus, 1971; Rushen et al., 2008).

Studies on free-ranging cattle or beef cattle kept on ranches give us some ideas about which climatic factors influence resting and lying time in cattle. Feral Chillingham cattle have been found to lie down 4.6 h in the winter time and 9.2 h in the summer time, but these mean durations differed between the two years that they were observed (Hall, 1989). The proportion of resting time spent lying by Hereford cows has been reported to be 0.55 (Dwyer, 1961) to 0.83 (Wagnon, 1963), with no obvious differences between the seasons (Herbel and Nelson, 1966; Kropp et al., 1973). Dwyer (1961) found that during the night most rest was carried out while lying down, whereas during the day climatic factors had stronger influence on proportion of lying while resting. In a study on beef cattle the proportion of resting time spent lying down decreased with increased temperature, especially when humidity was high (Larkin, 1954). In warm climate Aberdeen Angus cows were found to always rest in shade during the day, whereas Brahman cattle did not (Rhoad, 1938, see separate chapter). Growing beef steers lay down for longer as the temperature decreases (Redbo et al. 1996) and in very cold climate cattle lie more with increasing wind speed, presumably to reduce heat loss (Malechek and Smith, 1976). When there is a milder winter condition, cattle have been found to have a larger proportion of their resting time standing than in summer (Rutter, 1968). Most of these studies have been carried out on beef cattle with less research having been done with dairy cows.

However, Webster et al (2008) reported that dairy cows in New Zealand lay down less in cold, rainy weather.

In confinement, cattle may lie down for a longer time as they have easy access to feed and water and do not have to walk long distances to find these resources. The time dairy cows are lying has been found to vary from 6.7 to 14.7 h with the shortest durations being found on pasture and the longest durations on straw yards or deep bedded packs (Table 5). There are no obvious differences in lying time in tie stalls compared to cubicle systems. In cubicle systems the total time spent lying is affected by many aspects of stall design (dimensions), floor and type of bedding etc. (Tucker et al., 2004; Cook et al., 2004; Drissler et al., 2005). In tie stalls, lying time can be reduced by hard flooring (Haley et al., 2001). Lying times can also be longer if cattle are lame (Singh et al., 1993b; O'Callaghan et al., 2003; Juarez et al., 2003; see chapter 14.5.2). Presence of cows in heat has been found to reduce lying time and increase number of lying bouts (Sambraus, 1971; Beneke, 1985).

Table 5 Mean duration of lying per 24 h in dairy cows in different studies

Reference	Tie stalls	Cubicle system	Straw yards or deep bedded pack	Pasture
Dechamps et al., 1989	46,2%	52,9%		
Krohn & Munksgaard, 1993	12,5 h			10,1 h
Haley et al. 2000	10,5 h		14,7 h ¹	
Haley et al., 2001	10-13 h			
Rushen et al., 2007	8-10 h			
Manninen et al. 2002		10.8 – 12.9h		
Tucker et al., 2004		9,6-13,0 h ²		
Cook et al., 2004		11,7-12,0 h ³		
Drissler et al., 2005		11,4-13,7 h*		
Fregonesi et al., 2007		12,9 h		
Norring et al., 2008		11,2-13,7 h		
Fregonesi & Leaver, 2002		11,9-13,6 h	13,2-14,1 h	
Singh et al, 1994			9,7 h	
Endres & Barberg, 2007			9,3 h	
Dalley et al 1999				9.3–10.5h
Wales and Doyle 2003				7.17 h
Botheras 2006				6,7-10,1 h
Wechsler et al. 2000		9,93-13,27 h ⁴		

¹ Large individual pen with mattress and light straw bedding

² Differed between the stall widths ³ Depending on type of flooring in cubicles

* Depending on depth of bedding

⁴ Measured on different floor types (straw mattress and comfort mats)

Typically, dairy cows lie down from 6–13 times a day in bouts that last on average 55–90 mins (Haley et al., 2001; Manninen et al., 2002; Tucker et al., 2004; Drissler et al., 2005; Rushen et al., 2007; Norring et al., 2008). Wechsler et al. (2000) found that individual cows were lying down 10-17 times per day. This number was 12–13 on average on different soft surfaces (soft comfort mats or straw mattress) with bout length ranging from 43-73 min for individual cows, and 53-67min on average on different mattresses. Cattle can lie down in a number of postures that can be classified according to the position of their legs and head (Schnitzer, 1971). Haley et al. (2000) examined resting postures of cows in large pens with a

soft floor. Most of the time the front legs were tucked under the cow. The front legs were extended for only 7% of the time. In contrast, the back legs were tucked under the cows for only 21% of the time. For 90% of the resting time, the head was held up, supported by the neck. The remainder of the time, the head was resting against the ground or against the cows' body. The type of stall provided may prevent cows adopting certain of these postures, although Haley et al. (2000) found no evidence that this was true for the tie-stalls examined. However, Oertli et al. (1994) found that cows extended the lower hind leg longer on soft surfaces than on hard surfaces and in cubicles Oertli et al. (1995) found 10,2 - 13,8 % of lying time with front legs extended. Cubicle width in relation to cow size influences lying position so that larger cows (height at withers >1,45 cm) show less often comfortable lying positions with outstretched hind legs compared with smaller cows (Keil et al., 2004). When understocked (1,5 : 1 cubicle : cow) cows more often adopt more comfortable lying positions (Wierenga et al., 1985).

The degree of synchrony between cattle in a group in the time that they lay down can be highly variable. Many systems for dairy cows use the synchronised behaviour of cows in the management. In a study on tied dairy cows and heifers the majority of the animals were lying from 19.00 to 04.00 and from 11.00 to 12.00 (Figure 10). The heifers were even more synchronised in their lying, probably because they were not influenced by milking. However, Haley et al. (2000) found no strong evidence of diurnal rhythms in the cows' activity when in tie-stalls, with cows lying down during the light hours as much as during the dark hours (Figure 11). No more than 60% of any hour of the day was spent in lying down, showing that, at any time of the day, a substantial number of cows were standing up. Thus, the degree to which cattle are synchronised in their lying times is highly variable and is strongly affected by management. In fact, robotic milking systems rely on dairy cows not being completely synchronised in their lying behaviour. The degree of synchrony depends on the availability of resources. When less feeding space or cubicles exist, cows shift feeding/lying time but they do not if enough feed/lying space is available (for more information see chapter on social space). Too little is known about the factors influencing cows' synchronicity and their importance to cows' welfare.

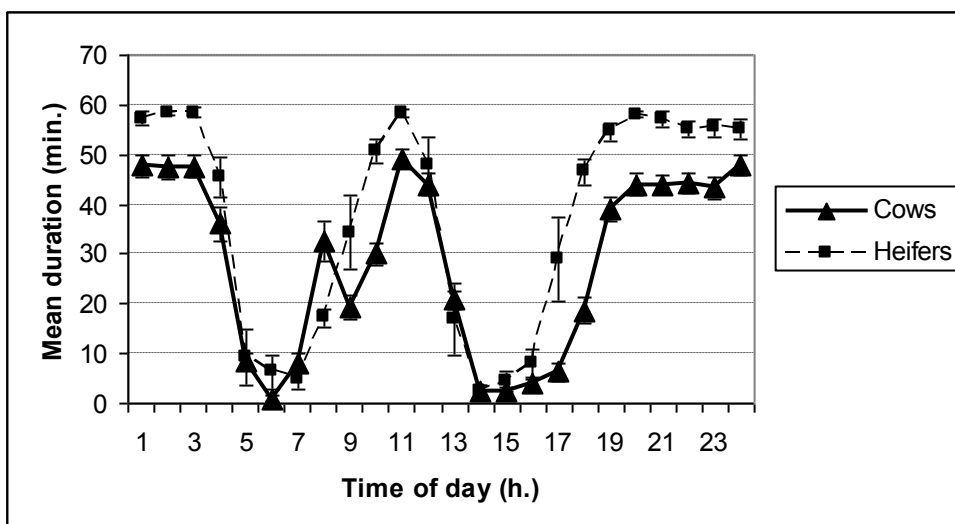


Figure 10 Mean duration in min. (\pm SE) per h of 9 diurnal cycles (24 h each) of tied dairy cattle lying down reported separately for cows (n=16) and heifers (n=4) (Figure drawn based on data from Aland et al., 2008).

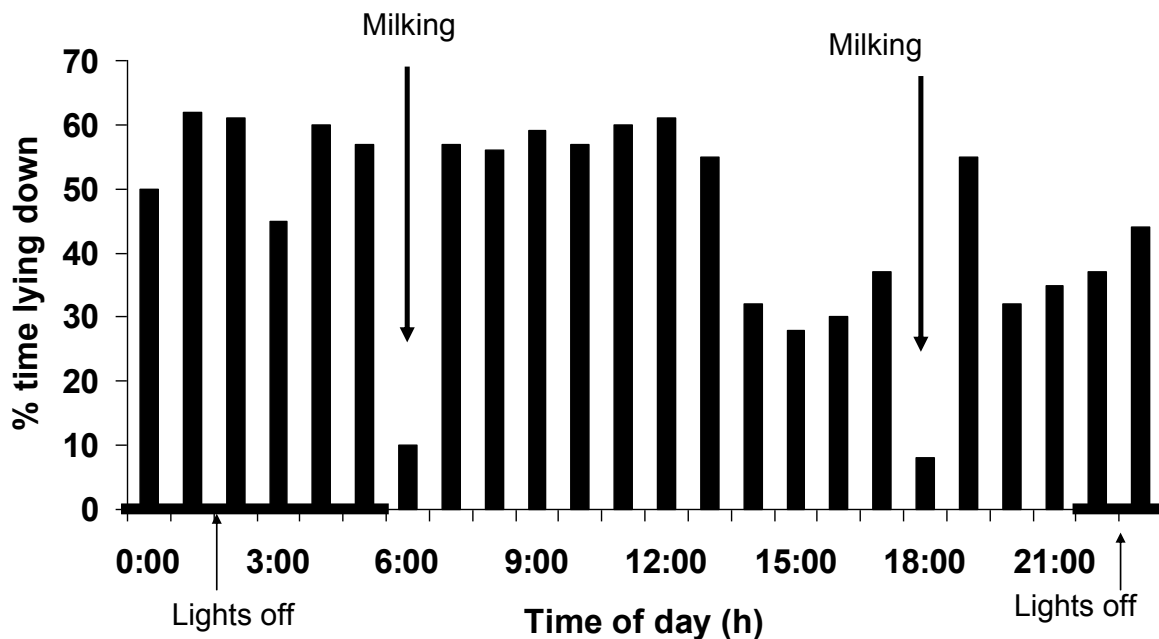


Figure 11 Mean percentage of cows' time lying down at given time of the day while kept in tie-stalls. Figure re-drawn from data presented in Haley et al (2000). The light was on from 06.00 to 21.00.

The motivation for lying in dairy cattle has been investigated in several experiments. In a study by Ruckebush (1974) cows were deprived of both feeding and lying (by use of a rope harness), except for a period of 4 h per day when they could do both. Initially, feeding appeared to be the priority behaviour with the cows spending most of the 4 h period feeding and very little time lying down. As the treatments continued however, the speed of eating was increased so that feeding time decreased, allowing the cattle to spend more time lying down. In another study, Metz (1985) prevented cattle from lying down for 3 hours each morning by placing them on slatted floors, and found that the amount of time lying in the subsequent period was increased, indicating that the cattle did attempt to compensate for the reduced lying time. In a second experiment the animals were also prevented from feeding for the same 3-hour period (Metz, 1985). When the cows had not been prevented from lying down, the feeding deprivation resulted in a significant reduction in lying time during the subsequent 3-hour period, because the animals were eating. However, when the cattle had been prevented from lying, the feeding deprivation did not result in a reduction in lying time during the subsequent period. This suggests that preventing cows from lying down can make lying a higher priority than feeding.

A number of more recent studies have further examined cows' motivation for lying down and compared it to their motivation for other activities. Munksgaard et al. (2005) limited the time

cows had available for eating, lying and social contact. Reducing the time with free access to the resources necessary for these behaviours reduced the time spent on all behaviours measured, but the proportion of time spent lying increased while the proportion of eating and social behaviour was constant. These results support the suggestions of Metz (1985) that lying time has a higher priority than eating. It has also been shown that the motivation to lie down in heifers increased with deprivation of lying time (Jensen et al., 2004a). Jensen et al. (2005) found that pregnant heifers were prepared to make an effort to lie down for 12-13 h/d suggesting that this is the average preferred resting time. Lying bouts longer than 20 mins also seem to be preferred to shorter bouts. Together these studies show that dairy cows are highly motivated to lie down for a considerable period of time and that lying down can take priority over feeding. The results indicate that cattle protect lying times and compensate for reduced resting times. From all these findings we can infer that cattle value lying down and will work to obtain it, indicating that insufficient lying will reduce the animals' welfare.

The effects of reduced lying times have also been investigated. In one study, lactating dairy cows were prevented from lying down for 2 periods of 7 h each day by the use of a specially designed harness. This resulted in reduced concentrations of growth hormone (Munksgaard and Løvendahl, 1993). Munksgaard and Simonsen (1996) noted that deprivation of resting behaviour in cows resulted in increased grooming, and tended to increase the incidence of licking the pen equipment. Although the duration of eating and ruminating was not affected, feeding tended to occur in more but shorter bouts and more rumination occurred while the animal was standing rather than lying down. Reduced concentrations of growth hormone (GRT), cortisol and ACTH, nor the cortisol response to ACTH were affected (Munksgaard and Løvendahl, 1993). In a similar experiment with growing bulls, deprivation of resting time did not affect basal cortisol or ACTH concentrations but tended to reduce cortisol and ACTH responses to CRF injections 3 days after treatment and increase cortisol responses to ACTH injections after 53 days of treatment (Munksgaard et al., 1999). Behavioural changes were also noted: use of the harnesses did not affect the total time spent eating or ruminating, but ruminating occurred in more frequent and presumably shorter bouts, mainly while the animal was standing. There was also an increase in the occurrence of licking and chewing the pen fixtures and an increase in the frequency of grooming. Overall, there was an increased frequency of transitions between behaviours, which the authors interpreted as due to frustration (Munksgaard et al., 1999). Fisher et al. (2002) prevented cows from lying down for a single 15 h period each day by using a harness that delivered a slight electrical shock each time the cow attempted to lie down. This reduced the time that the cows lay down from 8.1 hours per day to less than 4 hours per day. After 5 days basal cortisol concentrations were increased and ACTH and cortisol responses to CRF were reduced. Thus, deprivation of lying time has been found to result in some physiological signs of stress.

Increase in the chance of lameness is one of the most serious consequences for animal welfare of reducing the time that cattle can lie down (Leonard et al., 1994; Faull et al., 1996). However, lameness depends on the surface on which the cows are standing and walking. See chapter 14.5.2 for more references on the relationship between lameness and lying time.

6.6.2. Sleep

Wagnon (1963) found that 80% of the rumination took place when Hereford cows were lying. However, towards the end of the rumination bout cows may be slipping into drowsing, which usually turns into sleep. Adult cattle sleep for about 4h per day, mainly during the night time

(Ruckebush, 1972, 1974). Each sleeping bout consists of Slow Wave (SW) and Rapid Eye Movement (REM) sleep. Cattle normally sleep while lying down and must lie down when in REM sleep, which typically occurs in 2–8 min periods (Ruckebush, 1972; Ruckebusch, 1974). However, they can have non-Rapid Eye Movement (NREM) sleep when standing up if they are unable to lie down (Ruckebusch, 1974). It may be possible to judge whether or not a cow is sleeping rather than just drowsing by looking at resting postures. In calves, Hanninen et al. (2008) compared observations of resting postures with electroencephalography measures. Sleep was found to occur most often when the calf was resting with its neck relaxed and its head resting on the back or the ground.

A reduction in lying time due to poor housing is likely to have a more severe effect on animal welfare if the time spent sleeping is reduced. However, stall or cubicle design that prevents the animals from adopting the head postures associated with sleep could have a strong effect on animal welfare.

6.6.3. Lying down

The normal pattern of movements that cows use to lie down on pasture has been described in detail by Schnitzer (1971) and reviewed by Lidfors (1989). Cattle get up and lie down in a quite stereotyped pattern of movements (Figure 12). Before starting to lie down the cow walks slowly forward sniffing the ground, probably searching for a suitable lying place. The actual process of lying down occurs in a series of three movements: cows begin by bending the front legs, then fall onto the front knees, and finally let their abdomen and hindquarters fall sideward. As a last movement cow moves the front legs a bit forward allowing the belly a firm contact with the ground.

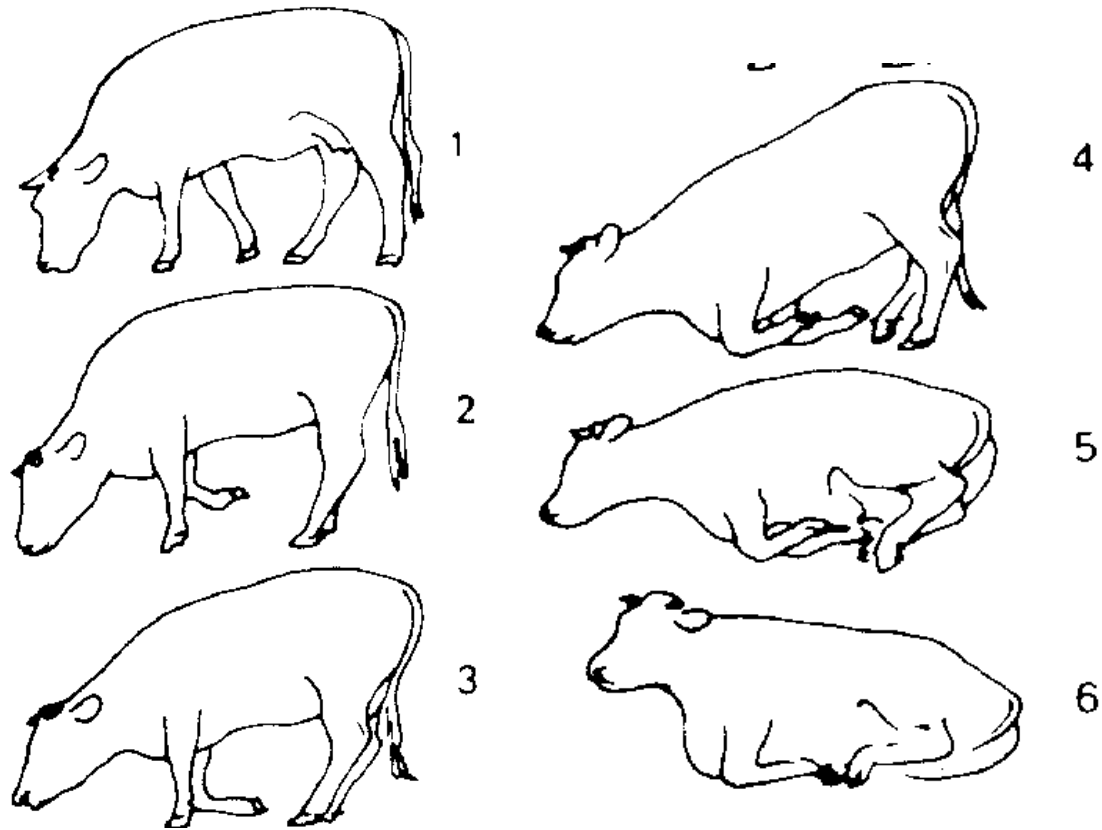


Figure 12 Sequence of movements of a cow lying down. Re-drawn from Schnitzer 1971.

On pasture dairy cows usually have no problems with lying down and it is mostly accomplished within some seconds (Lidfors, 1989). However, in tie stalls they may have problems to lie down due to bad design of the tethers (Mortensen, 1971), the manger edge being too high (Hoffman and Rist, 1975; Metzner, 1978), too short stalls (Hoffman and Rist, 1975) or a neck bow being in the way (Hoffman and Rist, 1975). When dairy cows have problems in lying down this will usually take much longer time, and it has been found that it took up to an hour from when the cow started to sniff on the floor until she was lying (Muller et al., 1989). Ladewig and von Borell (1988) found that it took 9 s from the first intention to lie down until the cow was lying on deep straw and 59 min in tethered cows. When cattle have problems lying down they may also have more interruptions before finally lying and fewer numbers of lying down (Kohli, 1987). Once they are lying they seem to compensate these problems by lying for a longer time (Mortensen, 1971). During the normal process of lying down, much of the weight of the cow is placed on her front knees. Hard floors in tie-stalls and in cubicles can lead to knee injuries, which make lying down painful (Rushen et al., 2007b). This will reduce the willingness of cows to lie down, which is apparent in a decreased frequency of bouts of lying down followed by an increase in the duration of bouts of standing (Haley et al., 2001). In cubicle housing the design of the cubicle can have detrimental effects on the cow's way of lying down (Koch, 1968; Sambras, 1971; Kämmer and Schnitzer, 1975; Kämmer and Tschanz, 1975; Oester, 1978; Kämmer, 1980; Kämmer, 1981). In most of the studies a lack of free space in front of the cow has caused changes in the movement pattern when lying down. The changes in behaviour observed was that cows were changing the

weight on their forelegs 14-19 times compared to 0-2 times on pasture (Kämmer, 1980; 1981). In addition, stall partitions hindered cows' sideway movements (Kammer and Schnitzer, 1975), interrupted the lying down sequence (Kämmer, 1980; 1981) or imposed laying-down through a sitting posture (Kämmer and Schnitzer, 1975).

In order to complete the lying movement sequence in the normal manner, the cows need sufficient space. Ceballos et al. (2004) provide some detailed measures of degree of displacement of various body parts when cows lie down and related this to the body dimensions of the cows. Cows used up to 76 cm (78% of back length) of forward lunge space and a total of 300 cm (300% of back length) of longitudinal space when lying down which was more than is typically provided by current industry recommendations for stall length. Most commonly the nose moved 60 cm during the lunge movement. Cows used up to 109 cm of lateral space (which was the equivalent of 180% of their hip width). Thus, stalls for cows should have a width of at least 180% of hip width and a length of at least 300% of back length. During the lying down movement, the maximal lateral movement of the hip occurred at two heights: one between 95 and 135 cm, and the second less than 50 cm above the lying surface. The maximal longitudinal movements of the nose occurred 10 to 30 cm above the surface. These heights should be taken into account when positioning stall partitions. The maximum velocity of body parts was 220 cm/s, which shows that the cows could hit inappropriately placed stall partitions and the lying surface with considerable force.

Udder distension due to the presence of a large amount of milk may also make lying down difficult. Osterman and Redbo (2001) found that cows milked three times a day lay down more quickly than those milked only twice a day.

6.6.4. Getting up

The normal getting up behaviour of dairy cows on pasture has been described in detailed (Schnitzer, 1971) and reviewed by Lidfors (1989). In short, the sequence of behaviours is the opposite of what occurs when they lay down. First, they gather their legs under the body, then they move their head and front body forward in a swinging movement, by this taking weight from the hindquarter, and then lift their hind part, after which they stretch out their front legs and when possible take a step forward and end by stretching their body (Schnitzer, 1971). The second phase of getting up has been compared with a jump on a spring-board (Schnitzer, 1971). The space needed in front of the cow for undisturbed getting up has been found to be 2.15 times the height at the cows withers (Oester, 1978), one third more than the length of the cow, i.e. 290 cm for a cow of 220 cm length (Kämmer and Tschanz, 1975), or twice the length of the back, i.e. 300 cm (Hoffmann and Rist, 1975). Ekesbo (1966) found that the cows head was positioned 60-70 cm in over the manger at the moment when she was getting up. Hoffman et al. (1975) found that during normal getting up the cow's muzzle moves on average 60 cm forward, the horns 70 cm, the shoulder joints 43 cm, the knee joints 15 cm, the front hooves 68 cm and the pelvis 60 cm.

When cubicles are too short, too narrow, the neck rail diagonal too low, stall fittings/bars or a wall installed in front of it, cows may alter the way they are getting up (see reviewed by Lidfors, 1989). The cow may then lift her head straight upwards during getting up, or extend her head sideways, and she may go through a horse-like getting up before standing (Kämmer and Tschanz, 1975; Kämmer, 1980; 1981). Furthermore, cows may hit the neck rail or fall down during their attempts to stand up.

If the tie stall is not suitable in its design the animals may have more problems standing up, and this may be done in a wrong way (Ekesbo, 1966; Mortensen, 1971; Hoffman and Rist, 1975; Metzner, 1978; Hennichs and Plym-Forsshell, 1984).

6.7. Bedding

The design, dimensions and bedding of cubicles in free-stalls and tie-stalls should meet the requirements of the cow. Cows should have enough freedom of movement to lie down and rise without restrictions. Lying conditions should promote lying down for 12-14 hours a day. The proposed dimensions of a cubicle for Holstein-Friesian cows are (Faull et al, 1996): the length >240 cm, the width >120 cm, a gradient of the laying bed of 2-4 %, and the bed should be situated 15-20 cm above the walking areas. Longer dimensions have been recommended like 250 – 260 cm (Danska anbefallningar, Nordlund and Cook 2003) and others even suggest that the length of the cubicles should be about 300 cm as cows take up 200% of their body length when laying down (Ceballos et al., 2004). Furthermore attention should be paid to other factors such as rails and boards that might restrict the positioning and movement of cows in cubicles.

A firm, dry and uniform bedding simulates best field conditions (pasture) or straw yard (Fregonesi et al., 2007b). Lying surfaces of dairy cows must therefore provide thermal comfort and softness, be durable and provide sufficient friction to allow rising and lying down without slipping. Moreover, they should help to keep the cows clean and healthy and minimise daily labour requirements (Chaplin et al., 2000).

There are different types of bedding material available:

- Deep litter, with straw, sand, saw dust and other materials. Composted bedding material also looks promising (Endres and Barberg, 2007). Deep litter is the best bedding material for cows provided that it is regularly refreshed in order to keep it dry, as organic bedding material can harbour some of the bacteria that cause mastitis (Zdanowicz et al., 2004). Other restrictions are the labour intensive and cost aspects of these materials.
- Mats and mattresses. Many different kinds of mats are available. For test results see www.dlg-test.de. They should meet the following requirements: be soft, be durable elastic, provide sufficient grip and be easy to clean. However, there are conflicting results concerning the effect of rubber mats on lameness (Cook et al., 2004). Other bedding materials like sawdust are used on top of mats or mattresses to overcome problems with the hardness of the mats and absorption of moisture on the mats and mattresses (Weary and Tazskun, 2000). Some disadvantages are however pointed out. After 5 years of use, many of them have lost their softness to a great degree, have developed depressions, hollows. Furthermore, the problem of disposal after use arises.

The time that cows spent lying down is a useful indicator of cow comfort and the quality of the bedding area (Tucker and Weary, 2001). Softer flooring surfaces reduce the incidence of swelling of the front knees, which occurs because cows get up and lay down by placing weight on their front knees (Rushen et al., 2007a).

However, there are limits to using lying-time to assess the comfort of the lying areas. For example, cows at pasture (which presumably is a comfortable surface) tend to lay down for

shorter periods of time than cows housed indoors. Furthermore, lame cows will lay down longer than cows that are not lame.

There is much evidence that cows prefer to lie down on softer surfaces, to spend more time on softer surfaces and that softer surfaces reduce injuries to both the front and hind legs (Herlin, 1997; Tucker and Weary, 2001; Rushen et al., 2007). Herlin (1997), Haley et al., (2001a) and Leonard et al. (1994) found that cows would spend more time lying down on comfort mats than on rubber mats and more time on rubber mats than on concrete. Lying time increased when concrete stalls were freshly bedded with straw or sand (O'Connell and Meary 1997; Jensen et al., 1988). Haley (2001a) compared 'high comfort' (large box, stall with mattresses) with 'low comfort' (tie-stall with concrete flooring) stalls. In the 'high comfort' stalls lying times were four hours longer, cows were more willing to rise and change positions and spent less time standing idle than in 'low comfort' stalls. Dairy cows showed a clear preference for a dry lying surface, and they spend much more time standing outside the stall when only wet bedding is available (Fregonesi et al., 2007b).

Hultgren (2001) showed that the type of flooring in tie-stalls has influence on cow behaviour. Cows, kept in stalls where the rear end had been replaced with rubber-coated slats, spent less time in preparing to lie down and slipped less frequently during rising. Cows preferred solid floors covered with rubber mats and straw compared to stalls with rubber mats and slats at the rear end when lying down. Tied dairy cows with daily exercise lay down more easily than tied cows without exercise (Gustafson, 1995).

Stall design also affects cow health, productivity and barn management (Tucker and Weary, 2001). Lower lying times can result in a reduction of growth hormone which might have a negative impact on growth in younger animals and milk production (Munksgaard and Simonsen, 1996). Cows spending less time lying down and more time on concrete alley ways appeared to have more claw disorders (Bell and Weary, 2000; Colam-Ainsworth et al., 1989).

Hock damage is one of the most common injuries in cattle. Poorly designed cubicles can restrict cows in getting up and lying down causing hock injuries (Weaver, 1997). Bedding appears to play a role in the prevalence of hock lesions (Weary and Taszkun, 2000; Rodenbrug et al 1994). They found that lesions were least common and less severe in stalls with sand or straw. Cows lying down on solid rubber mats had more lesions than cows lying down on geotextile mattresses. A significant negative relation was found between the length of the stall and the severity of the lesions. Pajor et al (2000a,b) found that geotextile mattresses reduced swelling of the front knees by half compared to concrete stalls with a small amount of straw, because mattresses better absorb the impact as cows lie down. Colam-Ainsworth et al (1989) found that the amount of straw on concrete influenced the prevalence of claw disorders. Heifers and cows kept in a straw yard had a much lower prevalence of haemorrhages of the sole and other claw disorders than heifers and cows kept in a free stall with comfort-cubicles (Webster, 2002; Somers et al, 2003). Cows on sand and some new organic materials (compost or material of separation from liquid dung) showed higher frequency of hock lesions compared with straw mattresses. The situation is much better compared with mats, mattresses or loose straw or sawdust (Zähner et al., 2007). Soft lying mats are equivalent to straw-mattresses regarding cow behaviour in temperate conditions (Wechsler et al. 2000), but cows prefer straw bedding in (cold) winter (Manninen et al., 2002). Sand is often recommended in cubicles to avoid mastitis, but cows prefer straw and soft lying mats (Manninen et al., 2002).

Table 6 compares lesions on dairy cows depending on the bedding material used. Wechsler et al. (2000) found that cows on soft lying mats/mattresses still develop more hock lesions and of higher severity compared with straw mattresses (a compact mattress of straw and dry dung composting after a while). Hock lesions were comparable on soft mats and hard rubber mats, and only somewhat lower and less severe on loose straw. A straw mattress was the only floor type where cows had almost no hock lesions (Buchwalder et al., 2000). The number of cows without any lesion can be summarised as: straw mattress: 89%; compost 59%, solid matters with separation from liquid manure: 59%; sand: 52%; small quantity of loose straw: 32%, comfort mats: 15%, rubber mats: 10% (Wechsler et al., 2000 and Buchwalder et al., 2000).

The effect of bedding material on udder health is an important consideration for farmers. It is generally thought that organic bedding material (e.g. saw dust) has higher bacterial counts than inorganic material (e.g. sand), leading to a higher bacterial load of the teats ends. Zdanowicz et al (2004) found more *E. coli* on sawdust and wood shavings but more *Streptococcus* on sand.

It may be assumed that higher bacteria loads can increase the risk of udder infections. However, there is little evidence for this assumption (Hogan et al, 1989; Groehn et al, 1992) and Reithmeier et al., (2004), found no difference between lying mats and straw mattresses in bacterial load indicating an important influence of management on this issue.

Table 6 Hock lesions on dairy cows depending on the bedding material used

Reference	Tie stalls	Cubicle system	Straw yards or deep bedded pack	Pasture
Dechamps et al., 1989	46,2%	52,9%		
Krohn & Munksgaard, 1993	12,5 h			10,1 h
Haley et al. 2000	10,5 h		14,7 h ¹	
Haley et al., 2001	10-13 h			
Rushen et al., 2007	8-10 h			
Manninen et al. 2002		10.8 – 12.9h		
Tucker et al., 2004		9,6-13,0 h ²		
Cook et al., 2004		11,7-12,0 h ³		
Drissler et al., 2005		11,4-13,7 h*		
Fregonesi et al., 2007		12,9 h		
Norring et al., 2008		11,2-13,7 h		
Fregonesi & Leaver, 2002		11,9-13,6 h	13,2-14,1 h	
Singh et al, 1994			9,7 h	
Endres & Barberg, 2007			9,3 h	
Dalley et al 1999				9.3–10.5h
Wales and Doyle 2003				7.17 h
Botheras 2006				6,7-10,1 h
Wechsler et al. 2000		9,93-13,27 h ⁴		

1) identical method as Wechsler et al. 2000

2) depending on type of mat: Kraiburg / Pasture / CowComfort / Mouflex

6.8. Locomotion, exercising and use of pasture

6.8.1. Locomotion

In cattle the most common gaits are walking, trotting and galloping, but they may also perform cantering, jumping, swimming and gamboling (Albright and Arave, 1997; Phillips, 2002). Gamboling, which is a combination of galloping or bucking movements is often observed in confined cattle when let out to graze, when they are released in a new large area or during play in young animals (Albright and Arave, 1997). Kicking and pawing, which may also be observed in cattle do not involve whole body movement (Phillips, 2002). In cattle the muscles are designed for forward movement where the centre of gravity is moved towards the front limb by the propulsive efforts of the hind limb, and the front limb is raised and repositioned to maintain the animal's balance (Nickel et al., 1986). The limbs may be positioned either in a symmetrical or an asymmetrical pattern (Phillips, 2002), and when cattle move faster they have fewer limbs supporting the body (Alexander, 1987).

6.8.2. Biomechanical aspects of locomotion

High speed of cinematography and kinematic analysis were used to measure various joint angles during walk of 17 multiparous dairy cows. Cows in cubicles had a smaller maximum angle of the elbow joint (Herline and Drevemo, 1997).

Walking is the slowest form of forward movement. The walking movements in cattle are similar to the movements in horses (Nickel et al., 1986). Flower et al. (2007) estimated walking speed to be 1.2m/s. There are three types of walk, the quick walk, normal walk and shortened walk (Nickel et al., 1986). During a step the two limbs on one side pass one after the other through the supporting limb and hanging limb stages, while the hindlimb, which provides the propulsive impetus, always moves before the ipsilateral forelimb (Nickel et al., 1986). The feet are both moved and placed on the ground in the following sequence; right hind, right fore, left hind and left fore (Nickel et al., 1986). Walking is carried out in different stages and can shortly be described as: lifting, swinging, supporting and thrusting, where the two first limbs are hanging and the last two limbs are supporting the animal's body (Phillips, 2002). For a more detailed description see Nickel et al. (1986) and Phillips (2002). Flower et al. (2005) have recently used kinematics to describe the walk of dairy cows. The amount of time that three hooves are on the ground appears to be an important variable related to lameness (Flower et al., 2007). It is desired that cattle walk with feet and legs straight. It is especially undesirable if lactating cows have their rear feet pointed outwards because the hocks then tend to point inward and then may rub against the udder (Albright and Arave, 1997). Some traits of dairy cows, for example weak pasterns, hocks with too much or not enough set, shallow heels and toes that spread, may change the cows gait and eventually lead to lameness (see Chapter 14). The presence of milk in the udder can also affect gait (Webster, 1993; Flower et al., 2006).

Methods used to identify lame cows are recording lesions of claws at trimming (Manske, 2002), assessing the back angle, (Sprecher et al., 1997) and estimating hind feet positions (Bulgarelli-Jimenez et al., 1996), see chapter 9 on lameness.

The way that the body weight is distributed over cows' hooves during walking can influence the development of lameness. In the hind limbs, the lateral claw touches the ground before the medial claw (Schmid et al., 2008) and almost all of the ground reaction force during the heel strike is exerted on the lateral claw (van der Tol et al., 2003). This may explain why lesions

are more often found in the lateral claw. The high forces exerted on the hooves during walking on concrete floors can constitute a major threat to the health of the hoof. Effective hoof trimming can increase the weight-bearing contact area, resulting in a significant decrease in average pressure (Van der Tol et al., 2004).

The way in which claws were placed on a treadmill was investigated in heifers before and after claw trimming (Meyer et al., 2007). The heifers were found to place their front feet on the ground in a plane sagittal to the shoulders, whereas the hind feet were advanced more toward the median plane (Meyer et al., 2007). Claw trimming leads to the lateral claws contacting the ground before the medial in 92% of the front limbs compared to 83% before trimming, and in 97% of the hinds limbs compared to 100% before trimming (Meyer et al., 2007). The claw trimming led to several other changes in how different parts of the claw made initial contact with the ground during walking (see Meyer et al., 2007).

Good descriptions of how cows walk can improve our ability to detect changes in gait that may signify lameness. A number of articles have used kinematic and other techniques to describe these changes (Flower et al., 2006; 2007; Telezhenko and Bergsten, 2005)

Trotting is a symmetrical gait with diagonally opposite limbs used synchronously, and it is used for long-distance locomotion where a faster gait than walk is required (Phillips, 2002). Dairy cows tend to change from a walk to a trot when the recovery of maximal mechanical energy from the muscles during the fast walk is exceeded and approaches zero, about 5 km/h. (Gustafson and Lund-Magnusson, 1995). Trotting is frequently used by cows with full udders, especially if forced by a herdsman when moving to the milking unit, as the forces on the udder can be absorbed in a rhythmical swinging motion (Phillips, 2002). However, Albright and Arave (1997) point out that if lactating cows are hurried to this speed, rubbing by hocks and thighs can be injurious.

Gallop is the fastest gait where the cows show an asymmetrical step pattern and a lengthened free-gliding phase (Phillips, 2002). There is a leading front limb, followed by the other front limb, then a pause after which the two hind limbs are placed on the ground, one fractionally before the other (Phillips, 2002). Albright and Arave (1997) describes the change from a trot to a gallop as when the upper limit of the “capacity of the elastic elements of the limbs to absorb and redistribute the external power needed for the vertical and forward forces” is reached (Gustafson and Lund-Magnussen, 1995). Free-ranging cattle will trot or gallop when being chased by heel flies, being chased by a dog or when rejoining a group following separation (Albright and Arave, 1997). Dairy cows are often observed to gallop when released to pasture, especially after being tied for a longer period (Loberg et al., 2004).

6.8.3. Motivation for locomotion

The motivation for movement in cattle is believed to be caused by many different factors both genotypic and environmental, such as demand for food, water, companionship, shelter, grooming, sexual partner, space and several other resources (Zeeb, 1983). The motivation increases with the duration and severity of resource restriction, especially space (Dellmeier et al., 1990). Albright and Arave (1997) write that cattle are motivated for locomotion and to be mobile.

In 17 studies of free-ranging cattle kept on pastures ranging from 0.1-2000 ha, it was found that they walked 0.9-12.6 km daily (Arnold and Dudzinski, 1978). The mean distance walked was 3.14 km daily, and half of the distance walked was explained by the variation in acreage (Albright and Arave, 1997). When dairy cows had access to a drylot and pasture during the

whole year round they walked 2.5 km during the summer, but only 0.8 km during the winter (Krohn et al., 1992). It has been recommended that cattle should walk one hour per day at about 3-4 km/hour (Phillips, 2002). In loose-housing systems dairy cows are able to move freely. Cows in a cubicle house were found to walk 2-4 km/day (Schofield et al., 1991). In another study cows were found to walk only 600-700 m daily (Bockisch, 1993). Floor properties and lighting may have played a role in the later study, because if the floor is slippery or the building is poorly lit cattle take shorter stride lengths and walk slower (Phillips, 2002). Space in the walking areas is one of the most important conditions for sufficient locomotion activity though it is usually heavily compromised in the modern cubicle barns.

6.8.4. Exercise

If dairy cows have a high motivation for locomotion problems may arise when they are tied all year around or during the winter period. Phillips (2002) states that today's cattle need exercise to keep healthy and productive. Regular exercise of tethered cattle leads to increased muscle and bone growth in growing animals (Melizi, 1985), prevents limb disorders, especially arthritis in bulls for semen collection. It has been shown that walking reduced the concentration of nonesterified fatty acids in the blood, which could imply a decreased likelihood of metabolic and digestive disorders (Adewuyi et al., 2006). A study comparing dairy cows tied up for four years without being released even during the summer with tied cows which were released once a day, forced to walk one km away from the barn and then allowed to walk back at their own speed showed that the cows had fewer feet and leg problems (Gustafson, 1993), and fewer problems in getting up and lying down (Gustafson and Lund-Magnussen, 1995). A study comparing tied dairy cows allowed to exercise every day, twice a week or once a week found that the cows performed more walking and trotting and more exploration with decreased access to exercise (Loberg et al., 2004). The same cows performed less rumination with decreasing access to exercise (Loberg et al., 2004). Whilst cows are tied they are unable to show some normal movements, including grooming and social interactions, that all cows will show if given the opportunity (Phillips 2002).

However, there may also be negative aspects of exercise. Cattle may be subjected to too much exercise, as in Africa where cattle have to make long-distance walks to water every 2-3 days. These walks can be up to 40 km, resulting in reduced feed intake and milk production (Homewood et al., 1987; Nicholson, 1989). In a French study dairy cows had to walk 9.6 km per day once a day for 23 days and were compared with cows remaining in the barn (Coulon et al., 1998). The exercised cows ate less hay and produced less milk, and this lower production stayed for at least 10 days after the exercise stopped (Coulon et al., 1998). However, the fat content and protein content in milk were higher, but the somatic cell count was also higher in the exercised cows (Coulon et al., 1998). Dry dairy cows and heifers which were forced to exercise daily in a circular electrically driven exerciser for different distances and in different speed had increased blood glucocorticoid concentration post-exercise (Arave et al., 1978). The conclusion was that cattle are stressed when forced to walk faster than 5 km per h. (Albright and Arave, 1997). Two year old Holstein heifers exercised on a treadmill for 30 min. at a 9% slope showed increased heart rate, respiration rate, rectal temperature and serum glucocorticoids (Arave et al., 1987).

It may be questioned whether cows prefer to be exercise outdoors or indoors. One study examined tied dairy cows' preference to walk outdoors or indoors when the cows could make an instantaneous choice (Loberg, 2005). Of the 10 cows tested five times each 2 cows always

chose to walk to the indoor exercise, 2 cows chose four out of five times the indoor exercise and 3 cows chose the outdoor exercise four out of the five times (Loberg, 2005). Because the cows were released indoors, it could be questioned whether they understood if they made the right choice, another test was done. In this study, 22 cows were released during 20 minutes in an area where half of it was indoors and the other half outdoors (Loberg et al., 2004; Loberg, 2005). There was no difference in the time cows spent indoor or outdoor, but there were large individual differences (Loberg et al., 2004; Loberg, 2005). The time spent outdoors decreased with increasing temperature within the temperature range from -1.3 to +11,7 °C, but there were no effects of wind speed, humidity, intensity of light or amount of rain and snow on time spent outdoors (Loberg et al., 2004; Loberg, 2005). Based on these two experiments tied dairy cows do not seem to show a preference for being exercised either indoors or outdoors.

On organic/ecological farms in EU cows housed in tie systems have to be exercised regularly from 24 of August 2000 (EC directive 1804/1999). After the 31st of December 2010 all dairy cows on organic/ecological farms in EU must be kept in some kind of loose housing (EC directive 1804/1999). After this time it is still allowed to keep cows on organic/ecological farms in tied housing in cases of “small farms if it is not possible to keep the cows in groups which are suitable for their special needs”, but they then have to give the cows’ access to regular exercise (EC directive 1804/1999). At the time of the decision of these regulations there was not much research available on how often cows need to be exercised. In Sweden the Board of Agriculture therefore initiated and financed a project on how frequently tied dairy cows should be exercised and the practical consequences for the farmers of carrying out the exercise (Loberg and Lidfors, 2001; 2002).

During two winters nine private farms that had chosen to exercise their cows from twice a month to three times a week were visited 2-3 times (Loberg and Lidfors, 2002). The cows were most active directly after being let out, but if the exercise continued for more than 30 minutes there were recordings when all cows in the group were standing still (Loberg and Lidfors, 2002). Only on one of the nine farms during one of the observations did the cows lie down during the exercise, but they were kept outside for 5 hours and the ground consisted of grass (Loberg and Lidfors, 2002). The number of social interactions was on a relatively constant level during the whole exercise (Loberg and Lidfors, 2002). When the cows were released from their ties in order to be let out, the most common behaviour was slipping during the first year, but during the second year no cows were observed to slip and fall (Loberg and Lidfors, 2002). It was about 50-70% of the cows that went to the wrong place when returning into the barn, and for farmers that wanted the cows to come back to exactly the same place it took a long time to tie them up again after the exercise (Loberg and Lidfors, 2002).

In order to investigate what farmers think about exercising tied dairy cows a questionnaire was sent to all organic/ecological farms with a tied system in Sweden 2001, and of the 361 farms 224 replied (62.2% reply rate) (Loberg and Lidfors, 2002). Only 22% of the replying farms had attempted to exercise their cows, however some only exercised their dry cows and some released their cows so that they could walk to the milking parlour twice a day (Loberg and Lidfors, 2002). Regarding how often the farmers would be prepared to exercise their tied cows 61% replied that they could exercise them once a week or more often. Regarding the positive effects, the farmers appreciated for the cows, 121 farmers replied movement, and other replies were healthier cows and that it was mentally good for the cows (Loberg and Lidfors, 2002). The negative aspect of exercise was any form of physical ill health caused by injuries during the exercise (Loberg and Lidfors, 2002).

Walton and King (1986) reported that in the Great Lakes and north eastern states of USA most dairy farms with tie stalls provide outside exercise one or more times daily, which also allows management to observe cows for oestrus. In Sweden farmers have kept cows tied indoors during the winter since the middle ages, but at that time some farmers let the cows out to let them drink water from a hole in the ice (Myrdal, 1999). During adverse weather conditions the farmer had to bring the water into the barn (Myrdal, 1999).

6.8.5. Effects of housing on locomotion and exercise

There are some results showing that loose-housing (Krohn and Munksgaard, 1993; Krohn and Munksgaard, 1994; Weary and Taszkun, 2000) and regular outdoor exercise (Gustafson, 1993; Gustafson and Lund-Magnussen, 1995) have positive effects on health and welfare of dairy cows. In a study on 134 farms in Switzerland where dairy cows during the winter were either tied (control), tied with regular exercise or kept in loose-housing with regular exercise, it was found that the odds for lameness was lower in tied cows with exercise (Regula et al., 2004). Further, the prevalence of alterations at the hock joints and the incidence of medical treatments were lower in the loose housing with exercise (Regula et al., 2004). The frequency of teat injuries was lower in both loose housing with exercise and tied housing with exercise (Regula et al., 2004).

6.8.6. Why are dairy cows not kept on pasture?

In many parts of the world, dairy cattle are housed indoors for at least part of the year. This is done because of the lack of forage, because the animals destroy the forage when treading on it (Phillips, 2002) or, most commonly, for protection against climatic influences during the cold part of the year. When indoors, cattle can be fed conserved grass (silage), dried cereal grain (concentrate) or total mixed ration. With this feeding regime it is possible to increase the cows' total intake of nutrients over what she can accomplish on only grass, and thus ensure that she gets enough nutrition to produce the high amount of milk she has been bred to produce. Higher milk production can be achieved with controlled grain feeding (Washburn et al., 2002). This will in the long run ensure that the dairy cow does not lack energy, and loose body condition due to the milk production. Cows on pasture tend to produce less milk and eat a different diet than cows without access to pasture (White et al., 2002). However, in some parts of the world, i.e. Australia and New Zealand, it appears possible to get a fairly high milk production from dairy cows that only feed from the pasture.

Over the last decades robotic milking systems have been developed and spread throughout Europe (section 11.1.3). These make it more difficult to keep the cows on pasture, because an individual cow has to take a decision to walk back to the milking parlour at regular intervals without being synchronised with the rest of the herd. It has been shown that dairy cows do not walk all the way out to pasture when it is too far from the milking robot, but rather lie down in the passage ways out to pasture, probably so that the distance they have to walk back will not become too large (Spörndly and Wredle, 2004). In one study dairy cows were provided with a device attached to the ear tag that produced a sound when it was time for the cow to walk back to the milking parlour (Wredle et al., 2004). The cows also received concentrate when visiting the robot without any auditory signal. The system worked during development on a small number of cows (Wredle et al., 2004), but did not work satisfactorily on a larger number of animals, i.e. too few animals reacted after the sound signal by walking to the milking parlour (Wredle et al., 2006). The robotic milking system puts a demand on the farm to have

enough pasture close to the barn so that the cows can combine grazing with being milked and also feeding on concentrate and silage in the barn.

6.8.7. Effect of access to pasture on health

There is a large number of studies showing that cows kept on pasture are healthier. Summer access to pasture has been found to reduce mortality of dairy cows in Denmark (Thomsen et al. 2006; Thomsen et al., 2007). A number of epidemiological or experimental studies in different countries have found that lactating cows without access to pasture suffer from a higher incidence of a variety of health problems including mastitis (Bendixen et al., 1986b; Bendixen et al., 1988a; Waage et al., 1998; Barkema et al., 1999a; 1999b; Washburn et al., 2002; White et al., 2002), tramped teats (Ekesbo, 1966; Geer and Grommers, 1975; Bendixen et al., 1986b), metritis (Bruun et al., 2002), *Salmonella enterica* infections (Veling et al., 2002), dystocia (Bendixen et al., 1986a), retained placenta (Bendixen et al., 1987a) and ketosis (Bendixen et al., 1987c). Hock and knee injuries are also more common when cows have no or limited access to pasture (Haskell et al., 2006, Rutherford et al., 2008). Thus, zero-grazing can be considered to increase the likelihood of all of these health problems. In a large epidemiological study on Swedish dairy cows where tied cows were compared when tied and when kept on pasture during summer time with loose housed cows with no summer pasture (Bendixen et al., 1986a; 1987a; 1987b; 1987c; 1988a; 1988b) there were no significant effects of access to pasture on the relative likelihood of parturient paresis (Bendixen et al., 1987b) or tramped teats (Bendixen et al., 1988b). However, tramped teats have been found to be lower in cows on pasture in other studies (Ekesbo, 1966; Geer and Grommers, 1975; Bendixen et al., 1986b). The reason for not finding an effect in the study by Bendixen et al. (1988b) may be due to many other factors having a greater influence on the chance of tramped teats than pasture. Washburn et al. (2002) reported that cows without access to pasture had 1.8 times as many clinical cases of mastitis and were 8 times more likely to be culled for mastitis in comparison to cows at pasture. The studies do not allow us to identify the actual cause of the difference but providing cows with access to an exercise area or dry-lot does not seem sufficient (Bruun et al., 2002; Washburn et al., 2002). Green et al (2008a) found the chance of having non-ambulatory cattle to be 4 times higher when the predominant flooring area was not pasture compared to when it was pasture. Another important aspect of giving dairy cows access to pasture is that they get vitamin D through the radiation of the skin. Vitamin D is the principal regulator of calcium homeostasis, and is important in skeletal development and bone mineralization, as well as for cell proliferation and the immune system (Horts et al., 1994; Holick, 2003; Mikkelsen, 2006). It has been found that solar ultraviolet (UV) radiation can supply the body with up to 80-100% of its requirements of vitamin D (Pfeifer et al., 2002). It is the UV radiation with wavelengths between 290 and 315 nm that can penetrate the epidermis and photochemically initiates the vitamin D₃ synthesis (Mikkelsen, 2006). In pasture-grazed dairy cows with no supplementation of vitamin D there was a seasonal variation of vitamin D₃ in the milk with the maximum level being reached during the summer period (Kurmann and Indyk, 1994). Flachowsky et al. (1993) found that the duration of sunshine and the UV intensity influenced the plasma concentration of vitamin D in cows. However, in the northern hemisphere the sun may not be able to supply cows being out-doors during the winter time with enough vitamin D, as required on some organic farms where D vitamins are not given in the feed. On two Danish farms it was found that the dairy cows on one farm managed a winter season without critically low vitamin D concentrations, where as most cows on the second farm had vitamin D status below normal at the end of the winter (Mikkelsen, 2006). In the early months of spring the solar radiation could, to some extent

supply the cows with vitamin D (Mikkelsen, 2006). Access to summer pasture will, however, give the dairy cows enough solar UV radiation to carry out endogenous synthesis of vitamin D₃ in the skin (Horst et al., 1994).

6.8.8. Effect of access to pasture on lameness

The most commonly reported welfare problem associated with restricted grazing is lameness (see Chapter 14). A large epidemiological survey of 4 516 dairy farms in the US, found that a lack of access to pasture in winter was a significant risk factor for a high incidence of digital dermatitis, and that providing access to a dry-lot was not sufficient to overcome this (Wells et al., 1999). Nearly four times as many farms on which cows had no access to pasture had a high (>5%) incidence of dermatitis than farms on which cows were kept only on pasture (Wells et al., 1999). A smaller study in Chile (Rodriguez-Lainz et al., 1999) found supporting results: cattle housed permanently at pasture had a lower probability of developing digital dermatitis than cows housed in buildings for some of the year. This suggests that occasional or seasonal exposure to confinement housing may be as important as the complete absence of grazing. In countries as large as the US and Chile, the type of housing used varies greatly depending on the region, and climatic differences could conceivably account for some of the effects of housing. However, similar effects of a lack of grazing have been noted in smaller countries, which do not have such climatic variation. An epidemiological survey of 86 dairy farms in the Netherlands (Somers et al., 2003) reported that all types of hoof disorders were more prevalent in cows in zero-grazing systems than among cows with some access to pasture. Again, the difference was substantial: the prevalence of severe cases of sole haemorrhage was twice as high with zero-grazing compared to other housing systems. Even where cows had some seasonal access to pasture, hoof disorders (but not digital dermatitis) were more prevalent during the period of indoor housing compared to the end of the period of summer access to pasture. In Kenya, where some dairy farmers use zero-grazing, the prevalence of lameness is lower in farms where cows have some access to pasture (Gitau et al., 1996). A survey of 37 farms in the UK found a higher prevalence of lameness in cows that could not graze compared to cows that have some ability to graze (prevalence of 39% versus 15%) as well as a higher frequency of swollen knees (Haskell et al., 2006). In Switzerland, the odds ratio for a cow being lame was higher in cows kept in tie stalls with no winter access to pasture compared to cows kept in tie stalls with continuous access to pasture (Regula et al., 2004). Recent work indicates that even a short period of access to pasture can reduce lameness. When a matched sample of cows were either kept in a free-stall barn or moved out onto pasture, cows on pasture showed a dramatic improvement in gait just over four weeks of exposure (Hernandez-Mendo et al., 2007). However, some studies report an increased occurrence of digital dermatitis (Holzauer et al. 2006) or of interdigital necrobacillosis (Alban et al. 1997) when cows do have access to pasture.

Although these studies indicate that lameness and hoof problems of various sorts are less common for cattle with some access to pasture, they do not allow us to isolate the cause of this difference. Cows in indoor housing are more likely to be standing in manure and on concrete, and eating more grain than cows at pasture, all of which increase the likelihood of lameness (see Chapter 14).

6.8.9. Welfare problems associated with pasture

Cattle at pasture are not all free of welfare problems. Cattle at pasture can be exposed to inclement weather, increased parasite load, flies and gad-flies, inadequate energy intake, toxic

plants and high competition for feed if stocking rates are too high. In many regions of the world cattle are housed continuously on pasture and must meet their nutritional requirements through the consumption of native herbage. Although, this provides a 'natural' diet and freedom of movement, risks to animal welfare arise when either the availability or quality of the grass is low. Even brief periods of feed deprivation cause some hunger in cows (Schutz et al., 2006). Longer-term effects of inadequate food intake include lost body weight and body condition (Stockdale, 2001). When the herbage quality is low in digestibility and protein quality, cattle are known to lose more than 10% of their weight (Ritter and Sorrenson, 1985). Cows can lose body condition and weight especially after calving when kept on pasture, which can be a cause for concern (Fontanelli et al., 2005). Poor body condition can also increase the risk of disease such as milk fever (Roche and Berry, 2006). Furthermore, the use of some forms of grass at pasture can increase the chance of sub-acute ruminal acidosis (O'Grady et al., 2008). When cattle are kept outdoors over winter, the design of the winter pens can influence a number of health parameters (O'Driscoll et al., 2008a,b). Poorly designed outdoor pens can increase the chance of some hoof lesions above those found in indoor housing (O'Driscoll et al., 2008a).

Even at pasture, cattle can compete for food (Phillips and Rind, 2001) so that the degree of social competition can be one factor that influences the relative advantage of indoor versus outdoor housing. The risks to welfare associated with poor grazing conditions should not be underestimated.

However, for most European dairy cattle this seems to be a minor problem compared to the verified health and welfare problems associated with zero-grazing. In general there is little information available on the welfare problems associated with outdoor rearing of cattle, and key issues are well summarised in two reviews on this topic (Hemsworth et al., 1995; Petherick, 2005). The insufficient amount of information might indicate that there are small health and welfare problems associated with keeping cattle on pasture, except parasite infections, when the pastures are intensively used year after year.

Walkways from a barn to a pasture may become very muddy when the cows have to walk back and forth on them twice a day to be milked. This may lead to cows' becoming dirty from mud, and may decrease the cows' comfort and ability to keep the temperature when the weather is cold. The type of ground and the amount of rainfall have an important influence making the ground muddy. Poorly maintained outdoor walking tracks can also increase certain types of lameness due to hoof injuries (Chesterton et al., 1989)

On pasture it is also important that the dairy cows have easy access to clean water where they can drink as much as they need without competing with other cows in the herd. The dominance order that develops for priority of access to water does not necessarily accord with the social hierarchy (Andersson, 1987). If there are any sort of water available in lakes, rivers, ponds, etc cows prefer to drink from them and may be infected if the water is not clean. They can also urinate and defecate in this water and thus contaminate the water. If the distance from where the herd is grazing to the water is more than 250 m, water intake is likely to decrease, but it is the extra intake that is reduced and not the intake required for physiological purposes (Phillips, 2002). The chance of drowning should not be neglected if drinking-water supply in rivers, ponds etc. are not arranged so that cattle cannot get stuck (Ingvar Ekesbo, pers. comm.).

The effects of heat stress can be especially important for cows kept outside, at least in some areas south of latitude 55° north in the northern hemisphere, especially when shade is not

available. A recent study from New Zealand investigated to what extent dairy cows seek shade from the sun when they had free access to shade cloths that blocked 25%, 50% or 99% of solar radiation (Tucker et al., 2007). The cows spent more time under shade cloths that gave the most protection from the sun, and time spent in shade was positively related to ambient solar radiation (Tucker et al., 2007). A number of experiments have shown the advantage of providing shade to dairy cattle housed outdoors (reviewed by Armstrong 1994; Silanikova 2000). More information about the cows' response to heat and solar radiation can be found in chapter 11.4.

Much less is known about the effects of cold, although one recent study (Tucker et al., 2008) compared behaviour and cortisol responses in cows kept indoors or outdoors under wet and windy conditions in New Zealand during the winter. Cows kept outdoors spent less time lying down, likely because of the wet lying surface, (Keys et al., 1976) and experienced higher cortisol levels. Moreover, the negative effects of the wet, windy conditions were most evident for cows that were low in body condition (i.e. relatively thin), indicating that poor food availability, typical of winter pasture, may aggravate the welfare effects of harsh climatic conditions. For more information on the effect of cold climate on dairy cows see chapter 11.4. Clearly, environmental conditions such as extreme cold or hot weather, wind, and rain will play a significant role in the welfare of dairy cows.

6.8.10. Difficulties in comparing access to pasture with different housing systems

It is quite difficult to compare the effect of access to pasture on the dairy cows health and welfare due to several reasons. Farms vary greatly in how much access to grazing the cows have. In some systems, cows are kept at pasture all the time. In others they have access at certain times e.g. during the summer or during the day. In true zero-grazing systems, cows have no access to pasture at all. Thus, it is needed to know whether the effects on animal welfare are due to the complete absence of access to pasture or the occasional use of indoor housing. Furthermore, zero-grazing systems differ from pasture-based systems in many respects. For example, air quality, the types of surface on which the cows walk and lie down, the stocking rates used and even light/dark cycles may be different. It is difficult to determine which of these factors may be responsible for any difference in welfare. Furthermore, there is always the possibility that some modification of indoor housing systems (e.g. using a different type of ventilation or flooring) would raise the welfare of cows in zero-grazing systems to a similar or higher level than found at pasture. For these reasons, any results concerning the effect of grazing on the welfare of cattle must be interpreted with care. It should not be assumed that providing cows with access to pasture will automatically improve their welfare, or that a high level of animal welfare cannot be achieved in zero-grazing systems (Rushen et al., 2008). However, at present, it is not possible to guarantee that indoor housing without access to pasture will result in the same or better level of welfare that could be achieved if the cows could have access to pasture.

6.9. Flooring

Floors and walking surfaces are important aspects of cattle housing concerning welfare of cows. Unrestricted and painless locomotion is crucial for cows in loose houses to successfully satisfy their biological and social needs (Metz and Bracke, 2003). Floors can have a significant impact on claw and leg disorders. A floor should meet requirements concerning hardness, roughness and slipperiness (Nilsson, 1992). Moreover, the surface of the floor should be clean and dry (Bergsten, 2001). The hardness of the walking alleys determines the

load on legs, joints and claws. Cows have a preference for softer walking alleys. Softer walking surfaces promote free locomotion due to the fact that the claws have a better contact with the floor. Rough floors lead to an unbalance between growth and wearing off the horn of the claws. Moreover, rough floors lead to high pressure points on the sole of the claw. The slipperiness of a floor can be expressed with a friction coefficient. The friction coefficient is expressed in Leroux values. Floors with a Leroux value between 50 and 70 promote locomotion. Floors with a Leroux value of less than 40 are too slippery and with a value of more than 70 deliver too much resistance (Swierstra et al., 2001). Stefanowska et al (1998) indicated that wet, manure contaminated, walking alleys and alleys with a gradient have a negative impact on free locomotion. Frequent use of manure scrapers over a longer period of time negatively influences the friction coefficient of floors.

The following cow problems related to the characteristics of the floor can be defined: 1) The number of slip accidents, depending on the surface of the walking alleys and the behaviour of the farmer; 2) The maximum pressure on the sole of the claw causes problems if it exceeds 19 N/cm² and 1950 N during walking; and 3) Claw and leg disorders (see chapter 14).

In cubicle-houses (= free stalls), concrete flooring either solid or slatted, is common. Concrete flooring has primarily been introduced for labour reasons. The abrasive and unyielding nature of concrete has been associated with a high rate of claw horn growth (Murphy and Hannan, 1987) and can cause claws to be deformed (Hahn et al., 1986). This can lead to an overburden of the lateral hind claw and trauma of the corium (Tousaint Raven, 1985, van der Tol et al., 2003). Straw yards are better than concrete flooring systems regarding claw health and locomotion (Somers et al, 2003; Somers et al 2005). Telezhenko and Bergsten (2005) and Flower et al. (2007) describe the influence of different floor types on the locomotion of dairy cows.

Vokey et al (2001) found no significant effect of rubber alleys on claw lesions and lameness, but did point to the complex interaction between cubicle type and walking surface. They recommended rubber alleys in high traffic areas. Jungbluth et al (2003) conducted a study on flooring in free stalls on the basis that soft rubber mats improve claw health and slip resistance. Less slipping was detected on rubber mats than on concrete floors. Step length on soft slatted floors was similar to pasture. Activity and walking speed increased on soft floors when compared to concrete slats. More frequent caudal licking, an indication how stable a cow feels, was measured on rubber floors. They also found a positive effect of soft floors on claw health.

Mechanical loads of the claws provoked by hard and slippery floors have specific negative impact on the claws of cows (Hinterhofer et al., 2007; van der Tol et al., 2003). Tarlton et al. (2002) described the effect of the mechanical load on those floors in the periparturient period due to weakening of the connective tissue of the hoof suspensory apparatus (Tarlton et al., 2002). Time spent standing with the claws in wet conditions reduces hoof hardness and thus makes them more susceptible to injuries (Borderas et al., 2004). On concrete flooring cows have a higher risk for claw disorders than on other floorings such as pasture and straw yards (Somers et al., 2002). Recently several studies have been presented on the positive effect of rubber flooring on claw health (Kremer et al., 2006). However other studies highlight the importance of a correct and frequent trimming in dairy herds kept on rubber flooring as well as for those kept on concrete slatted flooring (Kremer et al., 2007). Several studies (Vokey et al., 2001 and Vanegas et al., 2006) pointed to the positive effect for cows of rubber alley mats in combination with sand beds compared to cows kept on concrete alleys with concrete stalls or bedded with mattresses.

Telezhenko et al. (2007) show the cows' preference for softer flooring when standing or walking.

Farm tracks should be suitable for cows to walk freely (Clackson and Ward, 1991). Ideal track surfaces are defined as soft field, smooth swept tarmac, grassy track without stones. Stockman's herding practices also influence the free walking of cows. Good herding practices are described as walking at least 1 meter from the herd, talking quietly and no dogs, tractors or quads are used. To reduce lameness in summer, farm tracks should be maintained and patience employed during herding.

6.10. Cleanliness

Intensive milk production with high-yielding cows on intensive diets results in the production of manure with a higher water content and thus a larger spread of manure in the stalls. Estimations made of annual amounts of faeces and urine from cows kept on intensive feeding and yielding 8000 kg milk annually discard about 32 kg faeces and 16 kg urine daily (Statens Jordbruksverk, 1995). Studies show that cows defecate 9-15 times and urinate 4-10 times per 24h (Sahara et al., 1990; Phillips, 1993). Aland et al. (2002) showed that frequencies of defecation and urination did not vary with milk yield or feeding intensity and that the frequency of eliminations is lowest during diurnal resting periods. Manure contamination of the fur of cows may result in an increased need for comfort behaviour and a reduced thermoregulatory function. The removal of mud and faeces and the subsequent reduction in the risk of disease are suggested to be a hygienic function of grooming (Fraser and Broom, 1990; Kohari et al., 2002)

For tied cows, the use of cow trainers has been applied to reduce manure contamination of the cow and to improve cleanliness and foot health. For cow trainers, see chapter 11.11.1. Assessment of cleanliness is possible to conduct during regular slaughter procedures. Several methods for scoring of cleanliness prevail. One such method is regularly applied by the Swedish Meat Industry Association to assess cleanliness of cattle at slaughter. With the use of rubber slats at the rear end of the stanchion, cleanliness of cows were shown to improve and the risk of getting dirty was lowered (OR 0.12 for hind feet, 0.39 for hind legs and 0.38 for thighs and udder in stalls with dividers) (Hultgren and Bergsten, 2001). Cows that are kept clean have a lower risk for hoof disease in loose-housed cows (Ekesbo, 1966) and in tied cows (Blowey, 1990; Bergsten, 1995). For cows kept in straw yards, an influence of space allowance on dirtiness has been reported (Fregonesi and Leaver, 2002).

6.11. Use of and exposure to electric shocks

6.11.1. Cow trainers

The purpose of a cow trainer is to keep the stall floor as free from manure as possible by forcing the cow to step backwards as she arches her back when defecating. In a pilot study Metzner and Groth (1979) found that the number of contacts with the cow trainer was decreasing over time during the first days after installation. The cleanliness of the stanchion improved, no effects on the number of getting up and lying down behaviour were detected but the incidence of change of position was increased after exposure to cow trainers. Some increase in blood pressure and heart rate was detected one to two days after the exposure to the cow trainers. In a provocation study where cows were exposed to electrical shocks from a cow trainer, the effects on enzyme levels and pulse were studied. The level of CPK (creatinine

phosphokinase) increased by 21 and 67% within 1 and 7 hours respectively. Also, LDH (lactate dehydrogenase) increased but not ASAT (aspartate aminotransferase). The systolic and diastolic blood pressure increased by 47 and 34% respectively.

As a part of a study of 14 different types of stanchions, the effect of cow trainers on the cleanliness of cattle was investigated. Better cleanliness was found in cows kept in short stanchions and in long stanchions where the cows were not shut out of the feed table when they were exposed to cow trainers (Gjestang, 1980). In an experimental study Gjestang (1986) found a larger proportion of dunging in the dung alley with trainers using 1200V – 0.11 mC and 6500V – 0.72 mC than when 540V – 0.06mC was used. In a small experimental study Simensen et al. (1988) and Grommers (1969) found that more of the dunging was placed in the dung alley and the cattle were cleaner with the use of a cow trainer than without. Some animals avoided the trainer by standing in an oblique position in the stanchion. No effects on plasma cortisol or on grooming behaviour were observed. Kohli (1987) studied three herds with 8-9 cows in each herd. In 58-79% of the cases where the cattle were in contact with the cow trainer, there was no urination or defecation. When the cow trainer was in use, the stanchions were cleaner but the grooming behaviour of the cattle was less frequent, the latter effect also confirmed by a study by Oswald (1992). The time to lie down increased when the cow trainers were in use.

Cow trainers were used in a study to demonstrate the importance of tie-stall hygiene on the incidence of infectious disease (Bergsten and Pettersson 1992). These results were verified in another study on three farms where half of the cows in each herd were exposed to cow trainers and half of the cows were not. The cow groups were matched against each other. However, in a retrospective longitudinal study of 2148 Danish dairy herds with an inclusion criterion of herds with a minimum of 0.05 reported cases of mastitis per cow year, the use of cow trainers were found to increase the risk of hock lesions (OR constant use=1.00; OR no use = 0.44, $p = 0.007$). The effect was suggested by the authors to be a result of restriction of cow's movements and also, in part an indirect effect of restricted use of litter associated with the use of the cow trainer.

In an epidemiological study Nygaard et al. (1981) studied 3830 cows exposed to cow trainers and 1696 control animals on ca 700 farms using information on health cards. The use of cow trainers was positively correlated to the incidence of trampled teats, fertility problems and total morbidity. However, the study did not accurately take into account the effect of the whole herd. Bakken (1982) found in a study of 300 herds in Norway that the prevalence of sub clinical mastitis was significantly higher in herds using cow trainers. Österås and Lund (1988) studied 158 herds in Norway with high cell counts or high incidence of mastitis. They were not able to identify an effect of cow trainers in this group of problem herds. In a study of 182 cows in 20 herds where 92 cows were exposed to cow trainers, Eyrich et al., (1988) found a higher incidence of poor heat signs and silent heat in exposed cows than in non-exposed. Also, a cyclic rise in progesterone occurred one week later in exposed cows. Hansvik Saether (1994) studied 444 herds and found that herds with cow trainers had more treatments for trampled teats, mastitis, poor heat signs, reproductive disorders and a higher treatment incidence for "total morbidity". However, the study did not adjust for herd size, feeding intensity and milk production – factors which were different in the exposed and control groups.

In an epidemiological study of 60 000 cows performed during ten years, a shorter longevity of 2-3 months was found in Simmental cattle exposed to cow trainers independent of type of stanchion (Sölkner and Essl, 1990). In a study of 10264 Swedish Red and White and 5461

Swedish Friesian lactation records in 150 herds of which 33 used cow trainers, Oltenacu et al. (1998) showed that there was a significantly increased risk for silent heat (OR 1.55-2.34), clinical mastitis (OR 1.23-1.41), ketosis (OR 1.07-1.62) and culling (OR 1.15-1.16) relative to cows in herds not using cow trainers. No significant effects on incidences of veterinary treatments for foot health problems was demonstrated in this study although there was a trend that the herds starting to use cow trainers were herds with poorer foot health and after the use of trainers foot health was similar to those herds that never started to use cow trainers. Diseases had a negative effect on reproductive performance and this effect was larger for cows in herds using cow trainers.

6.11.2. Stray voltage

Stray voltage occurs when a current flows between a grounded circuit conductor on a farm and earth through housing equipment. This may happen if the electrical equipment and the fittings in the stable are not well fitted. In most cases, the currents are of power distribution frequency, i.e. 50 or 60Hz (Surbrook and Reese, 1981). The animals are exposed to the stray voltage e.g. through a metallic tether or during eating or drinking from metallic troughs or cups or when milked from the milking machine. Williams (1981) estimated that approximately 20% of all dairy herds in the US were affected by stray voltage. In Europe the incidence of such phenomena may vary due to variations in power applications, national regulations on wiring etc.

The perception level for dairy cows of stray voltage currents is estimated to be approximately 1 mA through the mouth or muzzle (Lefcourt, 1982). Jumping, kicking, arching, flinching or stepping from side to side are initial behavioural responses reported after exposure to stray voltage currents of 4 mA, 60Hz (Henke et al., 1982; Lefcourt, 1982). Other studies have reported on reluctance to drink and vocalizations (Lefcourt, 1982). Milk production is most likely affected adversely when animals are subjected to intermittent and irregular exposure to stray voltage (Appleman and Gustafsson, 1985).

Electric and magnetic fields

Magnetic and electric fields generated from high voltage transmission lines over pasture areas have been suggested to affect dairy cow fertility (Algers and Hennichs, 1985). However, although electric and magnetic fields may introduce various biological effects (see e.g. Algers and Hennichs, 1983), no such effects have been demonstrated in large scale epidemiological studies (Algers and Hennichs, 1985) or in experimental studies (Algers and Hultgren, 1987). Recent data, though, suggest that cattle align their body axes in relation to the earth's magnetic field (Begall et al. 2008) and that this alignment is disrupted by the exposure to low frequency electromagnetic fields from high voltage power lines (Burda et al. 2009).

7. Milking procedures in relation to welfare.

7.1. Introduction

Milking is a man-made evacuation of milk from the mammary gland (udder) of the cow. In dairy production this evacuation is completely emancipated from its original biological context. Nowadays cows feed with their milk billions of people. For that purpose cows are bred to yield large quantities of milk and this milk is collected from the udder by a machine in an automated process.

This chapter discusses animal welfare aspects of the milking procedure. Two main systems of milking will be discussed: (a) milking of cows indoors in batches in a milking parlour, here named ‘conventional milking’, (b) automated milking of cows indoors by a robot in a robot station, commonly termed ‘automatic milking’ (cf. Meijering et al, 2004).

Other more traditional procedures of milking in practice do hardly represent different items with respect to animal welfare and are therefore not discussed here. They are also mainly applied on smaller farms and are unlikely to play a substantial role in future developments.

Three aspects of the milking procedures will be considered with respect to animal welfare:

- the milking process as such
- cow traffic to the milking station
- the milking regime

At the end of this chapter attention will be paid to lactation management and its consequences for the cows’ welfare.

7.2. Conventional milking.

7.2.1. Milking process

Machine milking has been applied successfully for decades. It is one of the narrowest interfaces between an animal and a machine that exists in livestock production. The technical principle is that milking cups are attached to the teats and then milk is evacuated from the udder through a combination of lowering air pressure inside the milking tube and massaging the teat from outside by fluctuating air pressure around the teat cup liner. This method has proven to be effective, but the quality of the liners and fine tuning of the vacuum level and pulsation rate and ratio are critical points (Reinemann et al. 2008). They are critical from two points of view:

- a) In terms of milking speed and total time needed for milking the whole herd, a point of direct interest to the farmer.
- b) For the teat and udder health of the cow, to avoid malfunctioning, mastitis and pain; directly of interest to cow welfare.

Teat and teat end injury are mostly the result of unbalanced mechanical forces on the teat (Neijenhuis et al., 2001). But next to pulsation rate, vacuum and state of the liner, timely removal of the milking cluster are critical points (Neijenhuis et al. 2008; Hogewerf and Ipema, 2000). Empty milking causes deformation of the teat end and eases mastitis infections (Neijenhuis et al., 2001). Mastitis ranks high as an animal welfare problem on dairy farms (see chapter 15).

For preventive reasons, technical maintenance and periodic control of the milking machine settings are of great importance. Similarly the timely detachment of the teat cups should be properly controlled (Ortega et al., 2008).

The stockman’s effect on the quality of the milking procedure is so evident that words as ‘good dairy man’ and ‘bad dairy man’ are common vocabulary in dairy farming. Besides his technical skills, the behaviour of the stockman is an element within these qualifications. By bad handling and triggering fear in the cows, the stockman interferes with the neuro-endocrine process that controls the milk let-down. Milk ejection and excretion will be slowed down, and

at the end milk yield will decrease (Rushen et al., 1999; Seabrook, 1972). It results also in a negative effect on cow welfare (see chapter 18).

7.2.2. Cow traffic

Conventional milking is organised in fixed sessions, commonly two or three of them per day. Cows are collected in a special enclosure (so-called “waiting” room) or just at the end of the corridor in front of the milking parlour. Dependent on the type and capacity of the parlour, batches of cows of different numbers are successively allowed to enter the parlour. Through the design of the parlour and because cows are likely to push each other forward, cows get ordered in the right position, and the simultaneous milking of the full batch can start. The herding of cows near the parlour causes negative impacts on cow welfare specifically under the following conditions:

- Hastily driving together of cows and a narrow waiting area
- The use of electric devices for driving the cows
- Long waiting times under unfavourable conditions such a poor floor quality (dirty, slippery, uneven profile) and hot climate
- Cows are in bad physical state, with soar feet, lame and unhealthy
- Cows are highly pregnant and lack sufficient space for bearing the calf with them.

Problems arise when the waiting times in front of the milking parlour are not kept as short as possible. Moreover farmers should aim for a dry, clean floor surface in the waiting area. For lame cows a rubber mat on the floor, as more and more farmers apply these days, will help to provide cows relief from pain (Van der Tol et al, 2003). It also diminishes the negative effect of long standing on the recovery from claw disorders (Bierma et al. 2006).

Cows are mostly provided with concentrates in the milking parlour. That attracts them to enter and it has presumably a positive effect on milk let-down and production (Svennersten et al. 1995), though not all farmers choose feeding in the milking parlour.

Cows evidently have to learn the milking routine. Heifers, and sometimes also cows that are longer time away from the herd, will have to be trained passing the milking parlour and undergoing specific handling procedures. Stressful situations to the animals may occur. Skills of the herdsman play a key role in this respect.

Collecting cows for milking always causes close proximity between individuals. This could lead to peaks of aggression, but commonly it does not. Being densely packed prevents overt aggression in many animal species. The introduction of new herd members evokes more aggression during collecting cows. In general, an efficient and well-organised milking procedure and a proper barn layout will diminish the potential threats to animal welfare in the stage before, during and right after the milking.

Cows on pasture but milked inside may have to follow a long field path in order to reach their location of milking. Narrow concrete paths, uneven stony paths and paths with loose stones on its surface may be a considerable risk to lameness. In general farmers are aware of that. But proper conditions for larger herds to move from pasture to the milking parlour inside a building are sometimes not easy to establish.. Distances, soil type, weather conditions all play a role.

7.2.2.1. Milking regime

In conventional milking, a large majority of farms in Europe choose to milk twice a day. Twelve hours intervals would be most favourable to achieve milk synthesis capacity of the cow and an evenly distributed milk load in the udder at each milking time. Most farmers, however, choose for a longer interval over night and a shorter one during the day; for example a 14 vs.10 hours schedule. This provides the farmer with more convenient working hours. Milking three times per day increases daily milk yield substantially (about 10 percent or more). In Sweden many farmers choose three times per day milking for the evident economic incentive provided to them by the system (Algers, pers. com.). The choice of milking three times a day is affected by the price of the milk and by the availability of labour and labour costs (cf. Dijkhuizen et al. 1997). Globally milking three times a day is mostly seen on farms with a highly productive herd and in regions with low labour costs.

Welfare implications of the milking regime in conventional milking appear at two fronts:

- Large loads of milk in the udder inhibit cows from lying and resting. Those conditions may occur just from delayed milking, which may happen occasionally on a farm. More systematically it may be seen in cows that have constantly a high yield. Three times milking per day would take away in these cases a distinct negative welfare impact.
- More frequent evacuation of the udder diminishes the risk of mastitis, although total milking time per day is longer and thus also the mechanical impact of the milking machine on the udder. In practice, however, the balance between the two effects seems to be advantageous with higher milking frequency (Svennersten-Sjaunja et al., 2000), at least if the milking equipment is well adjusted .

7.3. Automatic milking.

7.3.1. Introduction

More than 4000 dairy farms in the world are practicing fully automated milking (AM) with a robot, and the numbers are increasing. In 2004 more than 80 percent of the AM-farms were located in Northern Europe (De Koning and Rodenburg, 2004). A further, large-scale application of automatic milking in the dairy industry can be expected (Dijkhuizen et al, 1997), although the motivation among the farmers for changing to automatic milking varies and a distinct number of farmers will continue with conventional milking (Meijering et al., 2004). Amount of labour, labour quality and higher milk yield of the cows are main factors for farmers to choose for an AM –system. Like conventional milking, AM-systems are vulnerable to cow welfare problems, at different levels.

7.3.2. Milking process

Attachment of the teat cups is effected by the milking robot. The difference from conventional milking is that this attachment may fail and for the four cups together it takes substantially more time than in the case of manual attachment in conventional milking (Artmann, 1997). But this difference seems to cause no real problem for the cow. From what happens if a cow is sucked by a calf, no rule appears that says that all teats must be milked completely synchronously. Another difference with conventional milking is that in robotic milking after the milk stream of a teat comes to a minimum, the teat cup is taken away independently from the other teat cups and their milk flow level. It diminishes the so-called vacuum milking on

teats and thus reduces the risk of mastitis (Neijenhuis et al. 2008). The yield of the udder quarters, especially between fore teats and rear teats, will always differ (Hogewerf and Ipema, 2000). But with the individual teat cup detachment the milking time of each quarter can be adjusted to that. Technological developments go in the direction of vacuum and pulsation control linked to the milk flow rate of the individual teats. This innovation may be a big step forward in reducing mechanical overload of teats and udder, thereby reducing the risk of teat injuring and the risk of mastitis (Svennersten-Sjaunja et al., 2000; Hogewerf and Ipema, 2000; Neijenhuis et al., 2008; Ortega et al., 2008).

Altogether, the technical innovation in the milking process brought by robotic milking has the potential of contributing positively to cow welfare. There can be problems if the system is not working well and the farmer is not available. But those difficulties are becoming largely cleared in practice (De Koning and Ipema, 2000; Hillerton et al, 2004). Wenzel et al. (2003) concluded from studies on step-kick behaviour that cows experienced more physiological stress in the automatic milking system. But in another comparison between automatic and conventional milking, Hopster et al. (2000) did not find any difference on measures of acute stress. Differences between breeds of cows may play a role when comparing milking systems. Lexer et al. (2004) found some indications of stress in Brown Swiss and Austrian Simmentaler cows in both milking systems.

7.3.3. Cow traffic.

In contrast to conventional milking, cows milked by a robot are supposed to attend the milking station voluntarily. That is why the milking interval will always vary, at least within the range set by the farmer as a minimum and maximum interval. If exceeding their maximum interval, cows will be fetched by the farmer so that the aimed minimum milking frequency per day still can be maintained. Timely visiting the milking robot is a complicated task for cows. First of all, milking itself does not motivate cows to go to the robot. In some way cows have to be enforced or specifically rewarded. A common way is to create a certain logistic routing in the barn, so that cows have to pass the robot station obligatory on their way from the resting to the feeding area (so-called 'forced' cow traffic). Another approach is to provide all or a main part of the daily concentrates ration exclusively in the robot station. Because of their eagerness to eat concentrates, cows are likely to visit the robot station at least for the required number of milking times per day. As a rule, attendance of the robot station is followed by a gift of concentrates and actual milking, if the minimum time interval since the last milking has passed, e.g. 6 hours. Cows not visiting the robot station on time (within the set time limit), even with concentrates availability, will by consequence, be fetched. This causes extra labour for the stockman, and often unrest in the herd. Between 'forced' cow traffic and voluntary visiting the robot, other models of cow traffic are researched (e.g. Hermans et al., 2003). The aim is to find a balance between an optimal milking regime for each cow and an efficient use of the robot capacity, together with freedom of movement, eating, drinking, resting and other activities for the cow. Apart from the given principles, various versions of the cow traffic can be seen in practice. Low voluntary attendance of the robot station by a cow is often caused by lameness or sickness or a low social rank.

Voluntary cow traffic in combination with grazing the cows is applied in practice, but it can be a cause of delayed milking (Spörndly et al, 2004) and some drop in milk yield. However, the variation between farms is great (Van Dooren et al., 2004b). This field received considerable attention in the robotic milking research in recent years (Meijering et al, 2004)

Robotic milking is introduced on farms as a 24 hours operation. It results in sequential milking of many cows within a tight time schedule (Van Dooren et al. 2004a). It has a great impact on individual cycles in eating, resting and sleeping. Individual cows have to divert their activities since milking in the robot station is done individually, and only 6 to 9 times per hour.

Chrono-biology tells that in most animal species behavioural activities are highly synchronised by the light regime. Moreover, mutual synchronisation is a rule in animals living in herds. Both principles are also applicable to dairy cows, which can be seen when cows are under unrestrained conditions as in the pasture. The sequential milking with abandoning the restraint of bio-rhythm and a light-dark cycle is sometimes hypothesised as a threat to cow welfare and health in the robotic milking environment. But convincing experimental or empirical evidence is still lacking. For good clarifications, this area needs a substantial research effort.

7.3.4. Milking regime

Robotic milking allows a variable milking regime. In practice cows are usually milked between 2 and 3 times per day. A higher frequency, especially at the beginning of the lactation, will stimulate milk production. But the rise of total milking times per day also increases the risk of physical damage to the udder by the milking machine and the risk for mastitis (see above).

A flexible milking regime, so that the number of times milking is adjusted to the amount of milk, can itself be a benefit for the welfare of cows (less 'overload' of udder).

Automatic milking has actually brought a new management concept to the dairy farm. Technical innovations and new operational rules are brought together in a concept in which the circumstances of the cows are drastically changed (Devir et al., 1997). From its beginning the achievements in the area of automatic milking have been compared time by time with conventional milking, including health and welfare aspects of dairy cows (e.g. Ipema, 1997; Lind et al., 2000; Svennersten-Sjaunja et al., 2000; Hagen et al., 2004; Hillerton et al., 2004). Results triggered new research and have contributed to new, more animal-oriented approaches, like abandoning forced cow traffic (Hermans et al., 2003), the transition to animal-based quarter cluster removal criteria (Hogewerf and Ipema, 2000; Neijenhuis et al., 2008), the inclusion of grazing (Ketelaar-de Lauwere et al., 1999; Spörndly et al. 2004; Wredle, 2005). Animal welfare evaluations on the bases of behavioural and physiological criteria were undertaken, among others by Hopster et al., (2000), Wenzel et al, (2003); Hagen et al. (2005); Lexer at al., (2008). These studies results varied between no difference and a slightly negative effect of automatic milking.

7.4. Lactation management

By lactation management we mean here the strategy of the farmer with respect to the milking regime, lactation length and dry-off of the cows.

From the viewpoint of physiology and health it makes sense to plan the number of milking times per day in relation to the milk yield and lactation stage of the cow. This is supported by a substantial amount of experimental evidence (Maltz and Metz, 1994). With robotic milking, such management can in principle easily be implemented (Devir et al., 1997). Advances are that, the genetic potential of the cow is more efficiently exploited and links can be made with

nutritional needs and the feed delivery. Individual differences between cows are also taken into account in conventional milking, but merely from the aspect of feeding, as the number of times milking per day is fixed. Automated self-feeding of groups of cows is practiced already for a long time (Maltz et al., 1992). It is one of the pillars for the use of automated concentrate dispensers.

Automatic milking has indeed introduced the principle of individual cow management with the possibility of varying the number of milkings per day and through the lactation. The farmer can set the goals, based on the individual cow performance (Devir et al., 1993; Maltz, 2000). In practice an average milking frequency per day is between 2 and 3 (Meijering et al., 2004). But when cows go to pasture, the average frequency may be below this range (Svennersten-Sjaunja et al., 2000). A higher milking frequency (above 2 or 3 times) will increase the milk yield but also the negative impact on cows' teat condition. The latter can be compensated by applying - as said before - quarter milking i.e. teat cup de-attachment based on residual milk flow rate of the individual teat (Hogewerf and Ipema, 2000; Svennersten-Sjaunja et al., 2000).

In the context of conventional milking new strategies are also explored. One milking per day is considered for farms that aim at extensification and reduction of labour. Preliminary research has been carried out. An option could be to change to one milking per day in lower yielding cows during the second part of lactation. Also omitting one milking in the weekend has been examined. Given the response to delayed milking (unrest, prolonged standing, milk leakage), occasionally one milking per day of high yielding cows will likely frustrate good animal welfare.

Another change in lactation management under focus is the delayed rebreeding of cows and prolonging the lactation period. Lactation periods with intercalving intervals until 18 months are under study so that rebreeding after calving is starting after the peak of lactation. This would provide a better fertility condition of the cow at the time of insemination and improve insemination results. Generally it is assumed that management of prolonged lactations would favour the health and fertility of high yielding cows while the loss of milk yield is kept within an acceptable range.

8. Social and maternal behaviour in relation to management and welfare

8.1. Social grouping

8.1.1. Social structure in feral or wild cattle herds

Cattle are extremely social, living in mixed herds based on several cow-centred groups (adult cows and their female and subadult male offspring). At two to four years of age, males leave their group to join a multi-male group or live in solitary. During the rutting season they join a cow herd, but some males might stay in the herd during the whole year (Bouissou et al., 2001). The herd rarely has more than 50 animals, although occasionally many groups will join together temporarily for migrations or because of food resources. Cattle form long-lasting social bonds, especially between mother and offspring, but also between same-aged animals and siblings (Reinhardt, 1980a; Reinhardt and Reinhardt, 1981; Kiley-Worthington de la Plain, 1983). Bonded partners prefer proximity to each other during different activities and are more often engaged in mutual social licking and head play (Sato et al., 1993). The social organization of cattle is distinguished by relatively stable dominance-subordinate

relationships, but even more by affiliative behaviour, behaviour that strengthens and maintains social bonds and the cohesion of the group and helps relieving social tension (Sambraus, 1969; Reinhardt and Reinhardt, 1981; Sato and Maeda, 1991; Waiblinger et al., 2002a). Individuals have roles within the group that may change, depending on circumstances. Daily activities of the animals in a herd are performed synchronously.

8.1.2. Social structure in dairy cattle

Common husbandry practices in dairy cattle inhibit many characteristics of the social structure of wild cattle herds. Mother-daughter relationships cannot form due to early separation of the calf from the cow. While in principle long-lasting social bonds in same-aged animals may develop due to group-housing of calves from at least 8 weeks on, the maintenance of such bonds is often hampered due to regrouping and thus separation of animals already in heifers and also in the dairy cow herd (see below for more detail). Nevertheless, longer-lasting affiliative relationships are observed in dairy cow herds (Waiblinger et al., 2006).

The strength of the bond or affiliative relationship depends on the age of familiarisation. Bouissou and Hövels (1976b) found that calves reared together from birth associate during feeding and resting. This behaviour lasted for a year after several groups were mixed. Heifers in groups formed at birth form closer associations than those formed at the age of six months, and the later form closer associations than heifers grouped at 12 months (Bouissou and Andrieu, 1978). Such early social bonds are lasting even if the animals are separated for some time.

Commonly, animals of the same or very similar age are kept in one group instead of the multi-age situation in wild cattle herds. Even in the cow herd the difference between animals is often low as cows today rarely grow old (see section 17.6). The similarity in age and thus weight and experience, may enhance the possibility of agonistic interactions since the outcome of the fight is less clear for the individual. This is also proved by the fact that animals seem to assess the fighting ability of the others by use of physical appearance and may accept subordinate position more easily if they assess the competitor to be stronger. In young herds more agonistic interactions were observed compared to an older herd (Sambraus and Osterkorn, 1974; Collis et al., 1979).

8.1.3. Affiliative relationships and welfare

Social affiliative relationships are characterised through spatial proximity, reduced agonistic interactions, enhanced socio-positive interactions and tolerance in competitive situations such as feeding (Bouissou and Hövels, 1976a; b; Bouissou et al., 2001; Aschwanden et al., 2007).

Beyond these positive effects on social interactions, there seem to be a stress buffering effect of bonding partners. In general, living in herds with conspecifics implies the capability to support each other and by this reducing stress (Wiepkema and Schouten, 1990). The presence or absence of social companions has major effects on various physiological and behavioural responses in animals and the presence of, or interactions with these individuals, appear to moderate the impact of environmental stressors (Dantzer, 1990; Veissier et al., 1998). Stress responses in challenging situations may be ameliorated by the presence of (familiar) conspecifics (Boissy and Le Neindre, 1990) showing that heifers are less likely to avoid an unusual noise in the presence of pen-mates. During exposure to a novel arena, heifers seem also less afraid of the situation when they are with social partners than when they are alone (Veissier and Le Neindre, 1992). The efficiency of such support depends on the familiarity or

the specific relationship of the individuals and in some species only bonding partners can give social support (Sachser et al., 1998). In cattle, behavioural and physiological (heart rate) stress responses of heifers in different challenging situations were lower when pen-mates were present compared to the presence of animals of another group (Takeda et al., 2003). The number of social partners also was influential: social buffering was highest, i.e. stress responses were lowest, in a group of five familiar (and probably bonded) animals compared to a group of two (Takeda et al., 2003). Dairy cows showed less behavioural signs of stress (no flinch, no vocalisation, less vigilance) when in an arena separated from the herd with a bonded herd mate compared to being with a non-bonded herd mate and animals also stayed closer to and licked more the bonded cow than the non-bonded (Waiblinger et al., 2006). There are also hints on long-term positive effects on health and production when social bonding partners are available. Fewer cows with one or more constantly available bonding partner(s) over a period of several months were lame compared to cows without a constant bonding partner (11% vs. 36%) (Waiblinger et al., 2006). This underlines the negative effects of frequent disruption of affiliative relationships.

The positive effects of bonding may be based firstly on antistress effects of tactile stimulation during social licking, as suggested by results in other species (Uvnas-Moberg, 1997; Hennessy et al., 1998; Uvnas-Moberg and Petersson, 2005), but also in cattle. The heart rate decreased in licked calves and cows and the amount of being licked was associated positively with weight gain and milk yield (Wood, 1977; Sato, 1984; Sato and Tarumizu, 1993; Schmied et al., 2005). Also, heart rate increased less during a veterinary procedure when cows were stroked, i.e. got tactile stimulation by a human comparable to social licking (Waiblinger et al., 2004). Additionally a bonding partner may give security and reduce arousal thus resulting in a reduced activation of the pituitary-adrenocortical and the sympathetic-adrenomedullary-axes (Sachser et al., 1998). A bonding partner can also provide direct social support by helping the other during agonistic interactions (Reinhardt, 1980b).

8.1.4. Dominance in dairy cattle and welfare

Dominance is defined as one animal having priority in access to resources and thus being able to inhibit the behaviour of the subordinate. Social status or social rank is the relative ability of an animal to gain access to resources. Cattle form dominance-subordinate relationships between pairs of individuals and a rank order in the herd, which rarely is strictly linear (Beilharz and Zeeb, 1982; Albright and Arave, 1997). On pasture cattle keep an individual distance (or personal space) between 0.5 and 10m (Bennett and Holmes, 1987). Once a dominance relationship is established, agonistic interactions with body contact are rare on pasture, i.e. with sufficient space and resources for the subordinate animals to avoid the dominant ones. Animals rarely intrude the individual distance of other animals. In an established dominance relationship the subordinate animals signal this status by clear submissive postures and/or withdrawal from the dominant animal (Bouissou et al., 2001). Although social dominance is an important aspect of social organization in “natural” herds, in many modern dairy herds, there is often no clear dominance hierarchy evident between the cows (Val-Lallait et al., 2008). This may reflect the limited age range that exists within most dairy herds.

In hornless (dehorned or polled) herds of dairy cows, weight is the main physical characteristic influencing rank (Wagon, 1965; Dickson et al., 1967; Fries, 1978), whereas in horned herds the age and size of the horns are the main influences (Schein and Fohrman, 1955; Brantas, 1968; Süss, 1973; Sambraus and Osterkorn, 1974; Reinhardt, 1980b).

Personality traits, e.g. fearfulness, also seem to be important determinants of social rank achieved by an individual cattle (Bouissou et al., 2001).

When animals from different herds are mixed or one or few unfamiliar animals come into a herd, dominance relationships have to be established. Dominance fightings don't always occur, nevertheless the considerable increase in aggression potentially leads to injuries (Menke et al., 2000; Bouissou et al., 2001). Aggression also increases when cows are returned into the herd after a period of separation, e.g. during the dry off period (Albright and Arave, 1997). The amount of aggression depends on the time of separation. Bremner (1975) observed reintegration of calved cows in the herd. Fighting occurred much more frequently between cows which had been separated for six or more weeks (18%) compared to separation for up to 5 weeks (5%).

As the definition of dominance and social rank implies, some animals may restrict the behaviour of others in a group, and this can even reach a level causing a decrease in productivity, health and welfare (Zayan and Dantzer, 1990). The higher the competition due to housing design or management is, the more relevant is the rank of an individual for its welfare (Bouissou et al., 2001). For example, the more intense the competition (reduction in trough length), the stronger the correlation between food intake and dominance value (Friend et al., 1977). Overcrowding of cubicles or feeding places causes reduced lying or feeding time, longer durations of standing and changes in daily rhythm (shift of lying periods, more feeding during the night) especially in low-ranking animals, and further overcrowding is associated to the prevalence of lameness (Wierenga, 1983; Olofsson, 1999; Schrader et al., 2002; Howell et al., 2003; Mülleder and Waiblinger, 2004). The results with respect to the relationship between physiological stress responses and social rank of an animal are ambiguous; some found higher stress reactions in low-ranking animals, others did not (Bouissou et al., 2001). This may well be explained by the different environmental and group conditions. In some situations (social instability) even the higher-ranking individuals may experience higher stress levels (Arave and Albright, 1976), as is known also from other species.

There are some indications that first lactating cows may benefit from being kept separately from older cows. Boe and Faerevik (2003) cites one study of Konggard and Krohn (1978) finding longer feeding time, higher feed intake and higher milk yield in first lactating cows kept separately from older cows compared to a group being in a herd together with older ones. These effects most likely depend on lower social status achieved by the lighter first lactating cows (Phillips and Rind, 2001; Gonzalez et al., 2003). Additionally, necessity for first-lactating cows to adapt to new environmental features such as cubicles or concentrate feeders may enhance the problems. Thus, when the environment is optimised with respect to social space, competition and possibilities to learn features during rearing, the first lactating cows may experience few negative effects within a herd of older cows. Keeping them in a separate group also seems only practicable in large herds.

8.1.5. Grouping, regrouping and welfare

Grouping can be defined as the formation of a group of animals by natural means or by human action, e.g. allocation of a number of heifers to a given pen or grouping of dairy cows according to milking performance. Regrouping can be regarded as grouping repeated once or several times (Boe and Faerevik, 2003).

Grouping is common in dairy cattle husbandry (see chapter 8). In general an individual animal encounters frequent regrouping during its life. Grouping generally aims at homogenizing the

animals in one group with respect to age, lactational stage or milk yield and thus housing requirements (e.g. size of cubicles) and/or nutritional requirements. In these aspects grouping should and often does contribute to a better welfare due to prevention of disease, e.g. when peri-parturient cows can be fed better according to their needs and are housed on better lying and walking surfaces (e.g. deep litter housing of dried off cows while lactating cows are on concrete and cubicles with rubber mats).

However, grouping has also distinct negative effects with respect to social interactions, social relationships and (social) stress and thus on dairy cow and heifer health and welfare (for review see Boe and Faerevik, 2003). As mentioned before, mixing of unfamiliar animals as well as regrouping familiar animals after a certain period of separation, leads to an increase in aggressive interactions (Brakel and Leis, 1976; Collis et al., 1979; Kondo and Hurnik, 1990; Menke et al., 2000; Bouissou et al., 2001) with the risk of injuries caused by butts (Menke et al., 2000). Increased amount of fighting and (sudden) withdrawal may also enhance the risk of claw lesions due to heavy pressure on claws, quick claw movements and slipping. Animals also show changes in their maintenance behaviours, physiological stress responses and decrease in milk yield in response to grouping. Grouped animals stood more, had shorter lying bouts and grazed shorter for up to two weeks (Hasegawa et al., 1997; Phillips and Rind, 2001), and had markedly lower lying time at the first day after grouping (Knierim, 1998; Knierim, 1999). Boe and Faerevik (2003) report studies showing negative effects on feed intake and weight. Milk production decreased for days to several weeks after grouping (Arave and Albright, 1976; Brakel and Leis, 1976; Hasegawa et al., 1997; Phillips and Rind, 2001), although some authors did report no change in milk yield (Clark et al., 1977; Collis et al., 1979). Effects on adrenocortical response and increase in bulk somatic cell count in the milk were also found (Kay et al., 1977; Hasegawa et al., 1997; Gonzalez et al., 2003). Differences in intensity and duration of negative effects of grouping may relate to differences in space allowance and competition, e.g. at the feeding place e.g. Arave: 63 cm feed bunk space per cow, Brakel: >1m/cow (Arave et al., 1973; Brakel and Leis, 1976) or number of cubicles per cow (e.g. cow: cubicle in Gonzalez et al., 2003 is 2:1) (see chapter 11.2.2. for effects of space allowance). Altogether the duration of negative impact of grouping seem to be restricted to a period of 1-2 weeks, but is still of great importance for animal welfare and production (Boe and Faerevik, 2003). It is important to note that in dairy cow herds' changes in group composition by adding new calved heifers or cows, removing dried off animals or regrouping animals due to changes in milk yield happen every few weeks.

Regarding the effects of previous social status of regrouped animals Arave and Albright (1976) concluded that previously dominant animals suffer at least as much as previously subordinate cows.

8.1.6. Management of the social group

Management practices, besides housing (see chapter 12), can have considerable impact on the level of aggression, injuries, stress and production (Menke et al., 1999; Menke et al., 2000; Olofsson, 2000; Waiblinger et al., 2001b; Boe and Faerevik, 2003). Examples are feeding management, measures with cows in heat or general maintenance of equipment. Management avoiding competition as well as agitation and frustration in the herd has positive effects. For example, removal of cows in heat could reduce the amount of agonistic interactions by approximately 50% (Hurnik et al., 1975).

The level of aggression and stress during introduction of unfamiliar animals into a herd seem to depend on the exact management practices or specific circumstances, although research on this topic is rare. The way of integrating new animals into the herd was related to the level of injuries caused by horn butts; fewer injuries were found when farmers adopted specific measures such as grouping the animals on pasture or giving them time to adapt to the new barn environment without the herd (Menke et al., 1999). Pasture not only offers more space to evade dominant animals, but also often better conditions to prevent claw lesions. When comparing the effect of introducing heifers singly or in a group of three, in five different horned dairy herds, Menke et al. (2000) found a higher amount of aggression both towards the new heifers and within the original herd-mates during the first hours after grouping. In contrast, in a dehorned dairy herd (Knierim, 1998; Knierim, 1999) found no significant difference in agonistic interactions, although heifers introduced singly had more social interactions with the herd members compared to heifers introduced in a group of three. However, there was a hint that single-heifers may have been more stressed compared to group-heifers: 4 single heifers (of 8) failed to feed at the first day due to the type of feeding rack which was new for the heifers, but all except one group-heifer (out of 15) succeeded. (Sowerby and Poland, 1978) did not find any consistent effect of group size during grouping. (Mench et al., 1990) found a relatively low amount of fights between unfamiliar beef cows that were grouped in the third trimester of pregnancy compared to earlier studies and suggest this could be an effect of late pregnancy. However, introducing heifers in late pregnancy into a cow herd of different stages of lactation may have different effects and there might be the risk for premature parturition. Spraying lactating cows with anise oil reduced the frequency of aggressive acts and alleviated the reduction in milk yield following regrouping (Cummins and Myers, 1991).

8.1.7. Rearing management, social interactions and social skills

The early social environment and the management of grouping during the whole rearing period may have long-term effects on later social behaviour and stress, but has commonly not found attention in practice. Animals reared together from birth show less aggressive interactions towards each other even after one year of being grouped with other animals and are more tolerant in competitive situations compared to animals grouped together at 6 or 12 months of age (Bouissou and Andrieu, 1978). The existence of such early formed social bonds has a positive effect on welfare of the animals as it can reduce the unfavourable consequences of the existence of dominance relationships for subordinates (Bouissou et al., 2001).

Previous experiences of grouping seem to speed up the formation of dominance relationships and reduce the amount of physical aggression involved in calves and heifers as well as reduce negative effects on milk yield in dairy cows (Sowerby and Poland, 1978; Bouissou et al., 2001; Boe and Faerevik, 2003). Generally, the ability to cope with social challenge may largely be influenced by differences between individuals in how they perceive and respond to the current social conditions, influenced largely by former experiences (Mendl, 2001). In a herd of beef suckler cows (Mülleder et al., 2003) and in a dairy cow herd (Waiblinger et al., 2000) individual animals were found to differ in their social strategies and probably social stress. During enhanced food competition (reduced ratio of feeding places to animals), the different strategies of the groups differed in the amount of agonistic interactions (Mülleder et al., 2003). Especially experiences during early life may disrupt or enhance the development of appropriate social skills (Sachser et al., 1998) to deal with the challenges of living in a social group. Influences of early rearing (individually vs. group) on the later social behaviour of

calves or heifers when mixed with each other were found mostly in agonistic interactions and social status achieved (Warnick et al., 1977; Broom and Leaver, 1978; Le Neindre and Sourd, 1984; Arave et al., 1985; Veissier et al., 1994). Regarding possible long-term effects of the early social environment on social behaviour of cows after the first parturition, Le Neindre (1989) found in Saler cows, but not in Friesian, that animals reared with foster cows dominated animals reared isolated even 2.5 years after mixing at 15 month of age. There are hints that the common practice of early separation of calf and dam and housing calves individually for the first weeks of life can hamper the social skills later in life (Boe and Faerevik, 2003). But research into this topic is rare and some authors conclude that the consequences of social deprivation have no long-lasting effect in cattle (Bouissou et al., 2001).

8.1.8. Group size

Group size was shown to relate positively to agonistic interactions, but negatively with socio-positive interactions in a survey in 35 herds ranging in size from 9 to 92 cows (Menke et al., 1999). Similarly, (Kondo et al., 1989) found more agonistic behaviour in larger dairy cow herds (28 herds ranging from 8 to 91 in size). Arave et al. (1984) ascribed this difference to two main factors. First, mutual recognition is difficult in large herds and this reduces the effectiveness of an existing rank order. Second, in large herds, the frequent integration of new cows also counteracts an existing rank order and reduces the development of lasting social bonds. Bouissou et al. (2001) reports that under conditions of excessively large group size individual animals appear to have difficulty memorizing the social status of all peers which increases the incidence of aggressive interactions.

The frequency and intensity of contact between the farmer and (individual) cows in general gets lower with increasing herd size (Waiblinger and Menke, 1999). In large herds there is an increased probability of frequent personnel changes and/or a higher number of different milkers as compared with small herds. In large herds compared to small ones, there is an increased probability of frequent personnel changes, a higher number of different milkers, a variety of problem solving managements by farmers, which may contribute to unwanted changes in agonistic and social bonding behaviour (Waiblinger et al., 2001a, Menke et al., 1999).

8.2. Pre-partum management

Exposing cows to repeated transportation stress during gestation altered their calf's physiological response to stress, and these alterations could have a profound influence on the calf's ability to adapt to stress, thereby influencing its welfare (Lay et al., 1997). Additional issues related to the cows transport in pre-partum and to the welfare of calves are considered in the EFSA opinions on Animal Transport and the welfare of calves (EFSA, 2004; 2006).

8.2.1. Signs of calving and choice of a calving place

Very early signs of imminent parturition can be observed as early as six weeks before parturition, and consist of the cow avoiding aggressive interactions with other cattle (Phillips, 2002). This continues for about a month, where the cow is increasingly reluctant to engage in social encounters, and she may also graze by herself or at the edge of the herd (Phillips, 2002). One to two weeks before parturition she is increasingly restless, which includes regular looking and turning around, vocalising, licking and pawing the bedding material, tail-waving,

frequent alternation of lying and standing and interrupted eating patterns (Metz and Metz, 1987). At the same time there is swelling of the udder and vulva, and relaxation of the pelvic ligaments. These morphological changes are usually what the stockperson uses as a sign of an imminent parturition, and leads to decision making about the time to move the cow to a calving pen. Closer to calving there may also be milk dripping from the teats in dairy cows.

In free-ranging cattle it is important that the cow finds a suitable birth place where both she and her calf can be protected from predators. Cows have been reported to isolate themselves from the herd in Massai cattle (Reinhardt et al., 1977), Chillingham cattle (Hall, 1979) and free-ranging domestic cattle on the Russian taiga (Baskin and Stepanov, 1993). However, in domestic cattle kept on pasture it has been found that only some cows seek isolation pre-partum (Edwards, 1983; Kiley-Worthington and de la Plain, 1983; Owens et al., 1985; Lidfors and Jensen, 1988; Lidfors et al., 1994). Availability of a habitat where the cow can find good hiding places during the calving appears to be an important reason for eliciting full isolation during calving. Lidfors et al. (1994) found that beef cows calving in a 30 ha area were more often found in the shelters put out for protection against wind and precipitation than the pregnant cows in the herd. In an old Finnish dairy breed kept in a forest, more cows separated from the herd and calved in isolation during the first year, than during the second year (Lidfors et al., 1994). The cows not calving in isolation calved in a shelter close to the feeding places and handling facilities (Lidfors et al., 1994). Primiparous cows were found to separate themselves further from the herd than multiparous cows (Lidfors et al., 1994). The calving places in the forest consisted of dry and soft vegetation underneath (mainly moss, leaves and heather), some trees beside and some cover overhead (mainly spruce, branches and birch) (Lidfors et al., 1994).

8.2.2. Calving in groups or individually

Dairy cows throughout Europe may calve in many different environments. Calving on pasture could allow the dairy cow to perform behaviours that are important to her at this time. However, if there are complications at calving a hiding dairy cow may not get appropriate help or assistance in time. Also, the cow will leave her calf and not show where it is hiding, thus making difficult for the farmer to find the calf. Calves have been found to walk under an electric fence and fall down in a nearby river where they drowned or were caused stress (KTBL, 2008).

In a deep litter system cows could be left to calve in the group, but it could be disturbing for the calving cow to have the herd so close. In a study where about 100 dairy cows were kept on deep litter, pre-parturient cows were most often sniffed by other cows in the herd, and a lower frequency of other cows butting, threatening and mounting the pre-parturient cow was recorded (Lidfors et al., 1994). In the same study some pre-parturient cows were also recorded to sniff and lick alien calves.

With increasing herd size there is a growing need to manage many calvings occurring close in time. In a recent investigation in Denmark it was found that 27% of the farms used group calving pens, 28% used individual calving pens, 11% let the cows calve in the tie system and 10% calved in the loose housing with other cows and calves (Skjøth and Mortensen, 2004). Further, it was shown that 43% of the cows in loose housing calved in a group calving pen, whereas 38% calved in an individual pen and 18% were not removed from the loose housing at all and thus calved in there (Marstal, 2004). In group calving pens, cows that have not yet calved may let alien calves suckle (Edwards, 1983; Ventorp, 1998), and thus the colostrum

may be gone when the cows own calf is born. Previous research has found that 25% of the calves (Illman and Spinka, 1993) vs. 33% of the calves (Edwards, 1983) had suckled other cows than their dam. It was also found that 66% of the cows that nursed alien calves had not calved themselves yet, whereas 15% nursed alien calves within six hours after their own calving (Edwards, 1983). Illman and Spinka (1993) found that the cows that nursed alien calves were within eight hours of their own calving.

Cows are most interested in newly born calves (Kiley-Worthington and de la Plain, 1983) and older cows show more maternal behaviour (Edwards and Broom, 1982). A negative effect of using a group-calving pen may be that because cows at the beginning of calving are very restless they may disturb other cows with newly born calves (Jensen and Röntved, 2006). Also, cows which are calving may be disturbed and the negative effect could be a prolonged calving. There is also a problem with paratuberculosis and Salmonella dublin that may more easily spread between cows and calves in a group-calving pen (Nielsen et al., 2007). It is generally recommended that individual calving pens should be used when trying to get rid of these pathogens in dairy herds. However, cows isolated from other cows at calving, may be stressed by being completely left alone (Nielsen et al, 2007).

In cubicle systems, cows should be moved to a calving pen time in good time before parturition in order to avoid having the calf born in the cubicle or worse on the slatted or concrete floor. As the cow changes position frequently during calving, i.e. standing up and lying down and changing side, it will be quite difficult for her to carry out these movements at the late stage of pregnancy and in small stalls with neighbouring cows and a tie restricting her movements. If the calving is not monitored and the calf is born without anyone being in the building it may be very stressful for the cow not to be able to turn around and lick her calf. The calf may fall in the dunging alley or walk away thus causing even more stress to the cow when not being able to interact with it.

8.2.3. Stages of the calving

Stage one (preparatory stage) of the parturition is characterised by cervical dilation and ends in breaking of the waterbag and the appearance of the calves hooves (Phillips, 2002). Raising and waving of the tail is also common at this stage, and the stage has been found to take a bit more than two hours (Schilling and Hartwig, 1984). During this stage free-ranging beef cows have been found to walk more than half a kilometre (Lidfors and Jensen, 1988). In primiparous cows that need assistance this stage is much longer (Schilling and Hartwig, 1984). See also chapter 18.

Stage two (calf expulsion) normally takes about one hour, but somewhat longer if the cow needs assistance (Schilling and Hartwig, 1984). Initially the cow may be standing, but normally she is lying on her side to expel the head and shoulders (Phillips, 2002). If the cow is frequently disturbed she often stands, and this can delay the labour (Phillips, 2002). Uterine contractions occur at 15-20 minutes interval, where the abdominal straining contract the diaphragm behind the calf and force it through the birth canal (Phillips, 2002). Expulsion of the head is critical, and once it has occurred the trunk follows quickly (Phillips, 2002).

Parturition has been found to occur randomly throughout the 24 hours, however, dairy cows have been found to avoid calving at milking times (Edwards, 1979). If the cows are fed late in the evening, this may lead to more births during the night, probably due to that the disturbance of the cows increases the likelihood that the waterbag will break (Yarney et al., 1979).

Stage three (placental expulsion) is when the placenta is discarded from the vulva at 3-6 h post partum (Schilling and Hartwig, 1984; Lidfors, 1996). When dairy cows (both primiparous and multiparous) were allowed to keep their calf in an individual calving pen the mean time of placenta expulsion was 3.7 h and when the calf was removed directly after birth it took 4.6 h, however there was no significant difference due to a large standard deviation (Lidfors, 1996). For multiparous cows who did not need assistance the placenta expulsion took 4.5 hours, whereas it took 6.3 hours for cows that needed assistance, and 5.4 hours for primiparous cows (Schilling and Hartwig, 1984). In free-ranging conditions the cow usually eats the placenta and it is believed that she does this to remove any traces of the birth that might attract predators (Phillips, 2002). In individual calving pens 77% of the dairy cows were found to eat the placenta, and there was no difference between cows that were allowed to keep their calf and cows that had their calf removed at birth (Lidfors, 1996).

8.3. Cow-calf interactions

After calving the cow stands up and starts licking her calf (Lidfors and Jensen, 1988, see review by von Keyserlingk and Weary, 2007). This licking is most intense directly after calving and declines with time after calving (Lidfors and Jensen, 1988). Dairy cows are no different from beef cows or semi-free living cattle in this respect and start licking their calves only some minutes after birth (Edwards and Broom, 1982; Metz and Metz, 1986; Lidfors, 1996).

Dairy calves may be left with their mother either for a short time after birth or for parts of or the whole milk feeding period. Especially on organic farms this is recommended, for example in Sweden calves should be left with the dam for at least the first four days (KRAV, 2007), and in Denmark the calf should stay with its mother for at least the first 24 h. According to statistics from USA, 52% of the calves were separated immediately at birth, 22% were separated at 0-12 h, 16% at 12-14 h and 10% more than 24 h after birth (USDA, APHIS, 2002). Some farmers have found methods for letting the calves suckle during a longer period, often by letting the calves suckle restrictively twice or three times per day (Hartman, 1994; Anderberg, 2001).

When the calf is suckling it induces milk let-down by tactile stimulation that evokes the release of the hormone oxytocin. It can be difficult to activate milk ejection in Zebu cattle and their crosses in the absence of the calf (Ryle and Ørskov, 1990) and to achieve a sustained lactation (Everitt and Philips, 1971; Alvarez et al., 1980). Restricted suckling is required when milking some breeds of *Bos indicus* and *Bos taurus* to induce the milk letdown (Ryle and Ørskov, 1990). However, this is not needed in pure dairy breeds of *Bos taurus*, as for example the Holstein cow. The calf stimulates the milk letdown by a short suckling before milking, and is allowed to suckle the residual milk after the milking (Jung, 2001). In cross-breeds between *Bos taurus* and *Bos indicus* cows may also release milk when having the calf placed in front of it (Fröberg et al., 2007). The residual milk may also be valuable for the calf as it is higher in fat percentage and gives the calf a higher total energy intake (Fröberg et al., 2008).

There are a number of positive effects on the calf during suckling. It has been shown that the increase in oxytocin during suckling is higher than when calves are fed the milk from a bucket, and this hormone has been suggested to influence anabolic processes and growth (Lupoli et al., 2001). Also, when comparing suckling a cow with suckling on an artificial teat, the former has been shown to result in higher milk consumption which led to a higher weight gain (Metz, 1987). Even a short suckling period of 10 days has been shown to result in a

higher weight gain at two months of age (Metz, 1987). However, positive effects on the cow behaviour, health and physiology from nursing the calf has not been much investigated. The few studies that have been carried out have found that dairy cows nursing their calf get a better udder health.

Several studies have reported that restricted suckling increases milk production in cattle of Zebu crosses (Knowles and Edwards, 1983; Mejia et al., 1998), but also in pure Holstein (Everitt and Philips, 1971; Bar-Peeled et al., 1995). However, other studies have not found an increase in milk production (Weary and Chua, 2000), but in these studies the suckling period has been shorter than in the previous studies. Milk production is believed to be enhanced due to teat stimulation performed by the calf (Bar-Peeled et al., 1995) and the increased degree of udder emptying when the calf suckles the residual milk after milking (Sandoval-Castro et al., 2000). Moreover, it has been shown that a more frequent udder emptying in early lactation benefits the development of the milk secreting cells (Hale et al., 2003). Increased milk yield in Zebu cattle can also be related to an improved udder health when cows are suckled (Preston, 1984; Mejia et al., 1998).

Although suckling in comparison to non-suckling, may induce similar and even higher total milk production when adding the amount of suckled milk, it has been reported that milk ejection can be disturbed in cows that are machine milked during the suckling period (Bar-Peeled et al., 1995; Sandoval-Castro et al., 1999; Krohn, 2001). Though *Bos taurus* cows do not normally need the calf presence for milk ejection, these cows in restricted suckling systems may fail to let milk down in the milking parlour (Boden and Leaver, 1994). Preston and Vaccaro (1989) reported that up to 20% of cows in restricted suckling systems may withhold most of their milk during milking and saving it for the calf.

When calves suckle the cow after milking they ingest the residual milk, which has a higher fat content than the machine-milked milk. Consequently, the fat content at next milking is reduced as a carry-over effect (Boden and Leaver, 1994; Tesorero et al., 2001), sometimes to levels undesired by the processing industry. By employing different restricted suckling systems it is possible to manipulate the composition of saleable milk (Sandoval-Castro et al., 2000). Tesorero et al. (2001) found that in a restricted suckling system where calves suckled before milking, the saleable milk yield and fat content increased, compared to no suckling before milking. Since the calves were suckling the first milk portion that has the lowest fat content, the fat content in saleable milk was elevated. It is a well known fact that milk fat content increases during milking (Johansson et al., 1952).

One of the problems with restricted suckling in dairy production is that if calves are allowed to suckle directly after milking, some dairy cows keep their milk in the udder during milking and then release it to the calf when it suckles (Hartman, 1994; Fröberg et al., 2005). However, the calf is not able to drink all the milk in the udder, and thus leave some teats un-suckled (Jung, 1994; Fröberg et al., 2008). In order to get the cows to release the milk farmers may then have to give the cow an injection with oxytocin, which may cause negative effects on milk let-down if used too frequently. Another effect of calves not suckling on all teats is that it may become a risk factor for udder health problems. It has also been found that body weight loss was greatest for suckled cows and least for cows milked three times daily (Bar-Peeled et al., 1995). Recovery of Body Condition Score (BCS) started at 6 weeks post partum for 3 times milking and only at 11 week for suckled. This might indicate a welfare problem for suckled cows.

Alternatively, dairy calves may be raised by a foster cow, i.e. a cow which nurses alien calves. In many studies on the use of foster cows for raising calves the focus has been on the increase in number of calves produced per cow (Kilgour, 1972a; Smith et al., 1973; Hudson, 1977; Wyatt et al., 1977; Rosencrans and Hohenboken, 1982). The number of calves suckling a foster cow has been shown to influence the weight gained from the calves (Kaiser and O'Neill, 1975): the higher number of calves per cow, the lower weight per calf is gained. However, the relationship between the foster cow and the fostered calves has been shown to influence the weight gain of the foster calves (Le Neindre et al., 1978). In that study it was found that if the foster calf was adopted, i.e. was allowed to suckle in an opposite-parallel position and licked by the cow, it had the same weight gain as the cow's own calf. Otherwise the weight gain was lower. To minimise the risk that the foster calves in a group have different weight gain, that might be due to a low milk intake, a foster cow should not keep her own calf at the same time as taking care of foster calves. In a study where four alien calves were fostered onto a cow there was no correlation between the amount of social interactions with the foster cow and the weight gain of the calves (Loberg, 2007), although it seemed as some of the foster cows had a stronger relationship, or bond, to one or two of the four calves.

Over 30% of calves that stay with the dam after calving have blood IgG levels below 10 mg/mL (Wesselink et al, 1999) or do not drink enough colostrum before 6 hours (Ventorp and Michanek, 1991; Edwards and Broom, 1982; Brignole and Stott, 1980). Calves hand fed had higher Ig than suckled calves (Franklin et al., 2003).

8.4. Separation from the calf

8.4.1. Why are dairy calves separated from their mothers?

On most commercial dairy farms in Europe and North America the calves are usually separated from their mothers within the first 24 h after birth. This is because the cows' milk is a valuable resource for the farmer and because it constitutes a large part of the income on the farm. There are also several practical problems with letting the calf stay with its mother, see above.

8.4.2. Reactions of cows and calves to separation

It is well documented that weaning and separation between a cow and her calf imposes stress on both (Hudson and Mullord, 1977; Lidfors, 1996; Weary and Chua, 2000; Flower and Weary, 2001; Haley et al., 2001b; Stěhulová et al., 2008). Previous research has shown that when the calf is separated within 24 h after birth, the response by the cow and the calf is mild (Weary and Chua, 2000; Flower and Weary, 2001; 2003). After the mother-young bond has been established, i.e. 2 days or more, both cows and calves show increased vocalisation, activity levels and place their head outside of the pen more often after separation (Lidfors, 1996; Weary and Chua, 2000; Flower and Weary, 2001; Stěhulová et al., 2008). It has also been shown that cows separated from their calves later after birth call with a higher fundamental frequency (Weary and Chua, 2000). Cows separated after four days has also been reported to ruminate less often immediately after separation occurs (Lidfors, 1996).

Since some foster cows seem to adopt one or more of her foster calves the separation after some weeks of suckling might impose stress as well. It has been reported that calves separated from their foster cow decreased their feed intake for up to 7 days, and that both cows and calves vocalised and seemed to search for each other for 7-10 days after separation. At

weaning and separation from the foster calves it has also been shown that the foster cows may not releasing milk to the milk machine (Hernandez, 2005).

8.4.3. Ways of reducing stress at separation

In some studies the objective has been to reduce the reactions in the cows and their calf after separation by different methods. Stěhulová et al. (2008) found that if the cows were moved to another building and released to the loose housing their reactions were much lower than when they were kept in the calving pen and the calf was placed so that they could see and hear them but not reach them.

In studies on the separation and weaning of beef cattle, the use of a weaning plate that was fitted in the nostrils of the calves to prevent suckling, reduced the amount of vocalisation and walking in the calves after weaning and separation (Haley et al., 2001; 2005). The perceived stress at each event seemed less. This procedure of weaning and separation have also been tested at separation between foster cows and calves, resulting in a significantly lower reaction at weaning and separation both in foster cow and calves (Loberg et al., 2007; 2008).

9. Lameness and welfare

9.1. Introduction and definitions: Why lameness is a welfare problem?

Lameness can be defined as any indication of structural or functional disorder affecting one or more limbs or the vertebral column (Stashak, 2002) that is evident while standing, rising, moving or lying down. Consequently, any painful, mechanical or neurological problem that impairs the function of the locomotor system can lead to lameness. The foot is the commonest site for lesions causing lameness in dairy cattle (Greenhough et al., 1981; Murray et al., 1996; Weaver, 1985).

The importance of any disease state in farm animals, whether defined in terms of welfare or economic cost, may be measured by three criteria: incidence, severity and duration. *Incidence* describes the proportion of animals that experience one or more episodes of lameness. This is usually expressed as annual incidence (case/year). *Severity* defines the cost to each individual in terms of emotional distress and physical loss of function/performance. *Duration* defines the (average) length of time for which animals suffer distress and loss of fitness in consequence of a single episode of lameness. *Prevalence* of lameness; i.e. the proportion of animals observed to be lame at any one observation period, is a composite measure of incidence and duration. Lameness is generally recognised to be the most severe welfare problem facing the dairy cow and the European dairy industry (Whay et al., 2003b).

9.2. Incidence and prevalence

There have been many scientific reports from Europe, USA and Australasia, describing the annual incidence of lameness in dairy cows over the last 15 to 30 years.

Studies based on large numbers of herds (>40) include Clarkson et al. (1996), Eddy and Scott (1980), Esslemont and Kossaibati (1996), Hedges et al. (2001), Prentice and Neal (1972), Smith et al. (2007), Whay et al. (2003a), Whitaker et al. (1983). The lowest values (7%, Eddy and Scott, 1980) relate only to animals treated by veterinarians. Records of cases treated by veterinarians plus farmers range from 17-25% (Esslemont and Kossabaiti, 1996; Whitaker et al., 1983). In farms overseen by independent scientific observers the mean and range were

55% and 11-170% (Clarkson et al., 1996). The use of different recording methods means that estimates of annual incidence must be tentative. For example, lowest estimates have been consistently derived from studies involving farmer self-reporting (Whitaker et al., 2000). The highest estimates have been recorded when veterinary treatments were provided free of charge and cow locomotion assessed from active detection by an experienced or trained individual. Reports that did not rely on farmer self-reporting of lameness (Prentice and Neal, 1972; Clarkson et al., 1996; Hedges et al., 2001) found annual lameness incidences ranging from 24 to 69%, approximately double the incidence calculated from “veterinary and farm treatment record” based reports. Farmer self-reporting of lameness should probably be considered unreliable for research and benchmarking purposes, and comparisons of incidence between reports should be made with great care.

Lameness incidence has been reported to vary considerably between farms, between regions and between seasons. Examples of between-farm variation in annual incidence within a single study range from 2 % for the best 10% of herds to 46% for the worst 20% of herds (Whay et al., 2003a; Whitaker et al., 2004). This variability in incidence reflects the multifactorial nature of lameness in dairy cows. Much of the variation between farms and regions can be attributed to variation in risk factors relating to standards of environment and management (Clarkson et al., 1996; Faull et al., 1996; Smith et al., 2007). These will be discussed in detail in section 14.8 with many of the important risk factors relating to seasonally determined environmental conditions. Seasonal variation is also influenced by season of calving, as lameness incidence has been shown to peak at around 4 months after calving (LeFevre et al., 2001; Hirst et al., 2002a). Lameness affects any age of animal in the dairy herd, but incidence of lameness tends to rise from birth until 6th parity (Hirst et al., 2002b). Lameness in animals prior to first calving is generally uncommon. Occasional episode of lameness in pre-partum dairy heifers are usually caused by injuries or digital infections (Frankena et al., 1993).

There are relatively fewer reports of lameness prevalence, defined as the proportion (percentage) of diseased individuals in a group at a defined point or period in time. Mean prevalences range from 1 (Wells et al., 1993) to 65% (Sprecher et al., 1997), with the majority of estimates within the range 20 to 25% (Cook, 2003; Espejo et al., 2006; Whay et al., 2003a). The reports reveal clear seasonal variation in prevalence that will be discussed further in section 14.8. Published values for prevalence are more reliable than those for incidence in the sense that they were all recorded by trained observers. On the other hand, they are limited by the fact that they are single brief observations recorded on a single day. For chronic disorders this may be accurate but for more acute disorders (e.g. infectious digital dermatitis) single brief estimates may not reflect the general state of foot health. Cows in the FTG group (3 times trimming/year) were 52% less likely ($P=0.05$) to develop a sole ulcer compared with CG cows (one trimming/year) (Smith et al., 2007).

9.3. Pathology, pathogenesis and treatment

It has been estimated that painful lesions of the foot account for over 90% of cases of lameness in dairy cows (Murray et al., 1996). The complete list of specific conditions that can potentially cause lameness in dairy cows is extensive. For simplicity however, all the common conditions giving rise to lameness originating in the foot can be grouped into two categories, according to whether they affect claw horn (Table 7), or the surrounding skin (Table 8). The diseases most commonly affecting the claw horn (e.g. sole haemorrhage/sole ulcer, white line disease), are generally associated, in their initial stages, with mechanical trauma; diseases of

the adjacent skin (e.g. digital dermatitis and interdigital necrobacillosis) are generally infectious in origin.

Condition	Lesions (primary)	Lesions (secondary)
Claw horn disruption	Sole haemorrhage	Sole ulcer Sole over-growth
	Poor quality (white powdery) horn	
	White line haemorrhage	White line separation White line infection (abscessation)
	Thimbling, laminitic rings and horizontal wall fissures	Toe-overgrowth
Other claw diseases	Heel horn erosion	Heel ulcer
	Soft claw horn	
	Toe-overgrowth	Toe ulcers Toe necrosis (“rotten toe”)
	Thin soles	
	Vertical wall fissures (“sand cracks”) Cork screw claw	Wall ulcers
	Sole penetration	Sole ulcer
	Medio-lateral claw imbalance	

Table 7 Claw horn diseases and their associated lesions

9.3.1. Claw horn diseases

Table 7 lists claw horn disruption (CHD) and other claw diseases, and describes gross lesions identified as primary; i.e. seen in early cases and secondary; recognised in more chronic, untreated cases. Sole ulcers are the predominant severe lesions of claw horn associated with lameness (40% of all horn lesions associated with lameness, Murray et al., 1996).

Many reports on claw horn lesions (CHD) in cattle have assumed that the pathogenesis involves mechanisms similar to the well-established model of laminitis of nutritional origin in equines involving marked inflammation and deterioration of the laminae (Pollitt, 1999). Hence, the term subclinical laminitis became generally accepted as the “scientific” name for the disease syndrome in cattle involving sole haemorrhage, white line haemorrhage, sole ulcers and white line disease in cattle. This persisted despite increasing evidence that major risk factors for CHD were environmental. Recent works (Ossent and Lischer, 1998; Tarlton et al., 2002) have demonstrated that sole and white line lesions can form without apparent evidence of laminar inflammation. Prior to this, Blowey (1996) had coined the term “coriosis” to reflect the involvement of the sole corium and enabled a distinction to be made with acute laminitis. Despite this, subclinical laminitis remains the conventional terminology for what is a group of lesions caused by a number of different and interacting conditions and risk factors. This section reviews the current understanding of pathogenesis for claw horn disruption, addressing sole haemorrhage and sole ulcers separate from white line haemorrhage and white line disease although many components of the pathogenesis are very similar. This section also

describes the epidemiology of claw horn disruption with respect to a number of associated conditions and risk factors: calving, claw trauma and contusion, abnormal weight and force distribution and ruminal disturbance.

9.3.1.1. Sole haemorrhage (sole bruising) and sole ulceration

Sole haemorrhage is the term used for the presence of petechial or ecchymotic haemorrhages on the sole horn. These are distributed in any part of the sole although they tend to cluster in sites corresponding to the position of the palmar/plantar processes of the distal phalanx (PIII), commonly referred to as the sole ulcer site, and near the toe at a site that corresponds to the apex of PIII. Full thickness deficits of horn exposing the sole corium can be found at any site on the sole, but sole ulcer is reserved for deficits that occur over the position of the palmar or plantar process of PIII. Most workers still regard the sole ulcer, first described in detail by Rusterholz (1920), as a severe form of sole haemorrhage with contusion bringing about prolonged interruption of claw horn production sufficient for the horn to fissure and erode at the ulcer site, with the eventual exposure of the dysfunctional corium. Thus sole ulceration usually occurs as a severe consequence of sole haemorrhage. Sole ulcers may result from penetration of the sole by a foreign body (e.g. a stone). However, contrary to common and traditional belief among dairy farmers, this is rare.

The proposed hypothesis for the clustered distribution of sole haemorrhages, particularly at the palmar/plantar processes of PIII, is that excursion of PIII results in contusion of the corium directly below the processes. Excursion of PIII in the periparturient cow has been demonstrated in post-mortem specimens, with the formation of a grossly visible lip in the laminar corium (Ossent and Lischer, 1998). Further evidence, in the form of a plausible mechanism, has been published by Tarlton et al. (2002) who reported a loss of supporting strength within the connective tissue of the support mechanism for PIII within the foot in the weeks immediately prior to, and following, parturition. Subsequent studies showed that the main risk factors for loss of integrity in the support apparatus in heifers were environmental (cubicle housing with concrete floors) and endocrinal changes associated with parturition/lactation (Knott et al., 2007). There was however no effect of feeding a ration designed to support lactation. The altered properties of the connective tissue were associated with changes in metalloproteinases involved in the maintenance of connective tissue. There was no biochemical or histological evidence for inflammation at this time (i.e. no evidence for laminitis).

Sole ulcer develops from the most severe sole haemorrhage. The prevalence of sole ulcers represents the “tip of the iceberg” in a herd, with many more animals exhibiting more or less severe sole haemorrhages at the ulcer site. For sole haemorrhage to progress into a sole ulcer, contusion between PIII and the sole corium, which is common in cows in early lactation, especially when in regular contact with concrete floors, must be severe and persistent, with severe focal inflammation of the sole corium, ingress of water, slurry and infection through fissured horn resulting in a painful f chronic inflammation of the sole corium, the pain being exacerbated each time the cow bears weight on the affected foot (Enevoldsen et al., 1991).

9.3.1.2. White line haemorrhage and white line disease

White line haemorrhage is the term given to the presence of ecchymotic or petechial haemorrhage in the horn along the anatomical landmark called the white line, the typically pale horn joining the wall of the claw with the sole. This damage can cause white line

separation, resulting in the uptake of soil and detritus from the environment, giving the white line a darkly discoloured appearance. This is referred to as white line disease. If white line disease extends to the corium, this can permit formation of a focus of infection. This can result in acute suppurative infection, with abscess formation and acute onset lameness. Alternatively, a chronic, low grade infection can result in chronic, low grade lameness.

White line haemorrhage grossly resembles sole haemorrhage but typically appears before sole haemorrhage, at around 60 days after calving (Webster, 2002). This suggests that the aetiopathogenesis may be different from that for sole haemorrhage (Blowey et al., 2004). As the white line horn is softer and more pliable than wall horn and sole horn, it is thought to be less resilient to physical forces operating in the dairy herd environment. Not only are tracks and concrete yards abrasive surfaces, but claws experience shear forces as cows push against each other along the feed barrier, in the collecting yard or along cow tracks. Supplementation of the diet with 20mg biotin reduced the incidence of lameness due to white line disease by 50% (Chesterton et al., 1989; Collis et al., 2004, Hedges et al., 2001). Biotin, a member of the vitamin B complex, (or vitamin H) is considered essential for good quality keratin production. Thus, the effect of biotin may improve quality of horn.

9.3.1.3. Laminitis

Many authors have investigated the possible association between sole haemorrhage and high starch or high protein dairy rations. The majority of the papers indicate a relationship (Manson and Leaver 1987, 1988a, b; Nocek 1997) but there are dissenting voices (Laven et al., 2004). The hypothesis that dietary-induced sub-clinical laminitis is a major risk factor for CHD has been challenged (see section 14.3.1., Ossent and Lischer 1998; Knott et al., 2007). However, dairy cows can experience severely painful acute laminitis in all four feet and this is typically associated with overfeeding (or engorging grain). However the incidence of acute laminitis in dairy cows on typical European ration is only about 2% (Clarkson et al., 1996)

9.3.2. Infectious diseases of the skin

A variety of conditions has been described affecting the skin surrounding, and between the hoof claws of dairy cattle. These are listed in Table 8. All of them are attributed to infection from organisms in the environment (especially anaerobic organisms recovered from slurry). The most common of these, and the one most likely to present a serious problem on a herd scale, is digital dermatitis.

Table 8 Diseases affecting the digital skin and their associated lesions grouped according to similar aetiopathogenesis

CONDITION	GROSS DESCRIPTION OF LESIONS
COMMON, “ENVIRONMENTAL” DISEASES	
Digital dermatitis	Ulcerative, erosive, granulomatous digital dermatitis Proliferative (verruccose, papillomatous) digital dermatitis
Interdigital necrobacillosis (Foul-in-the-foot)	Acute necrotic dermatitis of the interdigital skin

Super foul	Peracute necrotic dermatitis of the interdigital skin
Blind foul	Acute necrotic dermatitis of the interdigital skin, without an obvious point of infection (ingress) or drainage (egress)
Interdigital dermatitis	Epidermatitis of the interdigital skin
RARE CONDITIONS	
Mud fever (dermatophilosis)	Suppurative dermatitis
Foot and mouth disease	Vesicular dermatitis
Vesicular stomatitis	Vesicular dermatitis
Mycotic stomatitis	Vesicular dermatitis
Bovine viral diarrhoea	Vesicular dermatitis
Malignant catarrhal fever	Vesicular dermatitis

9.3.2.1. Digital dermatitis

Digital dermatitis is an infectious disease first reported in Italy by Cheli and Mortellaro (1974). It presents as erosive or papillomatous dermatitis affecting the digital skin of cattle. The disease is thought to be caused by a family of treponeme spirochaetes. However, the difficulty of isolating a pure culture and failure to reproduce disease by inoculation has meant there is still some doubt about whether the Treponemes are the sole causal agent. A number of other organisms have been isolated from digital dermatitis lesions (Murray et al., 2004). The incidence of digital dermatitis has increased markedly in recent years. Recent reports indicate that digital dermatitis accounts for 40-50 % of skin lesions associated with episodes of lameness (Murray et al., 1996; Offer et al., 2000; Blowey, 2005).

Prevalence of digital skin infections tend to peak in the first month after calving (Arguez Rodriguez et al., 1997, Alban et al., 1995), presumably due to factors relating to sudden management changes (e.g. introduction to slurry and contact with infected adult carriers). Risk factors associated with calving, milk production and milking herd management inevitably interact, resulting in a significant rise in lameness-related lesions soon after calving (Rowlands et al., 1985, Offer et al., 2000), the timing being dependent on the type of lesion, the individual heifer and herd-specific factors.

9.3.2.2. Interdigital necrobacillosis

Interdigital necrobacillosis “Foul-in-the-foot” presents as a severe, acute or subacute lameness, invariably affecting one limb, with swelling of the distal soft tissues resulting in splaying of the toes. On examination, the interdigital skin of feet is classically fissured longitudinally and discharging a serosanguinous fluid with variable amounts of necrotic debris. There is invariably a characteristic fetid odour. Occasionally, interdigital fissuring is absent and these cases are referred to as “blind fouls” (Radostits et al., 2000a). In a few cases, a foreign body may be identified in the interdigital space, which is likely to have been a causative factor. A traumatic walking surface constitutes a major risk, especially when this is

combined with mud or slurry, e.g. in farm gates. Affected animals are usually febrile, with a reduced milk yield and appetite. If left untreated, many animals recover without complication although lameness may be prolonged. A proportion of individuals go on to develop complications such as a deep digital sepsis and synovial sepsis, particularly in the iperacute form of the disease (Cook and Cutler, 1995).

9.4. Assessment and monitoring of lameness

Lameness is recognised by a number of abnormal behavioural changes. In dairy cows, signs observed during locomotion may include head nodding, non-rhythmic timing of foot-fall, shortened strides in one or more feet, spine-arching, abnormal limb motion or limp and possibly poor hindfoot-forefoot tracking (Flower and Weary, 2006; Sprecher et al., 1997; Whay, 2002). While standing, cows may also “paddle”, i.e. shift weight between contralateral pairs of legs (Rushen et al., 2007b). The mechanisms employed appear to be designed to reduce or restrict weight bearing on the affected foot or claw, which implies that they represent an attempt to cope with chronic pain. Some mechanisms, e.g. “paddling” while stationary, e.g. in the milking parlour may simply reflect general discomfort. This behaviour appears to be especially associated with the pain of bilateral infections such as digital dermatitis.

9.4.1. Locomotion scoring

A number of different locomotion or lameness scoring methods have been developed (Manson and Leaver, 1988a; Tranter and Morris, 1991; Winckler and Willen, 2001; Wells et al., 1993; Sprecher et al., 1997; Whay et al., 1997; 2003a; O'Callaghan et al., 2003). All these methods score abnormality of locomotion on a scale that ranges from sound to severely lame. However the methods all differ slightly in terms of the observations employed and the scores attributed to each set of clinical signs. Moreover lameness detection sensitivity (using the same scoring procedure) has been shown to differ between farmers and researchers (Wells et al., 1993, Whay et al., 2003a), and between similar types of individual assessor, particularly before any official training (Engel et al., 2003). These factors mean that comparisons between studies that use different detection methods and different assessors of lameness should be approached with great caution.

A regular, robust system for locomotion scoring is essential to the implementation of any lameness control programme. The subjectivity and time-consuming nature of visual locomotion scoring point to the need for an effective, economically viable automated system for locomotion scoring on farm. Several groups are seeking to develop and validate automated systems based on visual observation of gait or force-plate recordings of foot pressure (Bicalho et al., 2007; Pastell and Kujala, 2007). These approaches show promise but have not yet reached the stage where they can be incorporated into commercial practice.

9.4.2. Lesion scoring

Lesion scores have been used to assess the prevalence and severity of lameness (Leach et al., 1998; Le Fevre et al., 2001; Wells et al., 1993; Smilie et al., 1999). Once again these systems vary slightly in approach. However, all of them describe claw (sole, heel and white line) and skin lesions according to location, area and severity. There is a clear relationship between severe foot lesions, sole ulcer and lameness (Flower and Weary, 2006; Manske et al., 2002). Le Fevre et al. (2001) proposed a system for integrating lesions number, size and severity and

in this case claw horn lesion scores were highly correlated with lameness. However many milder foot lesions involving sole haemorrhage are not consistently associated with lameness (Manske et al., 2002). The relationship between lameness and the early stages of foot lesion development may be complex for a variety of reasons (O'Callaghan et al., 2003). Lesions such as sole haemorrhage, only become visible approximately two months after the suspected time of the internal insult (Leonard et al., 1996) due to the time taken for horn lesions produced at the corium to reach the bearing surface through normal horn wear. It is obviously more time consuming to lift the feet of cattle for lesion scoring than to assess lameness from observation of locomotion. However lesion scoring can be incorporated into foot trimming routines, especially when they are carried out by professional foot trimmers trained in accepted protocols for recording and scoring lesions. Automated detection of lameness is also promising (Pastell and Kujala, 2007) but methods are not all equally good (Bicalho et al., 2007).

9.5. Lameness and animal welfare

Lameness in dairy cows presents a major welfare problem whether assessed in terms of their physical state (fitness) or mental state (suffering). Table 9 summarises published reports of welfare problems attributable to lameness. These include infertility, loss of production, premature culling, pain and other behavioural indices of discomfort or distress. Recognition of lameness as a major welfare problem both in European legislation and in quality assurance programmes operating within the dairy industry gives emphasis to the assumption that all foot lameness is an expression of pain that may vary from slight to severe.

9.5.1. Lameness and pain

Lameness-causing lesions of the foot are painful (O'Callaghan et al., 2003; Dyer et al., 2007). Thus painful lameness can be relieved by analgesics (Rushen et al., 2007; Whay et al., 2005). The pain of sole ulcer is best alleviated by blocking and bandaging to take weight off the affected claw and keep the ulcerated area out of contact with slurry (Blowey 1993). Whay et al. (1997; 1998) demonstrated that lame cows have reduced nociceptive thresholds consistent with hyperalgesia (hypersensitivity to pain), a complication known to exacerbate the problem of chronic pain in humans. Hyperalgesia was still present 28 days after treatment in cows with claw horn lesions but not following treatment for digital dermatitis. This demonstrated that while effective treatment of a skin infection can bring prompt relief, pain arising from pressure of the skeleton through PIII on a damaged or destroyed sole is likely to persist. Many severely lame animals with intractable foot pain fail to make a full recovery, due to the development of complications or chronic changes. Unless these animals are culled immediately, these animals will suffer for extended periods of time. Some may be culled at the end of the lactation but others remain lame and in pain through subsequent lactations.

Table 9 Welfare indicators affected by lameness in cattle

Welfare measure	Report
Fertility	
Extended calving interval	Collick et al., 1989; Hernandez, 2001; Hernandez et al., 2005; Lucey, 1986.
Ovarian cyst formation	Melendez et al., 2003.

Reduced ovarian activity	Garbarino et al., 2004.
Infertility, premature culling	Sprecher et al., 1997.
Mild lameness had no effect	Gomez et al., 2004.
Health and performance	
Depressed milk yield and reduced milk solids	Coulon et al., 1996., Green et al., 2002 ; Warnick et al., 2001a.
Fall in condition score	O'Callaghan., 2002.
Increased risk of culling	Sprecher et al., 1997.
Increased risk of secondary disease	Sogstad et al., 2006.
Mental well-being	
Pain (and pain hypersensitivity)	Whay et al., 1997; 1998.
Abnormal bouts of lying behaviour	Manson, 1989 ; Cook et al., 2004 ; Singh et al., 1993 a; b; 1994; Hassall, 1993; Juarez et al; 2003.
Changes in feeding behaviour	Phillips and Schofield, 1994; Singh et al., 1994.
Fall in status within the social hierarchy	Sauter-Louis et al., 2004 ; Hassall et al., 1993.
More time lying out of cubicles	Galindo and Broom, 2000.
Less time walking	Galindo and Broom, 2000.
Elevated plasma cortisol, CPK	Belge et al., 2004.

9.5.2. Behavioural changes associated with lameness

Many behaviours conventionally associated with painful conditions such as lameness tend to be expressed less overtly in bovines (O'Callaghan et al., 2003) compared with other species such as the canines, felines or humans. This reflects an evolution of stoical behaviour in response to strong selection pressure on grazing herd animals to mask signs of pain or injury from potential predators that search for weakened or debilitated prey.

Walking, standing, mounting, being mounted, rising and lying are just a few normal behaviours that can be compromised by lameness. Lameness cow behavioural studies have primarily focused on characterizing locomotion and patterns of lying behaviour (Singh et al., 1993a,b; 1994; Hassall et al., 1993; Leonard et al, 1994; Phillips and Schofield, 1994; Galindo and Broom, 2000; Juarez et al., 2003; Cook et al., 2004) although patterns of feeding behaviour (Singh et al., 1993b; Phillips and Schofield, 1994) and changes in social status (Galindo and Broom, 1994; 2000; Manson, 1989) have also been assessed. Lameness cows lost social rank. They also ate for a shorter periods, consumed less dry matter and had a higher eating rate than healthy herd mates. A similar study by Galindo and Broom (2000) looked at 10 lame cows and 10 sound cows over a 32-hour period. They found lame cows had similar time budgets to sound cows for feeding and lying, but lame cows spent less time walking and more time lying out of cubicles. The authors concluded lame cows were less capable of coping with their environment than their sound counter-parts.

Most studies of bovine behaviour suggest cows prefer to spend 10-14 hours per day lying down (Singh et al., 1993a; 1994), usually in short bouts of a few hours. However, this preferred lying time can be compromised in the high yielding dairy cow if the required energy and dry matter intakes are not met through poor provision of rations or prolonged periods of restricted access to either food or lying area. Lying times can also decrease due to factors such as use of cubicle housing and cubicle comfort, high stocking rates and recent calving. Severely lame cows prefer to lie down for longer amounts of time per day, but moderately lame cows have been shown to stand for less time (Cook et al., 2004). Furthermore, the time spent lying down was concentrated in a smaller number of prolonged bouts. Cook et al. (2004,

2007) also assessed the lying behaviour of lame cows under a number of cubicle systems and found patterns of lying behaviour in lame cows varied according to the types of bedding system used. The authors concluded that sand provided a better surface to allow lame cows to grip as they rise to their feet and could provide an explanation for why lame cows appear to be more likely to become trapped in cubicles.

9.5.3. Physiological changes associated with lameness

Belge et al. (2004) demonstrated cows with signs of chronic claw horn disruption had raised cortisol levels compared with a control group. As well as plasma cortisol, Belge et al. (2004) assessed a number of other biochemical parameters, including blood potassium, iron, sodium, zinc, calcium, phosphorus, creatine phosphokinase (CPK) and total protein (TP) in cows showing evidence of chronic claw horn disruption. In this study, TP was significantly raised in the diseased group which was attributed to an acute inflammatory response rather than any other physiological response, although dehydration or presence of other inflammatory disorders such as gastrointestinal parasitism were not excluded and no plasma protein electrophoresis was performed to determine if acute phase proteins were raised. More difficult to interpret was the significantly raised of Gamma Glutamyl Transpeptidase (GGT), which suggested some degree of hepatocellular damage, was present in cows with Claw Horn Disease (CHD). However, it is unclear from this study whether GGT raise could have been secondary to reduced dry matter intakes and secondary to metabolic disturbance. Significantly raised Fe, low Zn and low Ca levels were also found and explained in terms of a response or consequence of the CHD present.

9.5.4. Productivity changes as a consequence of lameness

Dairy production measures are routinely recorded, and as such, can be used as quantifiable indicators of poor welfare. Depression of milk yield (Juarez et al., 2003; Warnick et al., 2001, Green et al., 2002c), reduced butterfat and reduced milk protein have all been described in dairy cows. Green et al. (2002c) estimated that clinically lame animals produced 360 kg less milk compared with their sound (non-limping) counterparts. Similarly, increased calving to first service and calving to conception interval (Sprecher et al., 1997), prolonged calving-to-calving interval, reduced ovarian activity, reduced bulling activity and reduced conception rates have all been associated with clinical lameness in dairy cows.

Reasons for culling and culling rates have been utilised as measures for assessing fitness and survival within the herd, and represent useful economic measures. Amongst UK dairy cows, Whitaker et al. (2004) found lameness to be the third most common reason for culling of dairy cows in the UK after mastitis and infertility. However, culling figures for lameness may be under-estimated and require careful interpretation. In many cases there is more than one reason for culling, particularly as many animals are infertile or have poor milk yields because they are lame. Sprecher et al. (1997) found lame cows were 8.4 times more likely to be culled per year compared with non-lame cows in one herd with a reported fertility problem.

Many chronically lame cows continue to produce economically acceptable amounts of saleable milk, particularly if managed at pasture or on straw yards close to the milking parlour, albeit of poorer quality and reduced quantity. Unlike cows with mastitis or infertility, lame cows are unfit for transportation. Therefore, these animals require on-farm slaughter with carcass collection if they cannot be nursed back to full recovery. Consequently many severely lame cows are retained within the herd until they are in one of three states: recovered

(partially or completely), too severely lame to be productive or suffering from a second condition. All these factors make the comparison of culling figures between conditions misleading for the true assessment of cost, both in terms of animal welfare and economics.

Loss of condition has been observed in clinically lame cows (O'Callaghan, 2002). This may be attributed mainly to reduced feeding, exacerbated in severe cases by the metabolic cost of mounting prolonged immune and inflammatory responses.

Studies looking at the prevalence of secondary disease have revealed that lame cows are significantly more likely to suffer from mastitis, cystic ovarian disease and metabolic disease such as ketosis. Hock injuries such as swelling, hair loss and ulceration are correlated with lameness and lesions of the foot (Whay et al., 2003b). It is probable that these hock injuries reflect the presence of other primary lameness risk factors, namely features of cubicle comfort.

9.6. Foot disorders and risk factors associated with lameness

9.6.1. Introduction

The causes of the clinical condition leading to lameness are multifactorial. Reviews of a cattle lameness literature database (Hirst et al., 2002) and of expert opinion based on Delphi principles (Whay et al., 2003a) have identified over 100 potential hazards for the four main categories of foot lesion leading to lameness, namely sole haemorrhage (including sole ulcer), white line disease, digital dermatitis and interdigital necrobacillosis.

9.6.2. Sole haemorrhage and sole ulcer

Sole haemorrhage, which may in severe cases progress to sole ulceration, arises from mechanical damage to the tissues that suspend and support the skeleton (specifically the third phalanx (P3) or pedal bone within the hoof, leading to progressive deterioration of the corium and sole horn. The presence and extent of this mechanical damage is determined by the severity of the external stresses on the foot and the capacity of the support structures within the hoof (resilience) to withstand these stresses.

External stresses may be static (e.g. prolonged standing on concrete) or dynamic (e.g. claw trauma cause by slipping). Factors that might contribute to prolonged standing without opportunity for adequate frequency or duration of rest included cubicle comfort, cubicle training, cubicle availability, bullying (Singh et al., 1993a; Leonard et al., 1994; Phillips and Schofield, 1994; Cook et al., 2004). Factors that may lead to claw trauma include rough stone tracks, rough concrete yards and walking long distances, especially when hurried (Chesterton, 2004). The relative importance of different hazards contributing to a loss of capacity to withstand stress without the support structures of the hoof is more contentious (see section 14). Stresses associated with standing on concrete can be reduced by improving cow comfort and increasing lying time by housing cows on straw or other soft bedding such as peat or sand (Bergsten and Herlin, 1996), improving cubicle comfort to increase lying time, or by covering the concrete walkways with asphalt or rubber to improve the quality of the walking surface (Vanegas et al., 2006; Kremer et al., 2007). Individual cows treated for claw lesions recover more quickly if moved from concrete onto straw or pasture (Hernandez-Mendo et al., 2007).

Calving and the onset of lactation constitute a major (though unavoidable) hazard, especially for first-calving heifers. This however is too crude a measure of risk since it can involve many

tangible hazards that can increase external stresses on the foot and/or reduce resilience to these stresses. Onset of lactation (especially first lactation) may coincide with a substantial increase in time spent standing on concrete. At the same time, the cow experiences major endocrinological changes and is provided with a substantially enriched diet. Increased time spent standing on concrete, especially in early lactation when the resilience of the support mechanism within the feet is impaired, presents a more severe hazard than feeding for lactation (Knott et al., 2007). However since the connective tissue changes in the foot are relatively brief unless exacerbated by bad housing, the incidence of CHD can be radically reduced by keeping cows off concrete for the first 8 weeks of lactation (Webster, 2001; Webster, 2002)

A further group of hazards relates to the quality of foot care. These include appropriate trimming of healthy claws to create a functionally sound hoof prior to calving, and the ability of the stockman to detect promptly and treat effectively any sole haemorrhage or ulceration. Claw trimming has been shown to improve the locomotion of cows, thereby alleviating lameness, through the correction of imbalanced weight distribution between medial and lateral claws and the treatment of painful foot lesions (Manson and Leaver, 1987; 1988b; 1989; Manske, 2002).

9.6.3. White line disease

Many of the risk factors for white line disease are similar to those for sole haemorrhage and ulceration. There is very little published data on risk factors specific to white line lesions in dairy cows. However, studies in New Zealand have demonstrated the importance of shear forces due to cow-cow interactions on cow tracks and in collecting yards (Chesterton, 2004). Track management along with gentle herding methods and backing gate operation have been identified as risk factors for lameness in New Zealand (Chesterton et al., 1989) and in the UK (Clarkson and Ward, 1991). Unlike sole haemorrhage and ulceration, there is clear evidence to suggest that dietary interventions using biotin can reduce the incidence of lameness due to white line disease (Hedges et al., 2001).

9.6.4. Digital dermatitis

Hazards associated with a high prevalence of digital dermatitis include low levels of biosecurity (Blowey and Sharp, 1988; Arguez Rodriguez et al., 1997; Rodriguez-Lainz et al., 1996; 1999; Wells et al., 1999), exposure to wet, unhygienic conditions (Rodriguez-Lainz et al., 1996; Brizzi, 1993; Cruz et al., 2001; Wells et al., 1999), housing type (Frankena et al., 1993), herd size (Frankena et al., 1993) and animal-specific factors such as age and parity (Rodriguez-Lainz et al., 1999; Frankena et al., 1993), stage of lactation (Arguez Rodriguez et al., 1997), breed and milk yield (Rodriguez-Lainz et al., 1999).

9.6.5. Interdigital necrobacillosis

Interdigital necrobacillosis, or 'Foul in the foot', presents in sporadic, rather than epidemic form. It is associated with anaerobic organisms such as *Fusobacterium necrophorum*, *Dichelobacter nodosum* and *Prevotella melaninogenica* which are causative agents for foot rot in sheep. Thus management of cows separately from sheep may reduce the potential exposure of cattle. It is probable however that penetrating wounds in the interdigital space, induced e.g. by walking on broken ground, is a major predisposing factor. Mud, stubble and stones have been reported as risk factors (Greenough et al., 1981) as has high rainfall (Eddy

and Scott, 1980; Nylín, 1980). The prevalence of IN appears to be greatest when cattle are at pasture and conditions are warm and wet (Eddy and Scott, 1980; Baggott and Russell, 1981; Rowlands et al., 1985). This could be due to the softening of the interdigital skin, making it more susceptible to abrasion, erosion, infection by other pathogens. Alternatively the conditions under-foot could provide a means by which abrasive materials such as mud and slurry can carry stones and pathogenic microorganisms into the interdigital space.

Several studies have found loose-housed cattle were significantly more likely to suffer FIF than cows in tie-stalls (Alban et al., 1995; Nylín, 1980; Blom, 1982). This could be for a number of potential reasons, including increased exposure to wet, slurry contaminated conditions, increased movement and social interaction, increased mixing of animals thus increasing the spread of pathogens or due to the abrasion of interdigital skin by straw trapped between the claws.

Stage of lactation has been shown to have a big influence on disease incidence with 40% of treatments occurring in the first month of lactation (Alban et al., 1995; Eddy and Scott, 1980; Baggott and Russell, 1981; Rowlands et al., 1985). One explanation for this finding may be the increased risk of trauma to the interdigital skin in the transition period due to competition for space and feed, social factors or unfamiliarity with the environment. Another possible explanation may be the increased risk of infection related to metabolic disturbances and periparturient immunosuppression.

Breed differences have been suggested but the results are inconsistent (Baggott and Russell, 1981, Alban et al., 1995; Blom, 1982; Monrad et al., 1983). It is possible that cattle with a wide interdigital space (splayed toes) may be at greater risk of disease (Greenough et al., 1981). Parity has also been reported as a risk factor but once again reports are inconsistent. Rowlands et al. (1985) found no parity effect. Alban et al. (1995) reported a significantly higher incidence in primiparous heifers. This finding could be explained by trauma due to social disturbances with heifers being most likely to traumatise the interdigital skin when avoiding dominant cows.

9.6.6. Categorisation of proximate hazards and analysis of proximate risks

Recognition of the multiplicity of individual hazards (>100) attributable to housing and management is necessary in order to identify risks and prioritise actions for control on individual farms. However their multiplicity does not lend itself to a generic evaluation of the severity of the different hazards and thereby identify critical control points for action within a Lameness Control Plan based on HACCP principles (Hazard analysis and critical control points). Table 10 (from Bell et al., 2008) presents an approach to categorization of all tangible hazards for Claw Horn Disease and Digital Dermatitis identifiable “on farm” into 11 categories of proximate hazard on the basis of similar direct (or proximate) action “at foot” in the aetiopathogenesis of disease. These may be thought of as hazards “at foot”. Bell et al. (2008) analysed the association between risks associated with these proximate hazards and the prevalence of unsoundness and severe lameness in first-calving heifers from an intervention study on 60 herds in U.K. The most severe proximate environmental hazards for lameness were prolonged standing on concrete and factors that cause claw trauma. The most severe management factors were poor slurry management and poor hoof condition at calving. The major hazard for severe lameness was failure to treat cases early.

Table 10 Classification of hazards for lameness characterised as tangible (“on-farm”) and proximate (“at-foot”). The full list of tangible hazards is available as an appendix to Bell et al. (2008)

Proximate hazards	Tangible hazards (examples)
"At foot"	"On farm"
Environmental	
Prolonged standing on concrete	Uncomfortable cubicles Time in collection yard
Factors that cause claw trauma	Rough, broken concrete
Slurry/wet conditions underfoot	Slurry remaining after scraping
Prolonged standing in slurry	from prolonged standing on concrete plus slurry underfoot
Managerial	
Breaches of biosecurity	Open herd Contract foot trimmers
Sub-optimal claw shape at calving	overgrown claws no foot trimming overzealous foot trimming
Sub-optimal foot health at calving	digital dermatitis acquired before calving
Inadequate lameness detection/treatment	inadequate foot trimming inadequate foot care for lame cows
Inadequate DD detection/treatment	no preventive foot bathing inadequate treatment
Animal	
Rumen disorders	Poor transition diet High concentrate feeding in lactation
Heifer phenotype/condition	Phenotype/ condition at calving

9.7. Lameness control at the herd level

The application of HACCP principles is especially effective in the control of lameness in dairy cattle since it is a multifactorial disease resulting from the exposure of dairy cows to a wide range of environmental and management hazards (Noordhuizen and Welpelo, 1996; Bierma et al., 2006; Bell et al., 2008). The same principles can be applied at the level of the individual farm or incorporated into a broader strategy to reduce lameness as part of a welfare-based quality assurance scheme operated by a dairy cooperative or retailer, or by government at a national level.

It is however distressing to report that despite the considerable investment of time and money in research, technology and information transfer, there has been no significant reduction in the prevalence of lameness in dairy cows in the last 20 years. This means that implementation of lameness control programmes based on new knowledge have not yet had any significant impact, whether at farm or national level. The evidence to date (Bell et al., 2007) suggests that this has been mainly due to failure to implement the agreed corrective action procedures. Reasons for these failures in compliance may include lack of money, lack of time and lack of

a tangible economic reward for action. This implies that the solution to the major welfare problem of lameness in dairy cattle lies more in socio-economics than in science.

10. Mastitis and welfare

10.1. Introduction and definitions

Mammary glands are accessory reproductive organs that develop in repeated cycles to nourish the offspring of the animal. Development of the mammary gland starts around puberty, which is for dairy calves between 8-10 months old. After the first parturition of a cow, the mammary gland starts to produce milk. On average, dairy cows are milked for about 305 days and then are dried off (period of no milking) to prepare the mammary gland for the next lactation period. To optimise milk production a dry period of at least 40 days is required. In that period epithelial cells in the udder are lost by apoptosis and damaged secretory tissue will be repaired (Hurley and Ford, 2003).

Through genetic selection, advances in milking technology and improved nutrition, the bovine mammary gland yields far more milk than is needed to nourish the newborn calf. Production levels of a herd on an annual base vary between 7 500–12 000 kg milk per average cow. This connects with an average milk yield between 25 and 32 kg milk per cow over a lactation period of 305 days. Nowadays high producing cows have the capability of producing a maximum milk yield of 70 kg milk per day during peak lactation.

Selection for milk yield and milk practices imposes stress on the udder. With an average daily milk yield of 28 kg milk the suspensory ligaments of the udder have to support more than 70 kg tissue and stored milk. As animals age the support capacity of the ligaments is reduced resulting in pendulous udders that might be vulnerable to injury and mastitis.

Mastitis as defined by the International Dairy Federation (IDF) is an inflammation of the mammary gland, with an infectious or noninfectious aetiology. Organisms as diverse as bacteria, mycoplasma, yeasts and algae have been implicated as causes of the disease. Although the majority of mastitis is of bacterial origin, mastitis is characterised by physical and chemical changes of the milk and pathophysiological changes of the mammary tissue with possible systemic symptoms. Clinical and subclinical mastitis are classified.

The IDF defined clinical mastitis as udder inflammation characterised by visible abnormalities in the milk or udder. Clinical cases can be classified in mild, moderate and severe. Cows with clinical mastitis may show swelling of the udder and apparent pain or discomfort and the milk may contain flakes or blood. Subclinical mastitis is defined as inflammation of the udder that is not visible and requires the measurement of SCC or microbiological analyses to diagnose.

Classically, mastitis pathogens have been classified as either 'contagious' or environmental (Blowey and Edmondson, 1995). Contagious pathogens can be considered as organisms adapted to survive within the host (i.e. the mammary gland). They can establish subclinical infections, which are manifested in elevation of the somatic cell count (SCC). They are typically spread from cow to cow at or around the time of milking. In contrast, the environmental pathogens are opportunistic invaders of the mammary gland, not adapted to survival within the host. After invasion of the mammary gland they are rapidly eliminated by the immune response of the host. Environmental pathogens spread between milkings through the environment (cubicles, bedding). Major contagious pathogens are *S. aureus*, *Str.*

dysgalactiae and *Str. agalactiae*, the major environmental pathogens comprise *Enterobacteriaceae* (*E. coli* and *Klebsiella*) and *Str. uberis*.

10.2. Incidence and prevalence of mastitis

Despite widespread implementation of mastitis control strategies mastitis remains a major challenge to the dairy industry. The impact of the implementation of mastitis control strategies, and in particular the Five-Point Plan (Neave at al., 1969) has been very successful in controlling the contagious pathogens. Bulk tank somatic cell count (BTSCC) has decreased dramatically in the last decades, but incidence of clinical mastitis remains more or less constant over the last 20 – 30 years. There has been a shift in the causing micro organism from the contagious pathogens towards the environmental pathogens, like *E. coli* and *Str. uberis*.

Although animal identity, production and disease recording are all essential parts of good dairy farm management, in most countries it is difficult to get reliable data on the incidence of mastitis. Only a few countries have reported disease recordings from the majority of the dairy cattle population within the framework of an animal recording system. These countries are Norway, Sweden Finland and Denmark. In these countries there is a national database which gives information about the incidence rate of clinical mastitis. Some other countries like United Kingdom have conducted large field surveys to get information about the number of infected and diseased animals (Bradley et al., 2007). In this study the incidence of clinical mastitis in England was 47- 65 cases per 100 cows per year, with *E. coli* and *Str. uberis* as the most commonly isolated major pathogens. Osteras at al., (2007) found an incidence rate for severe and moderate clinical mastitis of 21.3 per 100 cow-years. Besides the poor registration of clinical mastitis in most European countries, several definitions of clinical mastitis are used making it hard to compare numbers of diseased animals in the different countries. Therefore comparison between different studies and countries should be done carefully. An estimation of the incidence of clinical mastitis for the different countries varies between 20%-35% cows per herd per year.

10.3. Pathology, pathogenesis and treatment

The mammary gland is protected by a variety of defence mechanisms, which can be separated into two distinct categories: innate (nonspecific) immunity and specific immunity. Innate immunity is the predominant defence during the early stages of infection. If non-specific defence mechanisms function adequately, most pathogens are readily eliminated before the specific immune system is activated. Rapid elimination of bacteria will not result in changes in milk quality or production. If the nonspecific immunity fails, specific immunity is triggered and lymphocytes, antigen-presenting cells and immunoglobins will be involved.

Innate defence to infections consists of physical barriers as teat, milk somatic cells and other factors present in milk or in the udder. The teat canal provides the first line of defense against mastitis-causing pathogens (Paulrud, 2005). Anatomical and physical conditions of the teat and the udder influence the prevalence and incidence of mastitis and thereby udder health. Most of these traits have a small to moderate heritability. The teat canal is lined with keratin. Keratin inhibits growth of micro-organisms in the teat canal and forms the so called keratin plug that closes the teat orifice. Immediately after milking, due to keratin removal, the teat canal is more susceptible to penetrating of pathogens. Within 2–3 weeks after drying-off cows, a keratin plug blocks the teat canal and inhibits bacterial invasion.

In normal milk, i.e. milk of a healthy mammary gland, somatic cell count (SCC; white blood cells) is below 100.000 cells/ml. After invasion of bacteria into the mammary gland, the bovine immune system reacts by a massive influx of polymorphnuclear cells (PMN) within 6 to 9 hours after infection resulting in a SCC of more than 1.000.000 cells/ml. SCC is the best indicator of infected versus non infected quarters of the udder of a cow. SCC is an important parameter of milk quality as it reflects the health status of the cow and the quality of the milking machine and procedures. Bulk milk SCC (BMSCC) reflects the udder health of the lactating herd, but also the pathogen distribution among the herd. Herds that are *Staphylococcus aureus*- positive in the bulk milk have a higher BMSCC than *Staphylococcus aureus*-negative herds (Olde Riekerink et al., 2006). Different management factors like dry cow treatment, post milking teat disinfection and milking technique have a significant effect on BMSCC.

The European Union (EU) Directive 92/46 sets the maximum allowable bulk milk SCC for manufacturing milk at 400,000 cells/ml. The legal limit for total bacterial count (TBC) is 100,000 cfu/ml. Recommendations of management factors like treating cows with antibiotics during the dry period and the use of post milking teat dipping show variety among the different EU countries. Table 11 gives an overview of situation in several European countries in 2001.

Table 11 Mastitis control in European countries (Source: Bulletin IDF 367/2001)

Country	BMSCC (cells/ml)	TBC (cfu's/ml)	Antibiotic Dry cow Treatment	Post Teat dipping
Denmark	247,000	8,400	not a rule	not a rule
Finland	166,000	11,800	selective (20%)	20 – 25 %
Germany	171,000	20,000	blanket	frequently
Ireland	300,000 (subset of	34,000	blanket	frequently
Italy	?	?	blanket (40%)	frequently
Netherlands	201,000	12,000	blanket (65%)	majority
Norway	142,000		not recommended	12%
Sweden	200,000		selective (20%)	majority
Switzerland	101,000	12,500	selective	majority
United	160,000 – 180,000	13,000	blanket	majority

The average BMSCC in European herds is far below the legal limit of 400,000 cells/ml. At cow level SCC of less than 250,000 cells/ml and for heifers SCC less than 150,000 cells/ml is used to select udder quarters for intra mammary infections. Treatment of mastitis using antibiotics should preferable be based on bacterial culturing of the infected quarter.

Pre-dipping of the teats is forbidden according to the EU directive for milk quality. Post teat dipping is recommended in many of the European countries. Post teat dipping reduces bacterial population at the teat end is reduced which might decrease the rate of intramammary infections.

10.4. Teat disorders

Teat lesions are predominantly seen in heifers. Teat lesions are predominantly caused by viral infections such as pseudocowpox and bovine herpes virus 2. In 50 % of the cases a secondary mastitis will develop.

In recent years an increasing number of teat lesions predominantly in heifers, which in extreme cases resulted in sloughing of the teat, have been found. The etiology is variable originating from viral infections, disturbed blood supply, selenium supply, sudden changes in ration, periparturient period and extreme udder oedema and excema of adjacent legs in the pasture (Sol et al., 2005; Blowey 1996).

Teat problems are also described in combination with extreme udder oedema and eczema of the adjacent leg region. Sometimes heifers lick or bite off their teats, called “intersucking” (Lidfors and Isberg, 2003).

10.5. Assessment and monitoring of mastitis

The best milk quality indicator appears to be SCC, because it includes hygienic, compositional and technological aspects in addition to consumers’ demands for healthy cows. A distinct change of major milk components can be determined as SCC exceeds 100,000 cells/ml. This suggests that the physiological threshold should be set and thrived at a level of 100,000 cells/ml (Hamann, 2001).

For the field on herd level the following priorities can be given to the suitability of various diagnostic procedures: 1) clinical assessment of the udder, teats and the cow; and 2) individual SCC combined with the BTSCC and the composition of the milk. The individual cow SCC monitoring programme gives insight in the dynamics of the mammary gland. Cows that move from a low SCC to a high SCC are likely to have an intramammary infection and should be monitored very carefully. Depending on the herd situation milk samples should be taken for bacteriological culture and in order to prevent transmission of the micro-organism to healthy herd mates, followed by antibacterial treatment.

It should be considered, however, that cell counts below 10^6 /ml don’t seem to induce pain in the cow (Eshraghi et al., 1999). Pain and stress due to mastitis treatment would be greater than the presence of high cell count. The important part is to protect the healthy herd mates from being infected also considering that the cost effectiveness of such treatments is also very doubtful (Sandgren et al., 2007).

10.6. Pain and stress during mastitis

Bradykinin and other kinin peptides are important mediators of vasodilatation, pain and oedema. Bradykinin is released in relation to the severity of clinical mastitis (Eshraghi et al., 1999). The level of bradykinin is only slightly increased in cows with subclinical mastitis, it is therefore unlikely that cows with subclinical mastitis experience pain. Herskin et al. (2005) found that during the first 48 hours of an *E. coli* mastitis cows showed behavioural responses as indicators of pain, such as tail flicking, tripping and kicking during milking etc. Cows with moderate and mild mastitis cases responded to a treatment with Non Steroidal Anti-Inflammatory Drug (NSAID). Heart rate, rectal temperature and respiratory rates differed with the severity of the mastitis leading to the conclusion that mastitis is painful and the pain increases with severity of symptoms (Milne et al., 2005).

Stress is indicated as a source of reduced fertility. Mastitis, both clinical and subclinical mastitis, negatively affects the reproductive performance of cows (Schrick et al., 2001).

Stockmanship is the key to animal welfare. Negative actions by the milker affect the occurrence of intramammary infections. Shouting and beating increases rest milk in the udder.

Concerning the impact of mastitis on the welfare of cows, the suggestion of the integrated EU project (www.welfarequality.net) should be followed where animal welfare is assessed at cow level rather than evaluating animal welfare on the basis of the assessment of the production system. For mastitis the severity e.g. local or systemic illness, the duration of the mastitis and the number of animals suffering from mastitis should be included in order to assess the health and welfare status of a herd.

10.7. Effects of mastitis on productivity

Mastitis is an endemic disease that is considered to be one of the most frequent and costly diseases in the dairy industry (Kossaibati and Esslemont, 1997). Besides the economic effects mastitis affects milk quality directly in the technical characteristics and the hygiene quality of the milk and indirectly through the intrinsic quality of the milk.

In both clinical and subclinical mastitis there is a substantial loss in milk production. Production losses due to clinical mastitis have been estimated (Grohn et al., 2004, Hortet et al., 1998). Production losses due to subclinical mastitis are generally considered to be a direct log-linear relationship between somatic cell count (SCC) and test-day records (Bartlett et al., 1990, Miller et al., 1993).

10.8. Risk factors for mastitis

Mastitis is a multifactorial disease in which the environment, the pathogen and the host (cow) play a crucial role. Optimisation of the hygienic procedures in the barn and in the milking parlour combined with the optimal immune status of the cow will make it difficult for the pathogens to cause an intramammary infection. In addition, the overall management of transition cows influences the risk of clinical mastitis post partum, as well as the risk of many other health disorders. Overall management of dry cows includes factors such as controlled and nutritionally balanced feed intake, hygienic housing, minimised stress and proper calving assistance when needed. The dry (non-lactating) period of the cow is of great importance in the dynamics of intramammary infections (Neave et al., 1950; Totdhunter et al., 1991; Green et al., 2002a). Susceptibility of the bovine mammary gland to infection during the dry period is considered to be greatest in the days after drying off and in the 3 weeks before calving (Bradley and Green, 2004). Intramammary infections that are present during the dry period can be divided into those that were carried into the dry period from the previous lactation (existing infections), and those that enter between the time of drying off and calving (new infections) (Bradley and Green, 2004). The probability of a new dry-period infection is influenced by the rate of exposure to pathogens (e.g., from the environment), factors that affect an individual cow's susceptibility to infection (Dingwell et al., 2004), and the effectiveness of protection from medical interventions such as antibiotic dry-cow therapy or teat sealants (Bradley and Green, 2002; Berry and Hillerton, 2002; Robert et al., 2006).

Compared with an uninfected mammary gland, glands infected during the dry period are at greater risk of clinical mastitis during the next lactation (Bradley and Green, 2000; Green et al., 2002a). Furthermore, clinical mastitis in cows with an intramammary infection in the previous dry period occurs at a faster rate after calving than in uninfected cows during the dry

period (Green et al., 2002a). Therefore strategies that control intramammary infections during the dry period are likely to influence the rate of clinical mastitis after calving (Green et al., 2007). A recent study has shown that cow characteristics such as higher SCC at drying off and increasing parity were associated with an increased rate of clinical mastitis (Green et al., 2007). Nutritional status of the cow, in particularly poor vitamin E and selenium status (Smith and Hogan, 1993) as well as negative energy balance (Suriyasathaporn, et al., 1999) have been demonstrated to affect the immunity of the cow in a negative way.

Herd management factors associated with an increased rate of clinical mastitis were related to hygiene of the environment, hygiene measures associated with treatments and hygiene of the calving areas (Green et al., 2007). Cleaning of milking equipment should be performed adequately by chemical, thermal and physical processes and is essential to reduce the infection pressure of the udder. The environment of the cow should be clean, dry and well ventilated. In general, management of housing facilities and feeding practices is of importance for a good udder health status.

Management related variables such as clipping of hair from tail and mammary gland, following milking procedures, keeping of milking system, milking healthy cows first and infected cows later, clean laying beds etc dominated as explanatory variables.

Functioning of the milking machine is also of great importance. Teat end condition is influenced by the functioning of the milking machine. Teat end condition, measured in terms of teat end callosity (TEC) is an indication for increased incidence of mastitis and can be used as a monitoring tool for assessing the quality of milk management and machine handling (Neijenhuis et al., 2001). Control of the milking machine should take place once a year and teat liners should be renewed after approximately 2000 – 2500 milkings.

10.9. Mastitis control according to Hazard Analysis and Critical Control points (HACCP) principles

Mastitis research has been conducted for many decades and several udder health control programmes have been developed. Since the implementation of the Five Point Plan (Neave et al., 1969) there has been a dramatic decrease in BMSCC. However incidence of clinical mastitis and severity of mastitis did not change a lot. Nowadays mastitis is still the biggest problem in dairy cattle leading to impairment of health and welfare of the affected cows and impairment of the farmer's income. New udder health control programmes approach udder health from a systems analysis perspective. The great advantage of such an approach is the structured and formalised approach of the herd mastitis problem where the main areas of concern are integrated. These areas are management factors, cows and their environment and udder health performance features. Leslie et al (2002) stated that setting meaningful goals and monitoring the progress towards them are cornerstones of an effective programme. Well conducted therapy of mastitis cases is part of an animal welfare programme. The examination protocol starts with an early detection of the infected quarter and the determination of the severity of the inflammation. Information about the height of the SCC should be gained of all quarters. The medical history of the cow should be included as well. Preferable treatment should be customised for the individual animal affected with mastitis. However this requires well trained and responsible herdsman.

11. Reproduction and welfare

11.1. Reproductive disorders and welfare

There are several ways by which stressors regulate reproductive mechanisms. Different types of stressors affect the hypothalomo-pituitary-gonadal axis in different ways, but in general, stress (of sufficient severity or duration) reduces fertility. Prolonged or chronic stress results in suppressed gonadotrophin secretion and inhibition of reproduction. When the duration of the stress response is transient or acute the effects are less clear (Tilbrook et al., 2000). There is some evidence that acute stressors impair reproductive performance during critical periods of the reproductive cycle and early pregnancy (von Borell, 1995; von Borell et al., 2007). Transport stress in general has inhibitory effects on reproduction in cattle and sheep (Moberg, 1987). Repeated acute stress (restraint and rotation, confinement, electric shock) during the follicular phase of the oestrous cycle prevented the preovulatory LH surge in 2 out of seven heifers (Stoebel and Moberg, 1982, cited in Tilbrook et al., 2000). Administration of glucocorticoids can inhibit the secretion of the gonadotrophins in cattle and other species (Tilbrook et al., 2000), but increased secretion of glucocorticoids is not always associated with decreased secretion of the gonadotrophins, particularly in cases of acute stress. But most studies showed that glucocorticoids are not the predominant mediators of stress-induced suppression of LH secretion (Tilbrook et al., 2000).

Stress can reduce fertility by inducing different reproductive disorders depending on the period of the cycle when stress occurs and its intensity (Dobson and Smith, 2000). It may cause anoestrus by inhibiting follicular growth, idiopathic subfertility, when the integrity of the oocyte is preserved or development of the cystic ovarian syndrome, when the follicle persists due to an inappropriate LH surge unable to cause ovulation (Dobson and Smith, 2000).

Perinatal stress may delay puberty in females (Ward, 1984, cited in Von Borell 1995). Aversive human handling, which was shown to lead to acute and chronic stress responses in heifers and cows, (Breuer et al., 2003), is associated with reduced reproductive performance in dairy cows. Negative stockperson-cow interactions were negatively correlated with success at insemination, while in Australian as well as Austrian dairy herds positive stockperson-cow interactions were positively correlated (Hemsworth et al., 2000; Müllleder and Waiblinger, 2004). In an experiment with 20 tied dairy cows, control animals showed more stress responses (higher heart rate, more restless behaviour and kicking) during rectal palpation and sham insemination compared with animals that had received gentle human handling previously (Waiblinger et al., 2004). Thus higher levels of stress during insemination and during daily human-animal interaction are likely to cause impaired fertility.

Heat stress also affects reproduction. Embryos collected from heat-stressed donors are less viable and have delayed trophoblast function (Dobson et al 2001). When cows were heat stressed some days before artificial insemination (THI>80) conception rate decreased from 30.6 to 23% (Garcia-Ispuerto et al. 2007). Elevated environmental temperature reduces oestrus duration and intensity with smaller follicles and lower oestradiol and progesterone concentrations. Silent ovulations (unaccompanied by oestrus) are more frequent during very hot times of year (26 versus 9%; review: von Borell et al. 2007).

Apart from climate little research exists on effects of housing conditions on fertility. Tie stalls were associated with postpartum anoestrus in French beef cattle (Ducrot et al. 1994). The use

of electric cow trainers in tie stalls as well as slippery floors in loose housing relate to suppressed behavioural signs of oestrus (Eyrich et al. 1989; Benz, 2002; Bendel, 2005).

Thus higher levels of stress during insemination but also other human-animal interactions (acute and chronic stress responses are found in negatively handled heifers, Breuer et al., 2003) may cause impaired fertility.

Animals suffering from clinical diseases (e.g. milk fever, lameness, mastitis) in the postpartum period show reduced fertility, compared to healthy herdmates, i.e. an increase in the calving to conception interval as well as in the number of inseminations required per conception (Dobson and Smith, 2000; Dobson et al., 2001). Luteal activity and hence the onset of oestrus commences later in post-partum cows treated for mastitis or lameness. Cows with mastitis have smaller follicles than healthy herd-mates (von Borell et al. 2007). Further, the reduction in fertility is greater as the clinical conditions of lameness (see Table 9), milk fever or mastitis worsen (Dobson et al., 2001). Fertility is lower after caesarean operations. Delayed uterine involution after dystocia is associated with abnormal ovarian cyclicity and prolonged intervals to the next pregnancy (Dobson et al., 2001). Reproductive disorders may induce stress and reduce welfare by causing discomfort, pain, malaise and subsequent low production, or even death. Dystocia (prolonged or difficult parturition) leads to milk losses, impaired reproductive performance and an increase in cow deaths up to 5 % depending on the severity of calving difficulty (Dematawewa and Berger 1997, Meijering, 1984). Dystocia, retained placenta, and early metritis negatively affected milk yield in a study on Finnish Ayrshire cows, (Rajala and Gröhn 1998).

There is a growing concern that increase in milk yield is associated with reduced fertility (Dobson et al., 2001). Lawson et al. 2004, found a moderate positive relationship of milk yield with various reproductive disorders (retained placenta, uterine infections, ovarian cysts, induction of estrus, and induction of birth). Inclusion of reproductive management variables showed that these moderate relationships disappeared, but the directions of almost all those variables remained the same. In contrast, dystocia showed a weak negative relationship with production efficiency. The age of first calving is negatively related to the risk of reproductive disorders except dystocia. Furthermore the incidence risk of all these disorders except dystocia are higher in more efficient herds, where cows are younger at first calving (Lawson et al., 2004). Reproduction disorder variables (incidence risks of dystocia, retained placenta, uterine infections, and ovarian cysts) were all related positively with each other (Lawson et al., 2004).

Antagonistic relationships between high milk production and several fertility traits have been observed by several authors, while some others found no relationship (for review Rauw et al., 1998). High producing cows bred later, showed more days open, had a longer calving interval, a lower non-return rate at 56 days and required more services per conception than low producing cows (Rauw et al., 1998). This positive association of milk yield and reproductive disorders seems to have occurred since 1975 (Rauw et al., 1998). Although it is likely that metabolic stress due to, e.g., undernutrition, in high-yielding cows, is one reason for this negative yield – fertility association, other factors associated with high milk yield but not with stress and welfare may also to play a role (for review see von Borell et al. 2007). In higher producing cows shorter oestrus and lower plasma oestradiol concentrations were found and it has been suggested that the increased food consumption to produce higher amount of milk boosts liver blood flow which, in turn, enhances steroid catabolism (Lopez et al., 2004).

In sum reproductive disorders are associated to welfare in two ways: (1) they reflect prolonged or short-term reduced welfare (i.e. lack of oestrus, embryonic loss and others experiences

resulting from stress for a longer or for short time during specific sensible periods during the cycle; stress during insemination – inhibition of uterus motility) or (2) themselves cause a decrease in welfare or even death (i.e. dystocia, metritis, retained placenta or other genital infections associated with pain or inflammatory reactions).

11.2. Reproductive strategy and welfare

It is generally accepted that the decline in reproductive performance of modern dairy cows is one of the undesirable consequence of unbalanced selection for increased production. Through selection for greater milk production we created dairy cattle that undergo a high level of nutrient partitioning and adipose tissue mobilization during early lactation (Bauman and Currie, 1980) and the decline in ability to reproduce is one consequence of cows coping with metabolic stress associated with excessive tissue mobilization in early lactation. However, there are also health, management and environmental factors contributing to declining fertility in modern dairy cows.

Several epidemiological studies (Gröhn and Rajala-Schultz, 2000; Loeffler et al., 1999) suggest that disease in postpartum dairy cattle has an even greater effect on reproduction than level of milk production.

As a strategy to cope with declining fertility, many farmers resorted to intensive management of the reproductive biology of the dairy cow. The options available for reproductive management in the United States and in Europe, however, are somewhat different. Several European countries (Sweden, for example), do not allow use of hormones for reproductive management. Neither organic farms are allowed to use hormones except for individual treatment of reproductive disorders.

In the United States, most cows are either untreated (inseminated at spontaneous oestrus) or treated with biweekly injections of prostaglandin $F2\alpha$ ($PGF2\alpha$) followed by oestrus detection. Insemination at spontaneous oestrus and the use of $PGF2\alpha$ and oestrous detection are good but suffer from the age-old problem of detecting cows in oestrus. Combining regular $PGF2\alpha$ injections with some type of oestrus detection aid (tail paint, patches, electronic devices, etc.) improves the overall response but requires additional management and attention to details.

Timed AI for insemination of dairy cattle is also popular in the United States and represents a reproductive management strategy developed to eliminate oestrous detection. Most producers use the standard “Ovsynch” protocol of GnRH (wait 7 days), $PGF2\alpha$ (wait 2 days), GnRH (wait 1 day), and then insemination. When timed insemination and regular $PGF2\alpha$ injections are used to control the time of first insemination, only approximately 30 to 50% of dairy cows are likely to be pregnant after first insemination. As no reliable method for re-synchronizing cows after first service is available, the reproductive fate of the 50 to 70% of dairy cows that are open after first insemination still depends on the ability to detect the return to oestrus for non-pregnant cows (Lucy 2001b).

A major reason why intense reproductive management strategies are adopted is based on the paradigm that a calving interval of 12 to 13 months is economically optimal. With modern high producing cows, metabolic stress due to excessive tissue mobilization and increased risk of production and reproductive disease in the early postpartum are important contributing factors to poor welfare. A reproductive management strategy with extended calving interval (CI) of 15 to 18 months may offer significant advantages for the welfare of modern dairy cow by reducing the number of stressful calving periods a cow passes through. For example, with

18 m vs. 12 m CI, a cow would calve twice vs. 3 times in 3 years. With a majority of involuntary culling resulting from health problems in the early postpartum or failure to conceive during first 120 days of lactation, an extended CI should reduce involuntary culling, increase longevity, reduce incidence of production disease per day of productive life and, consequently, improve the welfare of dairy cow.

Some studies have found that a longer calving interval could be economically advantageous. For example, there is experimental data from 19 dairy farms in Israel that suggest that intentional delayed breeding may be economically feasible using modern Holsteins in year-round calving herds (Arbel et al., 2001).

In a Swedish study when cows were managed for 12 and 15 m, CI average daily milk, fat, and protein yields within the CI were 5% lower for Swedish Red and White cows and 2–3% lower for Swedish Holstein cows in the extended CI groups. The study concluded that Swedish Holstein cows, mainly primiparous cows and those with high peak yield could be suitable candidates for extended CIs beyond the conventional length (Rehn et al., 2000).

We suggest that even if a planned extended CI may result in slightly lower daily milk production within the CI, the production loss are more than compensated by better fertility and health, longer productive life, lower feed and replacement costs, and improved welfare.

12. Infectious diseases in relation to housing and management (other than mastitis and leg and foot disorders)

12.1. Introduction

In this chapter those infectious and parasitic diseases that have not been discussed already (“other diseases”) will be considered generally and in relation to the extent to which the poor welfare associated with specific diseases differs among housing systems.

The most important infectious disease in dairy cows is mastitis because of the high prevalence, poor welfare and economic losses caused. Examples of other frequently encountered infectious diseases of bacterial aetiology are metritis and endometritis, digital dermatitis, clostridial infections, mycoplasma infections, listeriosis, leptospirosis, Johne’s disease, and of viral aetiology, bovine viral diarrhoea (BVD), infectious bovine rhinotracheitis (IBR), bovine respiratory syncytial virus (BRSV) and coronavirus (winter dysentery).

An assessment has been carried out on how the welfare of the animals differs among housing systems in relation to introduction and persistence of some selected disease. In addition the methods for the prevention of these diseases by control measures and management will be discussed in a general way, as well as welfare related to transport, movement of animals and the use of drugs.

12.2. Expert consultation on the impact of different housing systems on dairy cow diseases

A survey was conducted as a possible way to explore whether or not different housing systems may have an overall impact on prevalence, incidence and outcome of other diseases. Mastitis, lameness, metabolic and reproductive diseases were not considered in the survey, or in this chapter. Thirty-two experts were contacted, twenty of which classified by EFSA’s Advisory Forum to be national experts on dairy cows. The remaining twelve were selected on the basis

of their bibliographic work. Experts were asked to answer the questionnaire on the basis of their general knowledge of disease, not specifically related to their countries.

Ten replies to the survey were received. However, they did not indicate any significant impact of different housing systems on the overall prevalence, incidence or outcome of other infectious and parasitic diseases a part of pasture-based systems which have a higher occurrence of certain diseases caused by agents to which cattle is exposed during outdoor conditions.

Mechanisms of transmission and the introduction of infected animals or carriers, the feedstuff offered and the stocking density are more significant for the incidence of many diseases, than the impact of the housing system used. A further consideration may be the exposure of animals to more than one housing system, for instance many dairy cows are housed during the winter in northern Europe, and managed at pasture during the summer.

For some diseases the impact is the same for all systems - Low (BSE or bovine tuberculosis) or Medium (bovine leucosis). For others the differences are mainly between inside and outside housing systems, depending on exposure to and persistence of the pathogen, for instance anthrax and bovine salmonellosis.

The impact of cubicle houses appears to be similar to that of straw yard housing. The highest impact of these systems is for bovine salmonellosis and infectious bovine rhinotracheitis. These systems had medium impact on bovine herpesvirus 4, bovine listeriosis and paratuberculosis (Johne's disease), for which the pasture system rated as low.

The tie-stall system has lower impact than other inside systems for some diseases (bovine brucellosis, bovine salmonellosis).

The pasture system has a higher impact for anthrax, bluetongue, bovine leptospirosis, echinococcosis, foot and mouth disease, Q-fever, anaplasmosis, babesiosis and liver fluke and a lower impact for bovine herpes virus, bovine listeriosis, bovine salmonellosis, paratuberculosis, campylobacter and respiratory diseases.

12.3. Prevention of infectious diseases (other than mastitis, leg and foot disorders) - biosecurity and health control

Regardless of housing system, high levels of management are essential for the prevention and control of infectious diseases in dairy herds. Measures to prevent the spread of infections in dairy production will gain increasing importance in the future because the farm is the primary part of the food chain and the responsibility of the farmer for the production of safe and healthy food will increase. This is enhanced by the increasing restrictions which are put on the use of veterinary drugs for food delivering animals. Therefore, prophylaxes, prevention and protection of production units are the keys for safeguarding health of farm animals in the future. Applying strict hygiene principles in dairy production meets the demands of the consumer for safe and high quality food.

Action to minimise the burden of infectious diseases is also an important way to improve animal welfare. The prevention and control of infectious diseases involves a wide range of measures. These can be summarised under different names and one often used is biosecurity, including restriction of contact with pathogen sources, such as infected animals, foodstuffs and vectors, quarantine procedures, vaccination, reducing vulnerability to disease, hygienic measures and various other aspects.

Biosecurity in relation to the dairy management can be defined as a strategy of management practices to prevent introduction of disease and pathogens to and to control spread within the herd (Wells, 2000, Hartung, 2005). Transmissible infectious diseases can be introduced into herds by new herd members coming from auctions or other herds or herd members that have been on animal shows or elsewhere. Quarantine and testing of individual animals is not totally effective as a means to prevent the introduction of diseases with a long incubation period or those for which the diagnostic tests have poor specificity or sensitivity at the individual level, such as paratuberculosis and tuberculosis. Complementing quarantine and testing by sourcing animals from herds known to be free of the disease or those of an equal or higher health status provides added assurance.

Some diseases may also be transmitted by humans, such as veterinarians, technicians, neighbours etc., visiting different herds within short periods and carrying infectious agents on mucous membranes, hands, boots, or clothing.

An effective biosecurity programme needs to be more than a generic list of actions. It needs to be decision-focused and flexible enough to adapt to the unique situations of individual enterprises. This requires an understanding of biosecurity and disease preventive principles, as well as specific information relative to the biology and epidemiology of the particular pathogens of interest. Diseases have a wide range of different aetiologies and this report is not intended to review diseases and different ways for their prevention and control. However, understanding the risks associated with important infectious pathogens and reducing these through various management strategies are important components of a biosecurity programme.

Biosecurity programmes need to be supported by monitoring and documentation of diseases occurrence and variables like patterns of antibiotic resistance. This allows improvement of strategies for prevention and intervention when incidence rates of production diseases exceed threshold levels, usually set with a herd veterinary service. Bulk-milk testing e.g. for BVD, IBR is an efficient and cost effective way to monitor health status.

The prevention of infectious diseases needs to be combined with measures for an early detection of disease. Frequent, close inspection of cows and early presentation of sick cattle to veterinary clinical assistance will reduce the period of suffering due to disease and should reduce involuntary culling due to chronic disease. Stockpersons can have a considerable role in this process e.g. for the surveillance at milking (especially for mastitis), but also during the day when cows are in stalls or at pasture. Many infectious diseases occur after parturition and regular close surveillance during the first 8-10 days after calving is of particular importance. Removing calves from their infected dams as soon as possible after birth, and rearing on specific pathogen free colostrum and milk is a strategy that have been applied to reduce the transmission of Johne's disease (Tavornpanich et al., 2008) and bovine leucosis virus (Mészáros et al., 1994).

Scoring of body condition and lameness can be helpful tools in detection of subclinical disease or health problems. Larger dairy farms sometimes rely on movement detectors (e.g. pedometers) to identify sick animals but these provide a limited amount of information. Automated feeding systems which identify individual cows can also be used to indicate animals with reduced appetite, whilst computer surveillance of milk yields can detect reduced milk yield which can be an early sign of disease.

12.3.1. Cow marketing and local movements of animals

Transport and movement of animals can be an integral part of different dairy cow systems e.g for marketing animals but also for the introduction of animals for recruitment. Due to the fact that such procedures are associated with substantial risks of poor welfare and spread of infectious diseases, special attention should be given to the reduction of such effects.

Transport is a potential stressor for all animals that are not regularly transported, including dairy cows. The report of the E.U. Scientific Committee on Animal Health and Animal Welfare “The welfare of animals during transport (details for horses, pigs, sheep and cattle)”, adopted 11 March, 2002, emphasised that the welfare of animals, including their health, can be substantially affected in the course of and as a result of transport. The most important factors of poor welfare in cows are those described by Broom (2003) for transported cattle. In particular, loading and unloading can be stressful for cattle (Hartung et al. 2000). Too high a stocking density, the mixing of animals of different origins, rough and unfriendly handling, poor driving, too high or too low temperature and humidity and too long a duration of the transport journey can lead to stress, aggression, fear, injuries and fatigue (Holleben von et al 2003). Any of these factors in cattle can also be associated with typical infectious diseases such as shipping fever, caused by several infectious agents like *Pasteurella* and some viruses (Storz et al. 2000). It seems that stress and reduced welfare can enhance the susceptibility for infection by lowering the infection threshold, or the amount of pathogen needed to initiate an infection in an animal or overwhelm the immune defence system. The effects of transport are of considerable importance for dairy cow welfare not only because of the acute or delayed effects on the animal being transported but also marketing and transport of cows and bulls are important ways in which many infectious diseases may be disseminated to dairy herds and then in turn increase the incidence and prevalence of disease and poor welfare in those herds (see for example Green et al. 2008b and EFSA, 2004).

Although of great importance, in this report such effects have not been further described.

12.3.2. Facilities for diseased or contagious animals

Whenever possible cattle tend to withdraw from the herd when injured or sick. This happens because there is reduced capability to secure hierarchy position and to avoid agonistic confrontations. It may also result in increased resting time and energy saving. It is well established that activity reduction can help an individual to recover from disease (Gregory, 1998; Broom, 2006). Sick cows kept with the herd are a threat to healthy animals spreading infection, e.g. via contaminated bedding or flooring (e.g. several mastitis agents, bovine salmonellosis).

Injured and sick animals may have difficulty in getting up or lying down when forced to do it in cubicles or when tied up. Prolonged lying on hard surfaces, as may happen with injured or sick cows kept with the herd, causes irreversible muscle and nerve lesions, leading to the Downer Cow Syndrome.

Proper facilities for severely sick or injured animals are essential because such animals need isolation or extra space to move, because it reduces spread of infection and because it prevents complications, trauma, stress and fear. These facilities also make human surveillance easier, facilitate treatments and allow for procedures that increase chances of recovery, e.g. regular lifting of a downer cow.

Pens for diseased cows are well ventilated, have a non-slippery floor, good drainage, soft bedding, milking equipment and easily accessible water and food trough. The height of these pens is sufficient to allow the use of devices for the lifting or turning of a downer cow. If cows that are sick or dying are not removed with care disease may be spread. The welfare of sick animals is improved if they are able to see other cows. If pens for sick cows are also used for calving, the risk of disease transmission is increased.

12.3.3. Drug usage and welfare

This section deals with the more general problems concerning the use of approved drugs or failure to use them. Particular issues, including mastitis, sub-fertility or metabolic disease treatments, are addressed in their specific chapters.

Animal welfare can be affected by drugs in two ways:

- Adverse effects that can result from misuse, abuse or individual reactions.

Some adverse effects may result from misuse or abuse of accredited drugs. At the EU level, “pharmaco-vigilance” is implemented in each Member State to record all the adverse effects observed in the field after the use of authorised veterinary medicinal products (eudravigilance.emea.europa.eu/veterinary/index.html). Frequent and improper use of intramammary antimicrobials facilitates the occurrence of multiple resistant bacteria (Pol and Ruegg, 2007). These are avoidable errors that usually lead to reduced recovery rate, increased culling rate and poor welfare.

In most EU countries farmers can administer drugs after veterinary prescription and under the surveillance of veterinarians. Improper injection of drugs can lead to severe adverse reactions followed by local infection. Lack of proper veterinary surveillance and training of stockpersons responsible for drug administration can result in substantially increased disease and poor welfare.

- Lack of use or insufficient or incorrect use.

Many drugs, including antimicrobials or anti-inflammatory drugs, are needed for the direct and indirect relief of pain and suffering in animals. Problems, often resulting in poor welfare of affected animals, arise when there is treatment failure or incorrect use of drugs. In some cases drugs are not used because of their cost or because of concerns about human food safety (WHO, 2000; Yan and Gilbert, 2004). Although principles intended to help reduce the misuse and the overuse of antimicrobials in animals intended for food exist (WHO, 2000), the professional judgment of practitioners is important to minimise poor welfare (AVMA, 2008).

Pain management may be far from optimal because of drawbacks in using analgesic drugs in food-producing animals. Some of these problems have been identified in surveys published (Watts and Clarke, 2000; Whay and Huxley, 2005; Huxley and Whay, 2006; Hewson et al, 2007; Huxley et al, 2008). The more commonly acknowledged flaws are: reduced cost-effectiveness, low practicability (few long acting drugs available), long withdrawal periods and lack of legal licence (e.g. opioids). These are the reasons pointed out by practitioners, who acknowledge severe pain in some pathologic conditions but admit seldom using analgesics to deal with it. For example, non-steroidal-anti-inflammatory-drugs (NSAIDs) were given to only 50% of cows that underwent caesarean section, 55% of claw amputations, and 1% of cases of dehorning (Whay and Huxley, 2005) and only 68% of respondents in another survey gave postoperative analgesic drugs to cows that underwent caesarean section (Watts and Clarke, 2000). In another survey, of the 605 respondents 1.7% and 4.6% said they used

NSAID after disbudding and castration respectively. A number of practitioners reported that they used xylazine (17%), lidocaine (74%) or no drug (25%) for these procedures (Huxley and Why, 2006). A large US survey reported that only 12.4% of dairy cattle owners use anaesthetic and 1.8% use analgesia for dehorning (Fulwider et al., 2008). An appraisal in Ontario showed that, although most veterinarians considered sole ulcers to be painful or very painful, very few used any analgesics in cows affected by this claw disorder (Anderson and Muir, 2005).

Organic farms restrict the use of antimicrobials and other drugs. Although this limitation may reduce antimicrobial resistance in bacteria (e.g. *S. aureus*) found in these farms (Tikofsky et al., 2003) it may also cause welfare problems by delaying adequate treatment.

Additional restriction in the use of antimicrobials in food-producing animals is to be expected, so research on alternatives to antimicrobials, such as vaccines and probiotics may be necessary. Antimicrobials are not a replacement for good management. Preventive strategies, such as appropriate husbandry and hygiene, routine health monitoring, and immunisation, in dairy herds are essential (AVMA, 2008).

The use of hormones and other drugs are very common in fertility controlling programmes in dairy herds. These drugs are used for heat synchronisation, uterine infection treatment, anoestrus treatment, repeat-breeders and other fertility problems. There is no evidence that deficits in nutrition, housing, handling and management resulting in poor fertility in dairy cattle can be compensated by hormonal fertility programmes. Using fertility programmes in herds with poor fertility is seen as unnecessary treatment.

13. Handling in relation to welfare

13.1. Human-animal relationship

Humans may affect dairy cattle in different ways, from buildings used to keep animals to diet formulation, but in this chapter we will look at the more direct contact of humans and its impact on welfare.

The form and effect of human-dairy animal interactions depends partly on the size of the herds. In small and family run dairy farms a very close relationship is usually found between stockpersons and animals, starting from birth. This results in animals being less afraid of humans, although low level of fear also exists in larger herd size (Waiblinger and Menke, 1999), and in better and earlier detection of problems by humans. However, there can be staff who handles animals roughly on farms of any size.

In contrast, as farms increase in size, human proximity and contact may be limited to milking times (and sometimes not even at these times). In large herds there is an increased probability of frequent personnel changes and/or a higher number of different milkers which seems to negatively affect welfare indicated by higher level of fear towards humans and lower milk production (Waiblinger et al. 2003). In addition, rapid handling procedures and mechanization (TMR etc...) has been encouraged resulting in less time near cows. Although dairy breeds are generally tame, this usually means that other human-animal interactions may result in increased stress, avoidance behaviour and injuries. Human-animal interactions can sometimes be limited to husbandry or veterinary treatments that are neutral or aversive. Difficulties arise in the case of operations like hoof trimming that are aversive and stressful in the short term but improve the animal's welfare in the long term (Rushen *et al*, 1999b).

In addition, this permanent distance between humans and animals results in very small periods of monitoring which leads to difficulties in identifying sick, injured or “in-heat” animals. This, in turn, may result in increased mortality and culling because when cows are identified as sick/injured, treatment is no longer possible or feasible. Thomsen et al (2006) found that mortality in Danish farms increased significantly with increasing herd size (odds ratio [OR] 1.05 for an increase in herd size of 50 cows). In very intensive husbandry conditions, disease is usually identified via reduction in milk production or computer based data (e.g. movements). Although this information can be useful it can also, if not complemented with careful monitoring of individual animals, result in delayed diagnosis and treatment. However, cows in large farms are also seen by veterinarians on a very regular basis (pregnancy diagnosis and fertility examination) which may lead to early and accurate detection of sick animals.

The introduction of high technology and the number of animals per unit of labor have meant that the training of stockpersons has been almost exclusively in the areas of technical knowledge and skills (Hemsworth and Barnett, 1987). These inconveniences of modern farms could be reduced if those working with cattle are trained to recognise not only normal behaviour and good health but also early signs of illness or disease (FAWC, 2003). It is well established that once-a-day inspection is not sufficient for lactating animals.

The quantity and quality of human-animal contact with animals on dairy farms may also differ accordingly to the system of production – contact with humans in tie stalls is much more frequent than in free stalls or pasture systems, in which proximity with animals is often limited to milking time. Detection of sick animals may be delayed in systems where assessment of individual feed intake is not possible (e.g. free stalls).

Finally there are differences in time and type of contact between young and adult cattle. Young calves may have a very close contact with humans, although sometimes for aversive reasons, like in disbudding, and this can influence future relations. In contrast heifers are usually kept completely isolated from human contact (for the exception of artificial insemination in some cases) and this may influence behaviour at calving and first milkings (e.g. stress, deficient milk let-down, aggressiveness).

Human handling factors that may affect dairy cows’ welfare can be divided in the following categories:

- stockperson personality
- human aversive attitudes
- human positive attitudes
- animals’ previous experiences with humans and the capability to recognise humans and locations.
- restraining and handling methods.

Effects of gentle or aversive human interactions on calving are presented in the Dystocia/calving section of this chapter.

13.1.1. Effect of stock person personality and attitude

Stockperson’s attitudes and personal characteristics affect the behaviour of the stockperson and remaining staff and subsequently the cows’ fear of humans, behaviour and milk yield (Seabrook, 1984; Seabrook and Wilkinson, 2000; Hemsworth, 2003). As an old saying

predicts “You can tell what kind of a stockman a person is by looking at his cattle” (cited in Grandin, 1996). This means that even the most welfare-friendly system may fail if not accompanied by good stockmanship and sound management practice (FAWC, 1997).

There is a small influence of herd size on intensity of handling but much smaller than the effect of the stockman personality or attitude (Waiblinger et al, 1999).

Relationships may exist between the personality, attitude and behaviour of the stockperson and the behaviour and productivity of dairy cows. Stockpeople at high producing farms tended to be introverted and confident. In the highest yielding herds animals were the most willing to return from pasture and enter the milking shed and were less restless in the presence of the stockperson (Seabrook, 1972). More agreeable stockpeople rated importance of contact with their cattle higher and used more positive and less negative behaviour towards the cows resulting in cows with low level of fear, while pessimist stockpeople had less positive attitudes. When stockpeople had more negative attitudes and subsequent negative behaviour, cows were more fearful and milk yield was lower (Waiblinger et al, 2002b).

Handling ease, fear and restlessness are also correlated with the stockperson attitudes. Use of negative tactile interactions, speed of movement and harsh voice, when moving cows, correlated with restlessness in the presence of the stockperson while the use of soft, quiet vocalization was negatively correlated with restlessness in the presence of the stockperson. (Breuer et al, 2000). Avoidance distances in the stable were highly correlated with intensity/quality and continuity of contact as well as with the frequency of friendly interactions by the milker (Waiblinger et al, 2003). Grandin (1996) suggests that a good stockman who handles cattle calmly will have calmer animals than a bad stockman who gets them excited. To reduce fear from humans’ handlers should spend time walking quietly among their cattle.

Programmes to improve the attitude and behaviour of stockpeople toward cows lead to reduce flight distance from humans and increase in milk, protein and fat yield (Hemsworth et al, 2002).

13.1.2. Effect of different human interactions

13.1.2.1. Aversive interactions

Fear of humans is not infrequent in dairy cattle and could be a source of stress. The level of fear of each specie or individual is influenced by genetics, previous experiences, habituation, associative learning, imitative learning, socialization during a sensitive period and human behaviour towards animals (Hemsworth and Barnett, 1987). Fear can increase if cattle are treated or handled aversively. There is a positive relationship between the frequency of negative interactions and plasma cortisol levels in dairy cattle (Hemsworth et al, 2000). Many of the handling treatments that animals find aversive are performed by humans, and it is likely that animals learn to associate aversive handling with people (Rushen, 1996). The risks to the welfare of animals that are fearful of humans arise because of injuries that they may sustain in trying to avoid humans, acute stress in the presence of humans and finally the effects of chronic stress on immunity (Breuer et al, 2000). Aversive handling experience can have a very long lasting effect (Hemsworth and Coleman, 1998)

There is evidence of a “fear of humans-productivity” relationship in commercial dairy cows. This has economic as well as welfare implications. The use of negative interactions by

stockpeople is significantly and negatively related to: approach distance, success at insemination and milk protein and fat yield (Hemsworth et al. 2000, Waiblinger et al. 2002, Mülleder and Waiblinger, 2004). For example, the presence of an aversive handler increased residual milk by 70% (Rushen et al, 1999) probably due to stress-induced decrease in oxytocin secretion that lowers milk-letdown. Moderate or forceful slaps imposed briefly before or after milking when animals failed to avoid humans, increased flight distance and tended to reduced milk yield in heifers (Breuer et al, 1997). The presence of an aversive handler increased movement and heart rate during milking (Rushen et al, 1999).

When handling methods are inappropriate, cattle may exhibit undesirable behaviour and become distressed or injured. Frequent changes in milking or feeding routines, cow grouping and stall locations can add to the level of stress (Roberts, 1997). Restlessness at milking, as measured by the number of flinch, step and kick responses (FSK), was suggested to be indicative of a stressful situation (Willis, 1983) although other studies have found less kicking in stressful situations (Rushen et al, 2001).

Negative handling results in an acute stress/fear response that may affect handling, including causing accidents to people and animals, and productive performance. Munksgaard et al, (2001) showed that cows keep longer distance from aversive handlers (Munksgaard et al, 2001). Negative handling results in an acute stress response that may affect handling and productive performance. On the other hand, rough handling, abusive handlers, constant yelling or beating of cows can also produce vicious and dangerous cows (Rebhun, 1995a). The fear responses to humans also influences aspects of the stockpeople jobs, such as ease of inspection and handling, and may affect job satisfaction, motivation and commitment (Hemsworth and Coleman, 1998). This could lead to handlers' frustration and resort to unnecessarily forceful methods (Crony et al, 2000).

Negatively handled heifers show signs of fear towards handler and signs of acute and chronic stress. Even neighbor animals may be influenced by the behaviour of cows that have been subject to responses to gentle or aversive handlers or locations (Breuer et al, 2003).

Some farms use radio/music in the stable as a way to reduce cows' fear of sudden noises and novelty.

13.1.2.2. Positive interactions

Cattle welfare can be improved not only by reducing the aversive interactions but also by increasing interactions that are seen as positive by the animals.

Calves that received gentle contacts were less agitated when transported and showed fewer abomasal lesions (Lensink et al, 2000b). Being gently handled (stroked) seems to be experienced as positive by calf and reduces withdrawal from people and environment (Lensink et al, 2000a). Calves (French Aubrac) handled 6 weeks after birth and heifers handled just after weaning were easier to handle during the tests than control animals (Boivin et al, 1992). Feeding the animals usually has a positive effect on the further relationships with humans (Jago et al, 1999). Handling at an early age may be influential on the future degree of fear of humans (Hemsworth and Coleman, 1998). Waiblinger et al (2002b) showed that cows avoided less often stockpeople that handled them positively.

Stroking by humans has positive effects on cows' relationship to humans reducing fear and thus increasing ease of treatment. (Schmied et al, 2008a). Human stroking of body regions often licked during social grooming led to more responses than stroking the ones licked rarely.

This suggests that cows may in part perceive human stroking of body regions often licked similarly to social licking (Schmied et al, 2008b).

Some interactions are neutral in nature but their frequent use should lead to habituation by the animals to the presence of the stockperson and so general fear may decline (Hemsworth and Coleman, 1998).

Positive interactions make handling easier, including milking procedure, and may reduce disease (e.g. mastitis) by allowing adequate milk flow. Recently, Bertenshaw et al (2008) showed that only 5min of brushing per week in the weeks before calving improved milk let-down and reduced kicking by dairy heifers. Gentle handling as young calves, heifers or at calving reduces signs of fear and avoidance behaviour of milking animals. Good stockpersons recognise those cows with a high “Flinch, Step and Kick response” and attempt to quieten them with the use of interactions that are positive in nature (Hemsworth et al, 1989). Although small amounts of concentrate fed in the milking parlour can motivate entry and reduce need for interventions that may have negative effects on the cows (Ceballos and Weary, 2002) it is also true that it may increase competition between cows, stress and cleanliness of the parlour.

After handling with restraint, returning cattle to the group of peers and not approaching the cattle needlessly should moderate their stress (Ishiwata et al, 2007). In contrast, Pajor et al (2003) did not find much evidence that cows enjoy positive interactions with people apart from being fed. In beef cattle, acceptance of contact such as brushing or stroking appears to be more the result of a habituation process than one of positive reinforcement. The effect was long lasting and was still observed 18 months after the end of the gentling period (Boivin et al, 1998). Cohabitant animals may be influenced by the behaviour of cows that have been subject to positive handlers or locations (Breuer et al, 2003).

13.1.2.3. Effect of previous experiences with humans and locations

Previous experiences will affect the animals’ response to handling (Grandin, 1984) but limited human contact also induces fear of humans in cattle (Boissy and Bouissou, 1988; Lensink et al., 2000a).

Aversive handling experience can have a very long lasting effect (Hemsworth et al, 1998). Behavioural response may extend to other humans through the process of stimulus generalization. Neighbour animals may be influenced by some animals’ responses to gentle or aversive handlers or locations. For example it has been shown that animals learn to avoid aversive handlers when neighbour cows keep longer distance from them (Munksgaard et al, 2001).

Previous handling experience of calves may influence their behavioural patterns (Croney, 2000; Trunkfield, 1990). Prolonged handling in young ages influences the expression of fear responses in heifers (Boissy et al, 1988). Heifers handled positively during calving show lower cortisol levels, were less fearful of humans and displayed less flinch, step and kick responses in the presence of a human during milking than not handled ones (Hemsworth et al, 1989; Hemsworth et al, 1987). Cows recognise individual people, and the fear of people who are present during milking may reduce milk yield (Rushen et al, 1999). In contrast, presence of humans when cows are exposed to isolation/novelty conditions did reduce some signs of fear and cortisol but did not increase milk yield (Rushen et al, 2001).

Cows learn to discriminate among handlers partially based on the colours of the clothes (Munksgaard et al, 1997). Cows use multiple cues to discriminate between people, for

instance the body height and face (but the use of the face alone is more difficult when cows cannot see the rest of the body) (Rybarczyk et al, 2001). Cows can also recognise locations where aversive treatment is performed and to avoid or approach the same person based on the location (Rushen et al, 1998). So performing an aversive treatment at a specific location or by either unfamiliar or familiar handler wearing different distinctive clothing may reduce the likelihood that dairy cows associate the procedure with the regular stockperson (Hemsworth and Coleman, 1998). Cows previously exposed to painful treatments (e.g. hoof trimming) are more fearful and more likely to refuse to get into a crush (Lewis and Hurnik, 1998). For these reasons, aversive treatments should be done in exclusive locations and never inside the milking parlour.

Novelty can be both fear inducing and attractive. Cattle can be trained to tolerate novelty and changes in their routine. If new handling procedures are introduced slowly the animals can be trained to accept them (Grandin, 1996).

Vigilance may provide information on the degree of fearfulness of the animals. The presence of the aversive person significantly increased vigilance time compared to the unfamiliar and gentle people (Welp et al, 2004).

13.1.2.4. Effects of handling and restraining methods

“The minimum restraint that allows the procedure to be performed quickly and effectively is the correct amount” (old saying, cited in Rebhun, 1995a).

People working with cattle should recognise the flight zone. The flight zone is the animal's personal space. Flight zone size is determined by three factors: amount of contact with people; quality of contact and genetics. Flight zone is larger when animal is approached head on. In confined areas handlers must be careful to avoid cornering an animal (Grandin, 1996). Extremely tame cattle can actually be difficult to drive because they have no flight zone. Many times, such cattle can best be moved by leading them with a feed bucket (Grandin, 1996).

Hitting, shouting and the use of electric prod are seen as very aversive by dairy cattle.

Cattle have very low electrical resistance, even small neutral to ground voltages (0, 5 – 3 V) can cause them to respond violently. Cows that were shock at currents of 12 mA were unapproachable (Lefcourt et al, 1985). In the study, electric prod caused more reactions but only the sound of an electric prod was enough to elicit movement in calves. Animals sometimes show fear of buzzing even without previous aversive experience (sprays etc.). Calves handled with an electric prod investigated less (Cronney et al, 2000). Psychological influences of being shocked may be more important than the actual shock (Roberts, 1997). Heifers find electrical prod and shouting very aversive (Pajor et al, 2000b). Shouting and the use of cattle prods is aversive but tail twisting is not aversive, if done gently (Pajor et al, 2003).

Habituation to devices in the absence of a negative experience reduces animal stress during handling and is reinforced by providing feed after the handling (Hutson, 1985).

Restraint is more art than science (Rebhun, 1995a). A restraint device must apply sufficient pressure to provide the feeling of being held but excessive pressure that causes pain must be avoided (Grandin, 1995). Very nervous cattle can bellow and jump and kick when they anticipate restraint, injections, or handling. Cattle may become dangerous simply because they are frightened and thus become defensive and in such mood can trap or trample a person.

Selection of the proper restraint for a given procedure requires common sense, judgment and humane considerations (Rebhun, 1995a).

Too little restraint may cause injury to the handler and animal. It also may cause the patient to become increasingly apprehensive, wild and progressively violent because the procedure takes too long (Rebhun, 1995a). It frustrates handler. Too little restrain may also result from lack of facilities or lack of knowledge.

After handling with restraint, returning cattle to the group of peers and not approaching the cattle needlessly moderates their stress (Ishiwata et al, 2007).

13.2. On farm monitoring

Herdsman should recognise and identify a sick cow and take actions to alleviate the suffering in the early stages. Proper training is crucial. Also aptitude and the desire to detect sick animals should be reinforced because of the tendency of employees to disregard signs that mean an increase in work. Although monitoring through computer data is useful in detecting diseased animals, regular personal monitoring of individual animals should never be neglected.

13.3. Movements of cattle on farm

Cattle have a tendency to move toward light and will tend to follow a leader (Grandin, 1987)

Cattle have depth perception but their ability to perceive depth at ground level while there are walking is probably poor (Hutson, 1985). Hurrying cattle along a path (to or from pasture) will increase lameness incidence (Chesterton et al, 1989; Dewes 1978). Speed in moving cows from pasture to milking caused more restlessness during milking (Breuer et al, 2000). To move cattle quietly, the handler should walk on the edge of the flight zone and only enter this area if the animal stops moving (Grandin, 1996). When grouping animals of different ages and sizes (e.g. heifers with adult cows) care should be taken to monitor hierarchy establishment.

Keeping primiparous cows in an isolated group during the early stage of lactation increases milk yield, reduces lameness, reduces mastitis incidence and avoids additional distress caused by conflict with old aggressive cows (Barkema et al, 1999a; Nyman, 2007)

Use of experienced and tame animal to lead heifers or frightened cows (e.g. through chute for foot-trimming), is a sound management attitude because it reduces stress and potential injuries to animals and stockperson.

13.4. Animal identification and mutilations

13.4.1. Animal identification and welfare

Proper animal identification is essential to efficient record keeping, proof of ownership, and routine observation.

Ear tagging (with plastic tags) is the method of identification most commonly used in European dairy farms. Some other alternatives are possible: tattooing, foot or neck electronic identifier, hot branding and freeze branding. The use of a microchip (subcutaneously injected, ear-tag or ruminal bolus) is a possibility for the future.

Application of ear-tags, especially in calves, can cause injury unless done with care. Problems may arise when two-part tags are used and the parts do not line up correctly, but the correct pin for that type of tag is used when tagging site is on the inside of the ear, when one-piece plastic tags are placed between the two ribs of cartilage that divide the ear, halfway between the base and tip of the ear, when the applicator is positioned so the tag will hang straight or angle away from the base of the ear (FAWC, 2003). Metal tags are now used very rarely and are placed on the top of the ear near its base. Ear tagging is not permanent and tags are frequently lost. Metal tags are more apt to tear the ear if snagged on an object. Complications of improper application of tags are: ear cartilage fracture, infection, abscesses, maggots gathering and otitis (Santos et al., 2007). These problems are more common and dangerous in young and small calves and in summer months when insects are abundant. The situation is worsened when official tagging (on both ears) is done simultaneously with farm identification. When complications (wound and abscess) arise, tags should be immediately removed and antiseptic should be applied to prevent infection.

Branding is considered aversive and causes acute pain. Hot-iron branded steers experienced more discomfort at the time of branding than freeze-branded (Schwartzkopf-Genswein et al., 1997; Lay et al., 1992a). Dairy cows showed elevated cortisol, heart rate and pain behaviours after branding, more intense in hot branded animals than freeze branded ones (Lay et al., 1992b). There are no studies on how to reduce branding pain.

13.4.2. Dehorning and welfare

Two previous reports, “Welfare of cattle kept for beef production” (SCAHAW, 2001) and “The risks of poor welfare in intensive calf farming systems” (EFSA, 2006) have dealt with disbudding effects on young cattle. This section will only present welfare issues in relation to methods that are used to dehorn heifers and cows.

13.4.2.1. General

Dehorning and disbudding are routine painful procedures carried out on cattle to facilitate management (Stafford and Mellor, 2005a). See also EFSA, 2001 and 2006. Disbudding can be performed by heat cauterization, by rubbing or covering the horn buds with chemical (NaOH, KOH) or by amputation (scoop). Heifers and cows are usually dehorned with wire-saw, common saws, scoop or guillotine clippers. If cattle are dehorned on dry cool days the wound dries quickly with the minimum risk of infection (NSW, 1998).

13.4.2.2. Disbudding

Dehorning causes pain in calves from birth onwards (Taschke and Folsch, 1997). Dehorning causes less tissue damage at younger ages (Rebhun, 1995a). Behavioural and physiological responses together indicate that dehorning calves by heat cauterisation is accompanied by considerable pain and stress (Stilwell et al., 2004a; Faulkner and Weary, 2000; Grøndahl-Nielsen et al., 1999; Graf and Senn, 1999; Wohlt et al., 1994), which can be significantly alleviated during and up to 2 h postdehorning by local anaesthesia (Graf and Senn, 1999). Routine field use of local analgesia using a cornual nerve block improved the welfare of young calves subjected to dehorning with a hot iron. The use of sedatives showed little differences (Grøndahl-Nielsen et al., 1999). Cortisol is maintained at base line levels in 2 week old calves dehorned by heat for 6 hours when local anaesthesia and ketoprofen are used (Milligan et al., 2004). Some signs of pain are still significant at 12 h (head shaking) and 24 h

(ear flicking) after hot dehorning, when compared with animals treated with ketoprofen. Animals treated with ketoprofen gain more weight during the first 24 h after hot dehorning (Faulkner and Weary, 2000). Signs of pain are evident after caustic paste (4 week old) (Stilwell, 2008a) or heat cauterization (8 week old) for 4 hours. Animals disbudded by heat cauterization tended to exhibit weaker reactions (different ages). Local anaesthesia induced a strong reduction of reactions in 60% of animals in both treatments (Morise et al., 1995). Calves treated with lidocaine showed no evidence of reduced pain response in the hours after the caustic paste was applied (Vickers et al., 2005).

Heifers dehorned at 8 week of age didn't show reduction in feed intake and growth. Cortisol rise for 1 hour. No long term stress was found (Laden et al., 1985).

Cryosurgical dehorning has been studied and is probably less painful, but is not a reliable and practical alternative (Bengtsson et al., 1996).

Preemptive use of NSAID, without nerve blocking, did not reduce signs of pain in calves disbudded with caustica paste (Stilwell, 2008b).

13.4.2.3. Dehorning of heifers

The cortisol response to cautery disbudding is significantly smaller than that to amputation dehorning which infers that the latter is more painful (Stafford and Mellor, 2005a). Pain behaviours are still present 24 hours after scoop dehorning in 4-6 month old calves (Stilwell et al., 2004).

Amputation dehorning of 6 month old calves, is a painful experience that lasts about 6 h. Local anaesthetic alleviates that pain during its period of action (Sylvester et al., 2004). When local anaesthesia subsides (3 h), cortisol levels and behaviours of scoop dehorned calves are higher than control dehorned animals (Stilwell and Lima, 2004). Long acting anaesthesia (8 hours) only limits cortisol rise during nerve blocking – when effect wears off plasma cortisol values rise sharply (McMeekan et al., 1998a). Dehorning by amputation of heifers caused increase in cortisol that went back to baseline only after 7 hours. Regional anaesthesia plus ketoprofen reduced cortisol levels (similar to non-dehorned controls) (McMeekan et al., 1998b; Sutherland et al., 2002a). Regional anaesthesia plus flunixin meglumine reduced cortisol and pain behaviours after scoop dehorning (Stilwell and Lima, 2004). Xylazine with regional anaesthesia prevents cortisol rise for 3 hours after amputation (Stafford and Mellor, 2005). In contrast high levels of cortisol have been shown in animals sedated with xylazine associated with local anaesthesia, even when sham dehorned (Stilwell et al., in press). Phenylbutazone does not reduce cortisol levels after amputation dehorning when local anaesthesia wears off (Sutherland et al., 2002a).

Combining local anaesthesia with cautery of the amputation wounds reduces cortisol response for 24 h (Sutherland et al., 2002b). There were no differences in pain-related signs after dehorning with four different methods of amputation (6 months old calves): scoop, guillotine, saw and saw-wire (Sylvester et al., 1998).

13.4.2.4. Dehorning adult cows

Dehorning adult cows occurs when animals were not dehorned at young ages because of human negligence. It may also occur when cows are moved from a tie-stall to a free-stall system.

Lay people who dehorn livestock almost never attend to details such as local anaesthesia, cleanliness or antiseptics and haemostasis. Chronic sinusitis is a frequent complication of dehorning (Ward and Rebhun, 1992). Complications such as sinusitis and tetanus are much more common when cattle are dehorned by unqualified people (Rebhun, 1995). Fatal haemorrhage occurs rarely after dehorning cows (Rhebun, 1995). A nose lead is preferable to halters in adult cows because it provides better restraint and does not interfere with effective haemostasis (accentuate or mask haemorrhage). Electro-immobilization of cattle for dehorning does not produce analgesia and may cause additional pain (Carter et al., 1983).

Dehorning with wire-saw is stressful for the cows, as measured by a significant increase of cortisol in saliva, even after regional anaesthesia. Cows show pain reactions when the effects of the anaesthesia diminished. However dehorning has a short effect on the milk yield of cows (Taschke and Folsch, 1997).

During fly season or extremely cold weather, dehorning cattle by any method that requires cutting, should be avoided. Maggots can be a problem during hot weather, and the exposed sinuses can lead to respiratory problems during extremely cold weather (Prichard et al., 2002)

Regional anaesthesia (10 ml 2% lidocaine for each horn) in combination with sedative (xylazine) eliminates almost all suffering in cows dehorned with wire-saw (Stilwell, unpublished data).

13.4.2.5. Tail-docking and welfare

Tail docking is illegal in some member states but this mutilation has become a routine intervention in some dairy farms. A variety of methods have been used to dock tails in dairy cattle, including cauterizing docking irons, application of elastrator bands, use of emasculators, and surgical excision. The application of elastrator bands is the most commonly employed method. The procedure is usually done by the producers by applying a latex ring around the tail, 7-8 cm below the level of the vulva. Lack of perfusion compromises the supply of oxygen and metabolic substrates to the tissues and results in ischemia. The necrotic distal portion of the tail detaches 3 to 7 weeks after banding, or may be removed by using clean shears (AVMA, 2006). Wilson (1972) demonstrated the importance of proper band placement to prevent unnecessary swelling.

Tail docking is usually performed on preparturient heifers or calves near weaning age (AVMA, 2006) but is sometimes done on adult cows. Application of tail bands within first week of age is possible (Stilwell, personal observations). Australian guidelines state it should be performed when recommended by a veterinarian for health reasons, and the tail stump must be long enough to cover the vulva (Stull, 2002). Farmers use the tail docking because they believe it increases cow cleanliness and milk quality. Research needs to be done to assess comfort and cleanliness of farm personnel as a reason for tail docking of cows (Aubry, 2005).

Tail docking is done regularly in the USA (see Table 12) and some European countries (accurate numbers not available) but is banned in some other European countries.

Table 12 N° of farms and cows tail docked in the USA (USDA, 2002).

Percent Operations				
Herd size (Number of Dairy Cows)				
	Small (less than 100)	Medium (100-499)	Large (500 or more)	All operations

Percent of Cows with Docked tails	Pct	Std Error	Pct	Std Error	Pct	Std Error	Pct	Std Error
0	52.8	(2.8)	38.3	(2.8)	53.6	(3.6)	49.5	(2.1)
1.0 to 24.9	18.3	(2.1)	15.8	(2.2)	13.3	(2.8)	17.5	(1.6)
25.0 to 75.9	8.8	(1.6)	10.0	(1.9)	8.9	(2.6)	9.1	(1.3)
76.0 to 99.9	6.5	(1.4)	12.0	(1.9)	11.5	(2.0)	8.0	(1.1)
100.0	13.6	(1.9)	23.9	(2.6)	12.7	(2.0)	15.9	(1.5)
Total	100.0		100.0		100.0		100.0	

13.4.2.6. Reasons for tail docking

In favour

The practice has gained popularity because some farmers maintain that tail-docking improves cows cleanliness, improves udder hygiene, lessens environmental soiling from tail-switching and prevents tail-switching on milkers face and body (AVMA, 2006; Rebhun, 1995a). Docking was thought to reduce the risk of leptospirosis by eliminating the possibility that a urine-soaked tail could contact the milker's skin or face. Farmers argue that tail docking improves milker's comfort (Mathews et al., 1995), especially in parlours where the milking occurs between the hind legs (Aubry, 2005; Bagley, 2002).

In opposition

Current scientific literature indicates that routine tail docking provides no benefit to the animal, and that tail docking can lead to distress during fly seasons. When medically necessary, amputation of tails must be performed by a licensed veterinarian (AVMA, 2006). The Canadian Veterinary Medical Association opposes the practice of docking of dairy cattle for management purposes (CVMA, 2007). Denmark, Germany, Scotland, Sweden, the United Kingdom, and some Australian states prohibit tail docking (AVMA, 2006).

No significant benefit to cow cleanliness or quality of milk can be attributed to tail docking. The high level of farm variation found indicated that other management decisions play a more significant role (Bagley, 2002). Milkers comfort may be affected by long tails but mainly in herds where bedding and general hygiene is poor. Alternatives to tail docking (e.g. improved milking parlour design) might be as efficient.

13.4.2.7. Effects of tail docking

Acute pain

Although age-related behavioural differences are observed, tail-docking of calves produces a minor pain response (AVMA, 2006).

Tail was heat sensitive distal to band for 2 hours. Distal tail sensitivity to hot water was absent 75 to 105 minutes after banding, indicating desensitization of the tail below the banding site (Eicher and Dalley, 2002). Preweaned calves that were 21 to 42 d of age demonstrated significantly more restlessness after application of tail bands compared to younger calves or control calves of the same age (Schreiner and Ruegg, 2002). After tail-docking no differences in cortisol, milk intake, weight gain, body temperature or faeces score were found (Tom et al., 2002a). No significant differences in cortisol, heart rate or body temperature were detected among groups of calves and heifers docked (Schreiner and Ruegg, 2002). Docked heifers

showed substantially higher stomping activity following application of a cold pack to the cut end. Greater changes were observed in the tail surface temperatures of the docked heifers following temperature manipulation (Eicher et al., 2006). The use of local anesthetic at the time of ring application provided no detectable benefit in reducing physiologic signs of stress (Petrie et al., 1996).

Rubber-ring amputation in heifers showed that the docked groups spent more time eating after banding and less time eating after docking. This may suggest displacement behaviour and mild distress. No differences were found in cortisol, lying, standing, walking, drinking, head-to-tail, or grooming behaviours. The authors also reported that the actual amputation of the tail on day 6 caused discomfort (Eicher et al., 2000).

After rubber-ring tail amputation, with or without epidural anaesthesia, adult cows showed differences in behaviour: cows spent less time tail shaking; less time raising the tail; more time tail against body, whereas they spent more time with their tails pressed to their bodies. No effect on milk production was found, and there was no difference between cows subjected or not epidural anaesthesia (Tom et al, 2002b). In another study, cows continued to graze "apparently unconcerned" immediately following banding (Stull et al, 2004).

Chronic pain

Continued growth of damaged nerve axons may result in the formation of a mass of tangled axons called neuroma. Neuromas are associated with chronic pain and may play a role in post-amputation pain in humans (Stull et al., 2002). Neuromas were observed at slaughter in tail stumps of adult cattle that had been docked using a knife at 12 to 18 months of age (Barnett et al., 1999). Lunam et al. (2002) also found evidence of neuromata in calves that were tail-docked.

The behaviours of docked heifers indicated changes in their sensitivity to heat and cold, similar to human amputees who are experiencing phantom limb pain, indicating that similar mechanisms are present in the stump of the docked tail (Eicher et al., 2006).

Udder health

Leg cleanliness scores were improved in docked cattle compared with intact cattle (AVMA, 2006). There is a significant association between the prevalence of intramammary contagious pathogens and udder hygiene score (Schreiner and Ruegg, 2003) but no statistical differences were observed with respect to udder cleanliness or somatic cell count (Eicher et al., 2001). In another study, cow cleanliness, udder cleanliness, and SCC scores were not different for docked heifers compared with intact heifers (Tucker et al., 2001). No significant differences were observed in SCC, udder cleanliness, or intramammary infection between docked and intact cattle (Schreiner and Ruegg, 2002; Compton et al., 2007).

Tail-docking does not correct dirty management practices, dirty stables or lack of bedding. Nor does it improve sound pre-milking, milking and post-milking hygiene (Rebhun, 1995a).

Farmer safety

Leptospiral titers of milkers bore no relationship to tail docking, and so transmission of leptospirosis in endemic herds likely occurs from sources other than tail contact (Mackintosh et al., 1982).

Insect avoidance

Cattle have a defence against those insects that a tail can beat away. If their tails are docked the cattle cannot rid themselves of flies.

More fly avoidance behaviours were observed (caused by increased fly attacks) on calves that had tails docked. Fly counts have been observed to be greater on the rear limbs of docked three-week-old calves during times of high fly activity (Eicher et al., 2002).

Almost twice as many flies were observed on the rear limbs of docked cows compared with control cows (Eicher et al., 2001).

Tail-docked cows show elevated levels of fly-induced behaviour but did not have an altered adrenal cortex function (Eicher et al., 2001).

Social behaviour

Tail docking limits the ability of cattle to exhibit normal signaling behaviour (Kahler, 2002). This may also be a welfare problem when hierarchy is being established.

13.4.2.8. Complications and alternatives

Possible complications of tail-docking include: chronic infections, osteomyelitis, ascending neuritis-myelitis, clostridial myositis and tetanus (Rebhun, 1995a). Tetanus and gangrene have been reported after tail docking, and vaccination against clostridia is recommended prior to performing the procedure (Stull et al., 2002).

A common alternative to tail-docking in dairy cows is switch trimming. In a study comparing docking, switch trimming, and intact tails, the proportion of flies on the rear quarters of switch trimmed cows was intermediate between cows with intact or docked tails. A compromise for milking personnel comfort might be achieved by trimming the switch in the spring (when the tail was more likely to be dirty) and allowing it to grow back over the summer (when fly numbers are highest and floor is drier) (Stull et al., 2004).

13.4.3. Supernumerary Teat Removal and Welfare

Supernumerary teats are the most common congenital abnormality in dairy cattle. There has been little genetic selection away from this trait simply because it is not reported back to stud services (Rebhun, 1995b).

Supernumerary teats can get infected and so provide chronic infection for other quarters and other animals. Mastitis in these teats can be very painful and even lead to toxæmia. Supernumerary teats can affect normal milking by affecting teat-cups adjustment.

Amputation can be done with sharp scissors or scalpel blade under local anaesthesia. No suture is needed if done on very young calves. Siamese teats need special treatment by a veterinarian.

Care should be taken to identify the supernumerary teat to avoid amputation of a true teat. Confusion is more probable in very young animals. If confusion exists amputation should be postponed a few months (Rebhun, 1995b). Removal should be performed at young ages (4-8 months) (Rebhun, 1995b). However supernumerary teats are sometimes removed after weaning at around 3 months of age (Corey, 2004). If removal takes place before three months the operation can be carried out by a non-veterinarian (FAWC, 2003).

13.4.4. Removal of hind dewclaws and welfare

Removal of medial hind dewclaws is a routine practice in some dairy farms and is done to minimise self-induced teat injuries (Rebhun, 1995a). In Europe this intervention is not common.

Removal of hind dewclaws is done at early ages with a scalpel or scissors. Acute or chronic pain caused by this procedure has not been evaluated. There are no studies comparing the incidence of teat and udder injuries between farms or animals with or without dewclaw amputation.

13.5. Reproduction: artificial insemination, embryo transfer, semen collection, natural mating.

13.5.1. Artificial Insemination

Artificial insemination (AI) is a current routine procedure in dairy farms worldwide. It should be done by trained personnel under the supervision of a veterinarian.

Cows held for insemination in unfamiliar surroundings (any area which is sited away from the remainder of the herd), for a number of hours, are likely to be stressed (FAWC, 1997).

Stress reactions of cows during rectal palpation/insemination can be reduced by previous positive handling as well as by a person providing positive, gentle interactions during the procedure (Waiblinger et al., 2004). Untrained, inexperienced or careless operators may cause genital trauma or infections that may lead dangerous or fatal disease (e.g. peritonitis). Keeping cows in heat tied up to avoid injuries is a common practice that should only be done if safety and welfare guidelines are addressed.

13.5.2. Embryo Transfer

Embryo transfer is not yet widespread but use will probably increase in the future. Widespread and arbitrary embryo transfer could lead to dangerous degree of inbreeding.

The procedure in cattle is mainly carried out by superovulation and non-surgical recovery. Embryos may be transferred directly or frozen for storage and future use.

The procedure for transferring single embryos to carefully selected recipients does not normally cause welfare problems except for the ones referred to in AI. The continued use of superovulatory drugs can result in subsequent fertility problems and premature culling.

Embryos fertilised in vitro have been implicated in the production of oversize calves. Dystocia and C-section incidence may increase with the use of certain embryos (problematic sire or breeds).

13.5.3. Oocyte Collection

Oocytes from follicles may be retrieved by laparoscopy or ultrasound-guided transvaginal oocyte retrieval – trans-rectal handling of ovaries and trans-vaginal ultrasound observation and trans-vaginal aspiration of oocytes.

The use of juvenile donors in embryo-transfer programmes offers considerable potential for accelerated genetic gain in domestic livestock through reduced generation interval. It also

provides a more rapid means of expanding the line from a particularly valuable genotype such as a transgenic founder animal.

Although the female calf is born with its full complement of oocytes (some 130,000), at 5 months of age the ovaries are very small and contain about 20 small (1 to 2 mm) follicles, but only 2 to 3 large (>5 mm) antral follicles. It is therefore necessary to stimulate the ovaries to induce the growth of many small follicles to a size suitable for aspiration.

Pregnancies and calves were obtained after in-vitro fertilisation of oocytes collected via laparoscopy from superovulated prepubertal calves at about 3 mo of age (Armstrong et al., 1992). Limited developmental competence of oocytes derived from calves prior to puberty (Duby et al., 1996). Oocytes have been collected from 10-12 week old female calves: 43% pregnancy rate and 33% live births (of embryos transferred) from fresh in vitro-produced embryos from calf oocytes (Armstrong et al., 1997).

Eleven pregnancies were obtained from eighty-four in vitro-produced embryos, from oocytes collected from 2 month and 4 month calves. Out of these 11 pregnancies, 9 reached full term and two were stillborn (Taneja et al., 2000). Higher rates of embryo losses later in pregnancy were observed for the calf oocyte group compared to cows' oocytes (Revel et al., 1995).

13.5.4. Natural and caesarean delivery practices.

13.5.4.1. Introduction:

Normal calving includes three stages:

Stage one – dilatation of the cervix. It lasts three to four hours in multiparous and five to six hours in primiparous (Mee, 2004). The pressure of the amniotic and allantoic bags are essential and early breakage of the "water bag" may delay the normal dilation of the cervix.

Stage two – delivery of the calf. The second stage is characterised by the progression of the calf through the birth canal and its expulsion. It may last from 2 to 10 hours. Attempts to speed up the calving by pulling the calves limbs are responsible for severe trauma and pain to the dam and calf.

Stage three – expulsion of the placenta. Usually placenta is expelled within the first 12 hours after calving.

The two major welfare problems surrounding calving are pain/stress, associated with dystocia, and perinatal mortality.

Other potential welfare problems are: metabolic diseases, udder oedema, toxic metritis, stress caused by handling, isolation, calf separation and lactation onset.

Calving difficulty is usually scored from 1 to 5. It is usually referred as dystocia (prolonged or difficult calving), when the score is above 3.

Perinatal mortality (PM) is defined in many countries as the death of the calf at any time after 260 days of gestation and until 24 hours after delivery. Mee (2004) indicates that 75% of perinatal mortality occurs in the first 1 hour after delivery, 15% during the next 48 hours and 10% before delivery.

13.5.4.2. Monitoring calving

Peri-partial monitoring of cows reduces neo-natal mortality and cow genital lesions, but may delay parturition. Continuous presence of an observer during second-stage was associated with an increase in both calving problems and assisted parturitions among penned cattle but the stillbirth rate was reduced in those animals undergoing dystocia (Duffy, 1981)

In an Irish survey, forty-four per cent of the farmers intervened within the first hour after the appearance of foetal hooves (Egan et al., 2001).

Monitoring calving is essential, particularly at stage 2, and intervening when necessary, but excessive direct supervision should be avoided (Drew, 1988). Observation of cows and heifers during calving is critical for reducing calf losses (Youngquist, 1997).

Intervention at 2 hours, compared with 15 minutes, after the onset of stage 2 reduced the calving difficulty score, the duration of assistance and proportion of animals with perineal lacerations, and increased the proportion of animals calving naturally and of calves standing 1 hour after calving (Mee, 2004). In a study with Hereford cattle, calving supervision led to higher survival of both heifers and calves (Hodge et al., 1982).

Late evening feeding before calving has been shown in some (Gleeson et al., 2003) but not all studies (Pennington and Albright, 1985) to result in more daytime calvings in dairy herds.

Monitoring approximately every 3 to 6 hours from the first detection of the onset of stage 1 is advisable to detect the onset of stage 2 of normal calving and to detect abnormal calvings early (Mee, 2004). Once-a-day inspection is not sufficient for lactating animals or those near to calving (FAWC, 1997).

Monitoring should continue after parturition for quick detection of uterus prolapse and hypocalcemia that can result in Downer cow Syndrome if not treated immediately (Cox, 1998; Cox and Onapito, 1986). Video monitoring is used in some large herds (Cox, 1998).

13.5.4.3. Maternity

Calving facilities can be managed to avoid problems. These include, among others, good hygiene, good bedding, non slippery floor, good protection against weather conditions, possibilities to lift a cow by artificial means etc. Sand is the preferable bedding during the maternity (Cox, 1988). Adequate maternity conditions are reviewed in Kersting, 1997 and Mee, 2004.

An Irish survey showed that inadequate maternity conditions are common –, approximately 80 per cent of the animals were housed in cubicles and 21 per cent of them without bedding material (Egan et al., 2001).

Early movement to the maternity unit fulfils the cow natural isolation-seeking behaviour but movement too early to the maternity unit will affect the cleanliness and management of the calving environment (Mee, 2004). Keeping cows isolated for too long may also be stressful and delay calving onset. However more mastitis occurred during lactation when heifers were moved to confined housing the day of calving instead of earlier (Svensson et al., 2006). Calving area management, delivery management and newborn management should be extremely important areas of dairy management focus. Events that occur here can affect calf morbidity and mortality, treatment costs, transmission of herd diseases, dam health and reproductive performance and ultimately the cost/benefit of replacement heifer rearing (Garry, 2004).

Maternities should have gates that are wide enough for a tractor to enter if cow lifting is necessary (Cox, 1988).

13.5.4.4. Stress influencing partum and post-partum

Heat stress reduces blood flow to the placenta (Alexander et al., 1987), increases placenta retention incidence (Dubois and Williams, 1980) and reduces IgG passive transfer (Donovan et al., 1986).

Incomplete dilatation of the vulva or cervix in primiparae is associated with periparturient environmental stress (Duffy, 1981; Sutherland, 1990). Incomplete dilatation of the vulva and cervix in pluriparae is associated with confinement and environmental disturbance at calving (Bendixen, 1986; Mee, 2004) and preterm calvings (Mee, 2004).

Social isolation may adversely affect the progress of calving resulting in dystocia (Van der Weijden and Schuijt, 1992). The movement of animals, particularly nervous cows and heifers, will suspend their calving behaviour possibly for hours (Mee, 2004).

Stress of parturition can be compounded to unacceptable levels by adverse environmental conditions (Kersting, 1997). The result of excessive stress is impaired immunity of dam and calf.

Lameness and severe mastitis can cause dystocia (Schuijt and Ball, 1986).

Fear, presence of humans or other animals (e.g. dogs) may delay parturition.

13.5.4.5. Dystocia and welfare

Risk factors

USA data on calving assistance: Dairy cattle – 18% assisted deliveries (32% in heifers) (NAHMS, 2002). Odds for dystocia has decreased by 4.7%/yr (Johanson and Berger, 2003).

The risk factors for dystocia (and Peri-natal Mortality) in dairy cows are shown in Table 13 (adapted from Mee, 2004).

Table 13 The risk factors for dystocia (and Peri-natal Mortality) in dairy cows (adapted from Mee, 2004)

Feto-pelvic incompatibility		Fetal maldisposition	Incomplete vulval or cervical dilatation	Twins	Uterine inertia	Uterine torsion	
Calf size	Dams Pelvic size				Primary	Secondary	
Sire, breed, gestation length, gender, weather	Sire, weight at breeding, weight at calving, age at calving, body condition	Sire, gender	Environmental stress, hormonal causes, pre-term calving	Parity, season, genetic, high milk yield (hormone treatments?)	Hypocalcemia, old age, debility, lack of exercise, pre-term calving	Prolonged calving, twins	Fetal oversize, excessive fetal movements, debility, lack of exercise. (transport at end of

							gestation?)
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Calfs' weight and dams' pelvic area are two of the most important factors that contribute to the incidence of dystocia (Youngquist, 1997). First-parity cows have a 4.7 times higher risk of dystocia than cows in later parities (Johanson and Berger, 2003; Bendixen, 1986). Primiparae dystocia is most influenced by sire (Meijering, 1984) weight at insemination (Drew, 1988) and age, weight and body condition at calving (Drew, 1988; Meijering, 1984). Over conditioned heifers have excessive deposits of fat in the pelvic canal which reduces its calibre and increases the difficulty of delivery, but calving difficulty is not diminished in underfed heifers (Youngquist, 1997).

First calving and male calves have more probability of assisted calving (Lombard et al., 2007). Heavy birth weight heifer calves have higher dystocia scores (Colburn et al., 1997). Odds of dystocia increase by 13%/kg increase in birth weight (Johanson and Berger, 2003). Twins, sex of calf (male) and breed of sire and dam have an important influence on the incidence of dystocia (Heins et al., 2003; Bendixen, 1986).

Animals on pasture have a reduced incidence of dystocia (Bendixen, 1986) probably because uterine inertia can be caused by lack of exercise (Mee, 2004; Gustaffson, 1993).

Dystocia increases with level of dam inbreeding up to 25%, however calf inbreeding has no significant effect on dystocia (McParland et al., 2007). So, the effects of inbreeding on incidence of dystocia are relatively small (Adamec et al., 2006).

Effects

Dystocia can have effect on the dam and the calf.

Dystocia and cow welfare

The effect of dystocia on the dam welfare ranges from discomfort because of laceration of the vulva to paralysis of the obturator nerve and downer cow syndrome (Egan et al., 2001). Calving paralysis occurs more frequently in heifers although it occasionally is observed in multiparous cows following seemingly normal parturition (Ciszewski and Ames, 1987).

Dystocia affects adversely milk, protein and fat yield, reproduction indexes, disease incidence, culling and cow deaths (Tenhagen et al., 2007; Garry, 2004; Lombard, 2003; Rajala and Grohn, 1998; Dematawewa and Beger, 1997; Phillipsson, 1976).

Dystocia requiring caesarean section or total foetotomy following unsuccessful extraction, causes enhanced postpartum adrenocortical function (Nakao and Grunert, 1990). Compared with cows with normal calving, cows with dystocia show higher plasma glucocorticoids during parturition (Heuwieser et al., 1987, Hudson et al., 1975). Depression or exhaustion of the adrenal cortex, if it occurs following adrenocortical hyperactivity, may cause many postpartum diseases (Nakao and Grunert, 1990). Vasopressin was higher in heifers that

needed assistance than in those that did not, indicating that this hormone is released in order to deal with the pain-related stress associated with labour (Hydbring et al., 1999). Cortisol was higher in heifers with moderately difficult calving (Kornmatitsuk et al., 2002). High levels of cortisol can hamper post-partum immunity.

Calf welfare and Peri-natal mortality (PM) related to dystocia.

Even mild dystocia has been shown to impact calf health and survival (Garry, 2004).

The prevalence of stillborns increased during the last years (Hansen et al., 2004; Steinbock et al., 2003).

Stillbirth rate for Holstein cows at first calving has increased during the last decades and is now around 10% in Denmark and Sweden. HF genes increased incidence of heavy calves, stillbirths and dystocia (Hansen et al., 2004). These findings show that PM may be seen as an important welfare issue in the Holstein breed.

Significant basic risk factors associated with PM following all calvings include genetic variables such as calf sire, sire breed, dam breed, inbreeding and gestation length (Mee, 2004; Johanson and Berger, 2003, Heins et al., 2003, Kindahl et al., 2002; Meyer, 2001; McNeil et al., 1989). Important nongenetic variables include year, season, beginning and end of the seasonal calving period, calving environment, and precalving nutrition (Mee, 2004). Induction of calving is associated with a substantially lower calf survival. Calf viability and value was lower when induced cows were at an earlier stage of pregnancy (Mansell et al., 2006).

Peri-natal mortality incidence (within 24 to 48 hours of birth, depending on the countries) is not included in evaluation of dairy cattle mortality. Deaths under 24 hours of age perhaps equal the death loss beyond 1 day of age (Garry, 2004).

The primary determinant of whether a herd had high or low PM is not management factors before calving, but rather calving management (Drew, 1988). Calves born in maternity pens have a significantly lower mortality rate than those born in common stalls (Mee, 2004). Ninety percent of calves that die in the perinatal period, were alive at the start of calving (Mee, 1991) and two-thirds of calf mortality within the first 48 h occur at calving (Mee, 1999).

Calving ease is a trait considered to be correlated with calf mortality within the first 48 hours (Johanson and Berger, 2003; Tenhagen BA et al., 2007; Lombard et al., 2007). More parturitions of primiparous Holstein cows result in the death of a calf, compared with multiparous cows (Meyer et al., 2001; Lombard, 2007). Calves born with difficulty have an increase incidence of DRB, other diseases, dystocia and overall mortality (Garry 2004; Lombard, 2007). Female calves born from difficult calving are more likely to first calve at an older age (Heinrichs et al., 2005).

Welfare calf issues related to dystocia include a degree of anoxia, acidosis and severe injuries (e.g. broken ribs) and death (Schuijt, 1990; Egan et al., 2001). Meconium staining of the foetal fluids or foetus is an indicator of intrauterine hypoxia (Duffy and Sloss, 1977). Up to 40% of veterinary-assisted deliveries may result in rib fractures and up to 10% in vertebral fractures (Tyler, 2003).

Difficult births tend to result in perinatal mortality 2.7 times more often than unassisted births (Johanson et al., 2003). Heavy calves had a 9.6% more probability of perinatal mortality (Johanson and Berger, 2003). Shorter length of gestation increases the probability of stillborn (Martinez et al., 1983; Meyer et al., 2000). Dystocia-born and body condition of 4 or above are risk factors for stillborn (Chassagne et al., 1999).

PM is also associated with calf compromised adaptation to cold stress (Mee, 2004). Cold stress, premature birth, cesarean section, and dystocias inhibit neonatal cortisol release and decrease colostrum absorption (Chase et al., 2008). The administration of corticosteroids to premature newborn calves may enhance their survival (Sanglid et al., 2003).

Managing calving

In forced extraction the amount of force applied has the potential to harm the dam and fetus (Youngquist, 1997). The pain (endorphins) and fear (adrenaline) associated with dystocia manipulations are known to impede uterine motility via an oxytocin block (Ehrenreich et al., 1985; Taverne, 1992).

In a survey it was found that farmers assisted 35 % of cows and 48 % of heifers (Egan et al., 2001). Accordingly to the same study intervention was initiated quite early: < 1h = 44% and 2 hours = 46%. A different Irish survey found that the calving jack was used in 21% of calving. These values may differ across Europe, farm size, stockperson training and between systems.

In herds where intervention was conducted less than 1 hour after the onset of stage 2, there was a significant higher use of a calf puller and incidence of downer cows (Egan et al., 2001). Early assistance of Jersey cows (as soon as the hooves were visible) caused premature umbilical cord rupture, increased dystocia and reduced perinate vigour (Hammer and Purse, 1999).

Squeeze chutes should not be used for assisting calving as cows tend to become recumbent. Asphyxiation and death can occur when using head gates to handle calving animals (Youngquist, 1997). Epidural anaesthesia facilitates moderate to extensive manipulation in dystocia (Youngquist, 1997). Ropes double knotted above and below the fetlock distributes the force of traction over the lower leg and prevents limb fractures (Mee, 2004).

Relaxing traction when dam is not contracting allows optimal fetal circulation and oxygenation (Schuijt and Ball, 1986). Sustained traction when the dam is not forcing will result in the calf's hips entering the dam's pelvis while the latter is not being dilated by abdominal contraction (Schebitz, 1980). These errors will increase the probability of "hip-lock" dystocia.

The duration of calving and the duration and force of intervention during calving affect fetal survival (Szensi, 2003; Mee, 2004). One, two, and three men can apply a tractive force of approximately 75, 125, and 175 kg, respectively, while the maximum manual traction that can be applied at calving is approximately 300 kg (Hindson, 1978). A force of approximately 170 kg can fracture the leg bone of a calf. The maximum tractive force applied by a calf puller is approximately 400 kg and that of a pulley block is 450 kg and a tractor is 5.000 kg (Hidson, 1978; Youngquist, 1997).

Simple nursing techniques such as warming, drying, provision of extra colostrums, shelter, stimulation, oxygen delivery, fluid therapy and extra mothering attention increase calf survival rate (Garry, 2004; Mee, 2004).

Prevention of dystocia

Heifers reaching 65% of their expected mature weight by the time of first service reduces the potential for calving difficulty (Youngquist, 1997). Replacement heifers of adequate body size by 22 to 24 months of age have less dystocia (Hoffman, 1997). Holstein replacement heifers normally weigh 580 to 635 kg at calving (Hoffman et al., 1992; Keown and Everett, 1986).

Pelvimetry is a way to measure pelvic space for calving. Some authors (Naazie et al., 1989; Gaines et al., 1993; Basarab et al., 1993) say that pre-calving measurements have low correlations with pelvic area at calving and dystocia incidence. Other authors say that dystocia probability decreases with increased pelvic area (Johanson and Beger, 2003).

Calf delivery and newborn calf management are undervalued as areas of concern. Dystocia has been almost ignored. Very few dairy producers incorporate breeding strategies to decrease dystocia or have delivery management protocols (Hemsworth and Coleman, 1998; Garry, 2004).

Sire predicted transmitting ability (PTA) for perinatal survival and calving ease is demonstrated (Meyer et al., 2003). Selection of sires for heifers reduces dystocia (Anderson et al., 1993). First-parity records should preferably be used for genetic evaluation of bulls for calving performance (Steinbock et al., 2003). Selection of sires with low birth weight is much more effective than selection of replacement heifers based on yearling pelvic area in reducing both the incidence and severity of dystocia in first-calf heifers (Cook et al., 1993).

Cows that exercised had fewer calving-related problems (Gustaffson, 1993). Hereford heifers in confinement during parturition had more dystocia (mainly due to vulva constriction) and stillbirths compared with animals left to calve in either the paddock or a large yard (Duffy, 1981)

Shorter dry periods (Barkema et al., 1992a) and good transition nutrition (Rogers et al., 1996; Studer, 1998) reduce the incidence of dystocia.

Inducing parturition is done when dystocia due to large fetus is feared or for management purposes (calving season). Induced parturition 3 weeks before the predicted end of gestation leads to very low calf viability (Barth, 1986).

13.5.5. Caesarean and welfare

If after 15 to 30 minutes, depending on operator experience, a fetal maldisposition cannot be corrected, caesarean surgery can be considered (Mee, 2004). Elective caesarean is sometimes performed on small heifers or dams carrying large calves. Waiting for full cervical dilation, even in elective caesarean section, is recommended before performing surgery, as it promotes postnatal respiratory and metabolic adaptation (Barkema et al., 1992b). There are some advantages to embryotomy: speedier, safer and less exhausting to animal and operator (Arthur, 1982).

Caesarean is most commonly performed at first calving (Cattel and Dobson, 1980; Egan, 2001) and 30% of animals usually suffer ill-health afterwards (Cattell and Dobson, 1980). Risk factors for caesarean section consist of first parity, single male calf, long gestation period, long interval between first service and conception, long dry period, sired by a bull of double-muscled structure, under 730 days of age at first calving, and having a previous cesarean section (Arthur, 1982; Barkema et al., 1992b).

Stillbirths were fewer in caesarean cows than in dystocia calvings or control, but culling was higher (Tenhagen et al., 2007). Milk production, fertility and placenta retention were lower in caesarean cows and culling was higher (Barkema et al., 1992a).

Calves born through C-section were lighter at weaning (Colburn et al., 1997).

As the prognosis following surgery is primarily influenced by the condition of the calf, emphysematous fetuses are generally not considered for caesarean section unless fetotomy is not possible (Mee, 2004).

13.5.6. Post-partum and welfare

Problems

Hypocalcemia, fatty liver, ketosis and toxic metritis are post-partum diseases that severely affect welfare (Correa et al., 1993; Smith and Risco, 2002; 2005). These are dealt with in chapter 5.

Short, heavy first lactation cows had an odds ratio of 3.1 of incidence of metritis at calving (Markunfeld and Ezra, 1993). Early metritis reduces milk production during next lactation (Rajala and Grohn, 1998).

Inducing calving may cause retained placenta, lower milk production and other problems (Mansell et al., 2006; Peters and Poole, 1992). Induction was also associated with low pregnancy rates in the next breeding (Peters and Poole, 1992).

Heifers may develop hyperalgesia in the periparturient period (Whay et al., 1998). Ingestion of amniotic fluid enhances the ongoing opioid mediated analgesia at calving (Pinheiro Machado et al., 1997). Eating the placenta enhances the analgesia produced by the release of endogenous opioids during parturition (Kristal, 1991). Problems expected from cows eating the placenta are asphyxiation and rumen putrefaction.

Monitoring the post-partum

Most of the problems that affect dairy cows' health and welfare occur or have its origin in the immediate post-partum period (15 to 21 days post-calving) – immune depression, metritis and endometritis, mastitis, ketosis, liver lipidosis, abomasum displacement, lameness... All of these problems and diseases have an enormous impact on the cows' future production, fertility and welfare. Only early prevention is efficient in reducing significantly these effects.

The main goal of any monitoring programme is to identify any change that occurs from what is considered a normal state (Correa et al., 1993). Dairy farms should use monitoring programmes to aid in the identification of clinically or even subclinically sick animals (Smith, 2005). There are various parameters that can be used to monitor the fresh cow's health status. These include milk production, general attitude, blood component analysis (calcium, ketone bodies etc...), rumen content pH (ruminocentesis), urine ketone body levels, and rectal temperature values (Smith, 2005). Monitoring fresh cow attitude and rectal temperature for 10 days post-partum help detect sick animals (Upham, 1998, Kristula and Smith, 2001). Early identification of sick cows also ensures management interventions that might guarantee that other animals are not affected by the same problem. In the USA a programme called the "100-day contract" was designed to improve early detection and resolution of problems in the peripartum of dairy cows and to improve future fertility (Spain, 1999). For each cow, the 100-day contract focuses on the critical period of 30 days before calving to 70 days after. This programme includes close and rigorous examination of cows (including daily measuring of rectal temperature and performing rectal palpation of the genital tract) during the first ten days post-partum to detect uterine or other infections.

13.5.7. Twinning and welfare

Twinning can be a welfare problem for dairy cows and calves. Cows losing excessive “body condition” (BC) during the dry period are suspected of carrying twins (Mee, 2004).

Risk factors for twin calvings are parity, season, herd, previous twinning and high cumulative milk production (Nielen et al., 1989). The probability of having twins increases with infertility treatments.

Because of the reduced BC at calving, susceptibility to metabolic and infectious disease may increase in cows that deliver twins. Reduced milk yield and reduced fertility (more fertility-related treatments, increased number of days open and increased number of inseminations per conception) are to be expected after twinning (Nielen et al., 1989). More dystocia, stillbirths, placenta retention, metabolic diseases, abortions and culling are to be expected with twinning (Talebkan Garoussi, 2002). Cows giving birth to twins are at a higher risk (odds ratio – 3.83) of being culled (Thomsen et al., 2007). Another effect of excess twinning may be less replacement heifers left on the farm because of increase calf mortality and “free-martinism” (Nielen et al., 1989).

13.6. Slaughtering: on-farm procedures.

This section will deal mainly with the care and procedures for stunning and killing individual animals (sick or injured) on the farm. Because general considerations for on-farm stunning and killing for disease control purposes have been dealt in other reports (EFSA, 2004), we will address only specific aspects.

A recent survey indicates that killing for production reasons is responsible for 58% of the mortality in the farm and that the proportion of early-killed cows has increased in the past years (Thomsen et al., 2004). On farm killing of individual animals in many cases is the only practical way to provide prompt relief of otherwise uncontrollable animal suffering (Shearer and Nicoletti, 2007). This option may be taken whenever transport to the abattoir will cause additional stress and suffering. The most common indications for individual on-farm killing includes: fractured leg (irreparable), severe trauma, loss of production and quality of life (severe mastitis, pneumonia, etc.), inability to stand or walk (disabled livestock), advanced ocular neoplasia, debilitating or toxic condition, cost of treatment prohibitive or extended withdrawal time for sale of meat and very poor prognosis (AABP, 2007). A Danish survey on causes of mortality at farm level indicate that 25% were due to locomotor disorders and between 30 to 40% of deaths occurred in the first 30 days after calving (Thomsen et al., 2004).

Too often, economics and the person’s aversion to kill the animal have been the primary deciding factors, to the detriment of the animal’s welfare. Farm animal literature holds little discussion and few guidelines for when a farm animal should be euthanised. There are guidelines for companion animals (Meyer and Morrow, 2004). Euthanasia is not and should never be considered as the “easy way out” for poor managers (Meyer and Morrow, 2004) but a high incidence of mortality (including on-farm killing) may be an indication of poor management and low cow comfort standards, including poor stall, poor bedding and no access to grazing during summer (Thomsen et al., 2004; 2006; 2007, Sandgren and Lindberg, 2007).

The stunning and killing of individual animals is done by farm staff and so stipulations, other than those presented in the 2004 EFSA report on stunning and killing, should be made. Euthanasia, regardless of the circumstances, impacts on a person’s emotional state. Some farm workers suffer psychological distress when asked to euthanise animals in their care especially

when it's a sound but uneconomic animals (Meyer and Morrow, 2004). In fact, observation has shown that constant exposure to, or participation in, killing procedures may result in psychological damage leading to work-related dissatisfaction and a tendency toward careless or callous handling of animals (Shearer and Nicoletti, 2007). Studies show that the training of staff makes their attitude to animals more positive and improves the welfare of animals prior to and during the process of stunning/killing (Grandin 2001; 2003). In case of stress, managers ideally discuss euthanasia protocols in detail and encourage handlers to participate in discussion groups (Meyer and Morrow, 2004).

Preparation of observers should also be taken into consideration (AVMA, 2001). Such procedures are usually performed in areas out of the public view (Shearer and Nicoletti, 2007).

Deciding for and performing on-farm killing is often done without prior consultation of a veterinarian. Although some countries in the EU impose the presence of a veterinarian for on-farm killing, it is not the case for most countries (no references published). In Wisconsin a producer-survey on animal wellbeing showed that veterinarians were consulted about euthanasia in 32% of the cases and were consulted less frequently in larger herds (27%) (Hoe and Ruegg, 2006).

If the animal to be killed is ambulatory and able to be moved without causing distress, discomfort or pain, it may be moved to an area where the carcass may be more easily reached by removal equipment. Dragging of nonambulatory animals is unacceptable (Shearer and Nicoletti, 2007). In cases where movement may increase distress or animal suffering (e.g. downer cow), the animal is killed first and moved following confirmation of death (Shearer and Nicoletti, 2007).

If death is not verified after euthanasia and before disposal of the animal very poor welfare may occur (AVMA, 2001). When killing a very sick or heavily toxæmic animal, special attention is needed because reactions and reflexes may be restrained but not nociception or consciousness.

Refusing or delaying killing severely sick, debilitated or injured animals is a possibility that may lead to unnecessary suffering. Delaying farm killing of animals in critical and irreversible pain and distress may happen because of negligence or for economic, religious or other reason and should be avoided at all cost.

13.7. Severely sick, traumatised or exhausted animals. Downer cows

13.7.1. Incidence

Sooner or later all cattle owners have animals that become downers. Except on a case-by-case basis it is difficult to generalise what the most appropriate approach to a downer may be (Garry, 2004). Incidence is increasing (Radostitis et al., 2000) with change in husbandry, installations and milk production. In a large survey in Ireland, it was noted that 66% of Downer Cows resulted from calving assisted within 1 hour of beginning. Another 36% were assisted at 2 hours of onset (Egan et al., 2001).

13.7.2. Causes

Once a cow becomes recumbent, a vicious cycle of additional problems can occur as a result of ongoing muscle injury, bruising and decreased blood flow to the tissues (Garry, 2004).

There are numerous primary causes of recumbency but pressure damage is a factor common to all downer cows (Cox, 1988). Significant pressure damage can occur after 6 hours of recumbency (Cox and Onapito, 1986; Cox et al., 1982). Managers and all cow attendants must realise that any cow which is involuntary down is an emergency case (Cox and Farmsworth, 1998).

13.7.3. Outcome

Outcome (EUA survey): 33% recovered; 23% were slaughtered; 44% died. Outcome New Zealand: 39% recovered; 32% destroyed; 30% died. (Radostitis et al., 2000)

The supreme importance of welfare in downer cows makes an accurate prognosis extremely important. A list of signs in relation to prognosis is presented in Harwood, 2003. There is no absolute rule regarding length of time a cow may remain down before the prognosis becomes hopeless (Rebhun, 1995c).

13.7.3.1. Nursing and prevention

Myopathy that occurs in downer cows is an extremely painful condition (Rebhun, 1995c).

A large part of the downer cow's welfare rests with the attitude and ability of the stockperson attending her. Thus the assessment of the quality of nursing that the cow is likely to achieve is crucial when reaching an opinion on the probability of recovery or deterioration (Harwood, 2003).

Good nursing involves sensitivity to the needs of the patient. Owners should realise that downer cow management is labour intensive, very similar to caring for a bedridden person (Cox, 1988)

Moving a downer cow off the concrete to a suitable place has to be done with care to prevent trauma, stress and pain. The animal can be pulled onto a sheet of plywood which can be pulled (Cox, 1988; Ciszewski and Ames, 1987).

The most important aspect of treatment and prevention of lesions are to provide the most comfortable bedding and roll the cow from side to side every few hours to prevent pressure sores, ischemic muscle necrosis and nerve damage (Radostitis et al., 2000; Rebhun, 1995c; Cox, 1988; Ciszewski and Ames, 1987). Dairy cows are best placed in a comfortable well-bedded box stall prior to calving and should remain there until at least 48 h after parturition (Radostitis et al., 2000). Sand is preferable to other bedding materials (Cox and Farmsworth, 1998; Cox and Marion, 1992).

If affected cows are left in a slippery ground surface they will not make an effort to stand and will become progressively worse (Radostitis et al., 2000; Cox, 1986).

Proper management of clinical cases requires intensive nursing and supportive care (Ciszewski and Ames, 1987), conscientious care and provision of good bedding, palatable feed and liberal quantities of water (Radostitis, 2000; Cox, 1988; Ciszewski and Ames, 1987; Curtis et al., 1970), food and water within easy reach of the down animal (Ciszewski and Ames, 1987) and care to prevent spilling of water.

Manual assistance is offered at regular intervals to aid recumbent animals in their attempts to stand in order to avoid the worst welfare (Rebhun, 1995c; Ciszewski and Ames, 1987). Lifting cows which make no effort to stand on their own is usually unsuccessful and causes stress, pain and additional trauma (Radostitis et al., 2000). Lifting devices must be used carefully by

experienced personnel. Hip clamps have a bad reputation due to misuse (Cox and Onapito, 1986). Hip lifters can result in traumatic injuries to the tissues surrounding the tuber coxae if not used judiciously (Radostitis et al., 2000; Cox 1988). Cows incapable of partially supporting some weight on the hindlimbs should never be left suspended by the hip lift (Ciszewski and Ames, 1987). Hip lifters are less injurious when used with a livestock wheelchair (Cox, 1988). Hip lifts should never be used to move animals.

Other lifting devices include air bags and slings (Cox, 1988). Water tanks are the most effective lifting method (Cox and Farmsworht, 1998) More than 70% of downer cows recover when water tanks are used.

Cows left unattended in a lifter device (Cox and Onapito, 1986) or water tank may be harmed.

Analgesics are useful in maintaining the comfort and appetite of the recumbent animal (Rebhun, 1995c; Ciszewski and Ames, 1987; Cox, 1981).

Frequent cleaning of the stall and skin cleansing will prevent sores (Cox, 1988).

If prognosis is hopeless or very poor at the outset, then euthanasia on welfare grounds is advisable (Harwood, 2003).

13.8. Pain management – surgery, disease, trauma etc.

Pain is responsible for stress and can lead to distress (Clark et al., 1997). Pain can reduce animal well-being substantially and prolong the time needed for recovery from the underlying condition (Muir and Woolf, 2001). Chronic pain can lead to infertility, reduced immunity, metabolic diseases, loss of production and premature culling.

13.8.1. Main causes of pain in dairy cows

Lameness is probably the most common cause of acute and pathologic pain, leading to hyperalgesia in dairy cows. A more thorough approach is included in other sections of this report (see chapter 14).

Downer cow syndrome and various mutilations are dealt with in other sections of this report and pain due to obstetrical interventions is included in a separate section.

Surgery results in acute pain, which is experienced during the procedure and for some hours or possibly days afterwards, may lead to the development of hyperalgesia, where the response to a painful stimulus is exaggerated, or allodynia when stimuli, that are normally not painful, become painful (Anderson and Muir, 2005; Stafford and Mellor, 2005).

Mastitis will cause localised pain and even allodynia such that adequate milking is not possible because of kicking, aggressiveness and lack of milk flow.

13.8.2. Pain detection

Cattle are a species in which concealment of vulnerability and weakness seems to be adaptive (Dobromylskij et al., 2005; Broom, 2001b). The signs of pain in this specie are, therefore, very subtle.

Leaning or nose pressing may be performed when cows are in pain or some kind of discomfort. Teeth grinding is also seen in situations of pain or discomfort from a variety of sources (Roberts, 1997). Chronic pain leads to reduced grooming behaviour (Dobromylskij et

al., 2005) and loss of body condition. Other signs of pain in dairy cows are: total or partial inappetence, dullness, depression, increased respiratory rate and grunting. Kicking the abdomen and gait alterations are signs of abdominal pain but signs are never as extreme as in horses.

Even brief intervals of acute pain can induce long-term neuronal remodeling and sensitization (“plasticity”), chronic pain, and lasting psychological distress in humans (Carr and Goudas, 1999; Clark et al., 1997). Preclinical studies show that neuronal expression of new genes—the basis for neuronal sensitization and remodeling—occurs within 20 min of injury (Carr and Goudas, 1999). The same mechanisms may justify the occurrence of hyperalgesia and depression in other mammals. Severe pain in cattle produces behavioural, autonomic, neuroendocrine, and immunologic responses that can result in self-mutilation, immune incompetence, and a poor quality of life potentially leading to gradual deterioration and death (Anderson and Muir, 2005).

By daily monitoring, farm managers can usually estimate pain duration but the difficulty of estimating pain intensity remains (Meyer and Morrow, 2004). Several different indices (physiological and behavioural) ought normally to be used to assess pain and their evaluation should be improved by training and experience. To give animals the benefit of any doubt, where there is a choice, judgments should overestimate the intensity of pain to avoid missing animals in pain at the cost of treating some that are not (Molony and Kent, 1997).

Stressors reduce nociception (Herskin et al., 2004).

13.8.3. Controlling pain

Pain management should combine the reduction of pain per se with the prevention of possible hypersensitivity (Nolan, 2000).

Several surveys have been published showing the level of pain management done by veterinarians. Many practitioners agreed that there are no long-acting, cost-effective analgesics available for use in livestock and that the long or unknown withdrawal periods of some drugs outweighed the benefits of using them (Hewson et al., 2007; Whay et al., 2005; Watts and Stookey, 2000). Analgesics used are often inadequate, and many veterinarians did not give analgesics to young animals (Hewson et al., 2007). Nonsteroidal anti-inflammatory drugs (NSAIDs) were given to only 50% of cows that underwent cesarean section, 55% of cases of claw amputation, and 1% of cases of dehorning (Whay et al., 2005). Significant differences between the pain scores assigned by respondents who routinely used analgesics and those who did not, the latter being more likely to assign significantly lower pain scores (Huxley and Whay, 2004).

General anaesthesia may be thought of as a “gold standard” for pain-free surgery. In research comparing various methods of castration, however, general anaesthesia consistently stimulated the most severe rise in serum cortisol (Anderson and Muir, 2005). These studies have suggested that general anaesthesia may be intensely distressful to a patient despite the absence of pain stimulus from surgery.

The same happens when using xylazine as a sedative for painful procedures (dehorning) even when a nerve block is used (Stilwell et al., in press).

Studies in humans and small animals have shown that a combination of drugs acting at different points in the nociceptive system provides a greater effect than individual drugs on

their own. Also the pre-emptive use of analgesics has shown to reduce pain and hyperalgesia that usually follows painful procedures like surgery.

14. Owner and stockperson training

Owners and stockpeople have large impact on animal welfare, health and production (Seabrook and Bartle, 1992; Hemsworth and Coleman, 1998; Boivin et al., 2003; Hemsworth, 2003; Waiblinger and Spoolder, 2007) via two main pathways (1) decisions on housing and general management practices; (2) the quality of stockpersonship summarizing the different aspects of taking care of animals. This is, for example, the way of handling animals, the quality of daily care (feeding, cleaning...), the quality of health care (e.g. how quickly sick animals are recognised and how quickly and efficiently they are treated) or problem solving management (how well are problems other than diseases recognised and how quickly and effectively are they solved) (Waiblinger and Spoolder 2007). Owners and stockpeople differ considerably in these aspects, for instance how they interact with their cattle, in their management style and decisions (e.g. (Ploeg van der, 1993; Hemsworth et al., 2000; Waiblinger et al., 2003). Major underlying determinants for such differences are attitudes, personality and empathy, interacting with knowledge and experience. Besides these, environmental or situational variables are also important, for example the (lack of) possibilities to perform a behaviour, social influences, e.g. by coworkers, or the level of workload or time pressure. These factors and their relations to animal welfare are reviewed for example in (Hemsworth and Coleman, 1998; Seabrook, 2001; Waiblinger and Spoolder, 2007; Spoolder and Waiblinger, 2008). Those factors give a framework how to optimise the quality of stockpersonship and decision makings.

If training is effective knowledge, and probably attitudes, can be changed by stockpeople's training and hand-on experience. Depending on the aspect targeted, different approaches may be necessary. For example to improve human-animal interactions (altering human behaviour towards increasing positive and minimizing negative behaviour to avoid stress during human-animal interactions) simple knowledge transfer may not be very successful due to strong habits in the behaviour of individual humans towards animals, while cognitive behavioural intervention was shown to be effective in dairy stockpeople (Hemsworth et al., 2002) as well as on pig farms (Coleman et al., 2000).

With regard to daily care, health care or management practices knowledge transfer paired with practical training may be effective. For example it has repeatedly been reported that farmers generally underestimate lameness prevalence. Whay et al. (2003a) report that on average farmers appeared to be aware of only 25% of the lame cows in their herd. (March et al., 2006) found on average only $45 \pm 34,3\%$ lame cows identified by the farmer. After three farm visits including training of farmers to detect lameness, the percentage increased to $82 \pm 61,5\%$ of lame cows identified by farmers. Thus by training at early disease detection, welfare can be improved.

It is important to consider possible competitive, contrasting attitudes (e.g. economic considerations) which may hinder the trainees to change their own attitude due to the new knowledge and consequently impairs the implementation of this new knowledge. Hemsworth and Coleman (1998) review some factors influencing the success of training courses, such as credibility of the trainer. Farm specific „training“ within a herd health and welfare plan may be especially effective.

15. Longevity in relation to welfare

As explained earlier in Chapter 1 and Section 4.1, death of cows earlier than expected is likely to indicate a problem in coping with adversity, longevity in modern dairy cows has been declining and some adverse factors in life have been found to reduce longevity. The higher mortality rates in Holstein Friesian compare to Swedish Red and White breed indicates also genetic effects. (Hallén Sandgren and Lindberg, 2007b). In a recent Swedish study consistently high mortality rates and/or poor fertility were associated with poor welfare and may be an indication of failure by the stockperson in monitoring and/or acting on signals of animal performance and that this general failure has a wide range of negative consequences for the welfare status of the animals on that farm (Hallén Sandgren et al., 2009).

The use of longevity as a welfare indicator in dairy cows is valid where animals are adversely affected by their environment or genetic make up to the extent that they are at greater risk of being culled. It is not the shortness of the economic life itself that indicates poor welfare but a reduction in the longevity expected. The relevant data may be of animals that die on farm, or animals that are culled because they are severely lame, or have mastitis, or are unable to reproduce (Broom 1992).

Indications that a problem exists are provided by Agger (1983) who recorded numbers of dairy cows sent to rendering plants in Denmark because they had died on farm or had been killed but were not fit to go to a normal abattoir. This number increased from 2% in 1960 to over 4% by 1982. Whilst some of this effect could be due to a more rigorous culling policy most is likely to be a consequence of a genetic change in the cows. Subsequent data on this issue are provided by Thomsen (2006) and other data sets are described in several chapters of this report which indicate that the major causes of early mortality in dairy cows have increased more rapidly since 1983. It would seem that increased metabolic pressure on the cow is associated with more reproductive problems and reduced life expectancy (Roxstrom 2001). Much of the evidence refers to higher culling rates but the reason for culling is almost always that the animal has difficulties in coping with its environment so its welfare is poor.

Table 14 Risk (%) of being culled per lactation (Holstein, USA) if born in the 1960s or 1970s as compared with cows born in the 1990s.

Lactation	Birth date of cows	
	Cows born in the 60s and 70s*	Cows born in the 90s**
First	21.8	16.9
Second	26.3	34.8

Third	29.3	46.7
Fourth	33.2	71.1
Fifth	37.1	96.7

Herd-level mortality statistics can be calculated easily in the same way as disease incidence rates or risks. In this case, the outcome of interest is death. Mortality can be calculated for different animal categories separately, e.g. calves <6 months or first-lactation cows. Overall mortality describes the rate or risk of death regardless of its cause. Cause-specific mortality instead describes mortality due to specific causes, e.g. low production, infertility or certain diseases. Sometimes farmer records of reasons for culling exist and can be used for cause-specific mortality statistics. The rate or risk of spontaneous death can be described accordingly. Buenger et al (2001) calculated a heritability for longevity of 0.17-0.18 and found a significant relationship with udder conformation and the use of bedding in the cow house.

Other factors can affect mortality rates.

- Farmers who want their herd to expand, increase the proportion of heifers kept for herd replacement, and may maintain the present animals for more lactations:
- Technical changes in the system such as transition in dairy husbandry from tied stalls to the cubicle houses, many older cows did not adapt and had to be culled. A similar phenomenon is seen on farms that switch to robotic milking, where culling is mainly based on poor udder shape and behaviour i.e. the unwillingness of cows to visit the robot voluntarily.
- Milk quota and milk price policy factors may also force farmers to increase or decrease the herd size and to keep individual animals longer or shorter, both with direct consequences on the age profile in the herd.
- Disease control programmes can make farmers cull diseased or carrier animals.

16. On-farm monitoring of dairy cow welfare

16.1. Dairy Cow Welfare Assessment Protocols

16.1.1. Aim

This report has presented knowledge and understanding of the scientific principles that determine the welfare of dairy cows. However, knowledge alone is not enough. This knowledge and understanding must be communicated to, and implemented by those who have direct responsibility for care of the animals. It is also necessary to define standards and inform retailers and consumers seeking quality assurance in matters of animal welfare. In order to ensure compliance with welfare standards on individual farms, within farming systems, or within market-led quality assurance schemes, it is necessary to establish effective, robust procedures for assessment, monitoring, and implementation of these standards. The development and animal welfare implications of existing Farm Assurance schemes have been reviewed by the UK Farm Animal Welfare Council (FAWC, 1993). Existing assurance schemes for dairy farms that give major emphasis to welfare include national dairy farm assurance schemes, the “Freedom Food” scheme operated by the Royal Society for the Protection of Animals (RSPCA) and Organic Standards. Codes outline the essentials of good

husbandry, i.e. stockmanship, health care, accommodation, provision of food and water, and management specific to the needs of different classes and ages of animal. The elements of stockmanship are set out in detail, including the creation of a written health and welfare plan, acquisition of handling and husbandry skills (e.g. castration, tooth clipping), and the ability to recognise early signs of ill health. Protocols are based on audit of the provision of resources to the animals and records of management procedures, such as the provision of health care. None of the current Quality Assurance (QA) schemes for farm animals incorporates a significant element of animal-based welfare assessment. The view widely shared among the scientific community that these observations and records of the provisions necessary to establish good husbandry, should be augmented, and in many cases replaced by animal-based measures, that provide a more direct assessment of animal welfare (Calamari et al. 2004, Waiblinger et al 2001a, Webster et al 2006). The European Commission, through FP6, has funded a major integrated programme “Integration of animal welfare in the food quality chain: from public concern to improved welfare and transparent quality” (acronym Welfare Quality[®], Botreau et al. 2007). Two of the main subprojects in this programme are directly concerned with the development and implementation of animal-based procedures for monitoring and control of on-farm welfare, namely:

- To develop robust on-farm welfare monitoring and information systems for selected farm animal species;
- To implement welfare monitoring and information system and the welfare improvement strategies developed.

There are many problems with outcome based measures as they require a level of technical skill that many auditors may not have. Also behavioural measures of welfare require observations of animals over long periods of time, which is often not possible during a brief inspection. The result is that behavioural measures may be either dropped or measured on an inadequate time sample. The time frame of a farm visit also leads to the use of prevalence measures (which are not good for mortality or infrequent, short lasting illness) or reliance on farmers records (which may be faulty) to obtain an estimate of incidence. Good outcome measures are available for some welfare hazards (i.e. measures of lameness may show problems with stall design, flooring or periparturient management) but there are not good practical outcome measures for other welfare hazards (i.e. the pain of dehorning without pain control).

16.1.2. Protocols based on assessment of resources and management

Currently the protocols monitoring welfare within QA schemes are based almost entirely on measures of husbandry (resources and records). This approach has practical merits. The information can be collected in objective fashion, free of observer bias. Moreover it addresses directly the aim of QA schemes. It recognises that no farmer can achieve ideal welfare in all the animals all the time and concentrates on what the farmer does, or could do to promote welfare in his animals. However the effectiveness of these approaches can only be established on the basis of reliable methods to assess animal welfare state. Animal-based audits on animal welfare in dairy herds (Whay et al. 2003b) are presented in more detail in the following section (16.1.3). These animal-based audits revealed no significant overall differences in cow welfare between dairy farms operating to the allegedly higher welfare standards of Freedom Food (Main et al., 2003) and the Soil Association (Huxley et al., 2006) and those registered within the more universal standards laid down by the Assured Dairy Farms scheme. This fact

can be interpreted in two ways. Either the welfare standards do not lead to an overall improvement of welfare or the outcome based measures do not measure the full range of welfare problems that were addressed by the standards. This failure to provide evidence to confirm claims of higher welfare clearly highlights the need to develop direct animal-based protocols to monitor animal welfare on farm and ensure that the welfare assessment procedures lead to an effective strategy for action.

16.1.3. On-farm monitoring protocols based on direct animal-based measures

Good assessment procedures for incorporation into on-farm monitoring protocols are based on scientifically proven measures of animal welfare and should be robust, quantifiable and sufficiently objective to minimise between-observer variation. Moreover, for practical purposes each set of measurements will need to be accomplished within a day or less. This may place major limits on the value of the outcome based measures and on their ability to replace resource based measures. The outcome based measures may shift the attention to the most easily measured welfare problems, which may not be the most serious one. This inevitably requires a degree of compromise between the scientific need to achieve the closest approximation to the truth and the practicalities of making observations on farm without causing undue disturbance to the animals and the operation. Protocols based on animal-based measures taken by an independent observer on a single day also raise the concern that they may be no more than snap shots which fail to reflect the long-term picture. However this can be offset by selecting animal-based measures that integrate long-term consequences of past husbandry.

In the protocol developed by Whay et al. (2003b) welfare was assessed within 6 categories, nutrition, reproduction, disease, external appearance, environmental injuries and behaviour. Nutritional state was obtained from observations of body condition (thin or fat cows), state of the rumen, milk fever (periparturient hypocalcaemia) and other production-related diseases. The prevalence of lameness (%) was assessed by observing the locomotion score of all cows as they left the milking parlour. The results for the 53 farms in this study are summarised in Table 15 and presented and arranged into five quintiles from A (best) to E (worst) so that 20% of herds are within each banding. The allocation of a farm to a particular band is specific to each observation. Table 15 shows, for example, that the prevalence of thin cows was 0-6% in the best 20% of herds, 33-61% in the worst 20%. The prevalence of lameness was 0-14% in the best 20%, 30-50% in the worst 50%. Farms did not perform consistently well or badly. Most were good at some aspects, poor at others.

A panel of 50 experts was asked to indicate the Score Category at which intervention was necessary to remedy a welfare problem apparent at herd level. The threshold for intervention was taken as that recommended by 75%. In the case of thin cows, intervention was necessary for farms in Bands D and E, (i.e. when prevalence was >21%). For mastitis, intervention was recommended at an annual incidence above 20% (Bands C-E). For lameness, intervention was recommended when prevalence was greater than 15% (Bands B-E): i.e. 75% of competent judges considered that lameness was a welfare problem that required attention in 80% of the recorded herds.

Table 15 Results profile for indices of welfare on 53 Dairy Farms arranged in quintiles from A (best) –E (worst) (from Whay et al. 2003)

Measure	Type	A	B	C	D	E
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Nutrition						
Thin cows (CS<2%)	Obs.	0-6	6.3-11	13-21	22-31	33-61
Fat cows (CS>3.5%)	Obs.	0	0	0	1-5	5-28
Bloated rumen (%)	Obs.	0	3-6	7-17	18-24	25-47
Hollow rumen (%)	Obs.	0-6	7-14	14-20	21-31	32-82
Milk fever (&/y)	Est.	0	0	0	1	1-31
Metabolic disease ¹ (%/y)	Est.	0-3	3-4	5-7	7-9	10-19
Reproduction						
Conception to 1st service (%)	Est.	80-68	66-60	59-56	55-49	47-28
Assisted calving (%/y)	Est.	0	0	1	1-5	5-40
Disease		0				
Mastitis (%/y)	Rec.	0-9	11-21	21-34	41-46	47-120
Mastitis (%/y)	Est.	3-13	15-19	20-33	33-47	47-89
Lameness prevalence (%)	Obs.	0-14	14-18	19-23	24-30	30-50
Lameness incidence (%/y)	Rec.	0	0	2-4	4-11	11-42
Lameness prevalence (%/y)	Est.	3-9	9-14	15-21	21-34	35-54
Claw overgrowth (%)	Obs.	0-12	12-25	27-34	35-46	46-76
External appearance						
Dirty hind limbs (%)	Obs.	65-85	90-96	97-100	100	100
Dirty udder (%)	Obs.	0-8	10-18	18-23	24-33	36-70
Dirty flanks (%)	Obs.	0	2-7	8-11	14-23	26-78
Hair loss (%)	Obs.	0	4-7	8-13	15-31	33-88
Environmental injury						
Hock hair loss (%)	Obs.	0-8	10-22	22-45	47-71	74-92
Swollen hock (%)	Obs.	0-11	11-28	29-36	37-68	70-97
Ulcerated hock (%)	Obs.	0	3-4	5-12	12-25	29-50
Non-hock injuries (%)	Obs.	6-43	46-59	59-66	67-79	80-100
Behaviour						
Average flight distance ² (m)	Obs.	0.6-1.1	1.2-1.5	1.5-1.7	1.7-1.9	2.1-3.4
'Idle' cows ³ (%)	Obs.	0-2.6	2.8-3.7	4.7-5.1	5.6-8.3	8.5-25
Rising restriction ⁴ (%)	Obs.	0-10	12-20	30	33-40	50-78

The approach of Botreau et al (2007) (Table 16) is based on four principles, good feeding, good housing, good health and appropriate behaviour, and defined by 12 criteria. For example, "good housing" is defined by the criteria of comfort around resting, thermal comfort and ease of movement. The specific observations and measurements necessary to establish these criteria are still being tested for accuracy, robustness (i.e. insignificant variation between trained observers) and practicality in relation to its implementation on farm.

Table 16 Welfare principles and criteria proposed for animal-based assessment by the FP6 Welfare Quality programme.

Welfare principles	Welfare criteria
Good feeding	Absence of prolonged hunger
	Absence of prolonged thirst
Good housing	Comfort around resting
	Thermal comfort
	Ease of movement
Good health	Absence of injuries
	Absence of disease
	Absence of pain induced by management procedures
Appropriate behaviour	Expression of social behaviours
	Expression of other behaviours
	Good human-animal relationship
	Absence of general fear

16.1.4. Implementation of welfare assessment protocols and improvement procedures

The success of any protocol for the assessment and monitoring of farm animal welfare can only be defined in terms of a demonstrably beneficial impact on the welfare of the animals. For this to occur, Webster (2009) suggested a need for a monitoring procedure to identify both welfare hazards and outcomes, free from observer bias and to be completed within 2-3 hours. Action can follow the identification of hazards and welfare problems and dairy farmers can receive financial recognition or reward for improvements to welfare, through increased income or security of contract.

In addressing these problems, Webster (2009) has proposed the concept of the “Virtuous Bicycle” (Figure 13); a policy that seeks both to improve welfare on farm and to provide assurance of welfare to retailers and consumers through the simultaneous operation of two virtuous cycles of assessment, action and review. The Producer cycle starts with a structured self-assessment carried out by the farmer that is largely based on elements of husbandry (resources and management). This self-assessment is followed by an independent animal-base monitoring procedure, as described in section 16.1.3. The monitor will provide an overall assessment of on-farm welfare and (possibly) identify specific areas where improvements are desirable or necessary to ensure compliance with the QA scheme. This creates a prioritised plan of action for the farmer, possibly in association with his veterinarian. After an appropriate interval (e.g. one year), there is a further review of welfare in general and the effectiveness of specific prioritised actions. This should, once again be based first on self-assessment, then independent monitoring. The aim is to create a dynamic cycle of continuous improvement. The merits of this approach are many. Initial self-assessment by the farmer saves time, and can reflect the fact the farmer knows most (if not best) about his farm. While the first independent assessment may be comprehensive, subsequent assessments can concentrate on the most important issues. Moreover in this system, failure to meet compliance with the standards of the QA scheme would normally not be based on the results of any one assessment but on failure to take effective action where problems had been identified.

The other wheel of the “virtuous bicycle” is designed to improve the communication of steps taken to improve animal welfare into the public domain, though information transfer to the public and retailers who claim high standards of animal welfare as part their claim to added value. The procedure would again be dynamic, first assurance based on evidence of attention to improved welfare standards, then promotion, then review to assess impact and possible steps towards further improvement.

These issues have also been addressed by Botreau et al (2007) (Fig 14). The 12 preference dimensions given value judgments are to be derived from ca. 30 specific, proven robust measures of physical and mental state. Information at this level of integration will be used as the basis for focused plans of action designed to address specific welfare problems. For the purpose of communicating information to consumers, it is proposed that farms will be ranked on a four-point scale: unclassified, basal, good and excellent. For most purposes, this would define the welfare status of the farm, or the system; in this case the dairy unit. Retailers and concerned consumers seeking a greater understanding of the basis for this overall ranking would have access to rankings given for the four independent dimensions of welfare, good feeding, good housing, good health and appropriate behaviour. This approach shows great promise, but unresolved issues remain, e.g. the appeal (or lack of appeal) to farmers, retailers and consumers of a ranking system defined as “unclassified, basal, good and excellent” and the criteria necessary to benchmark farms within these four categories.

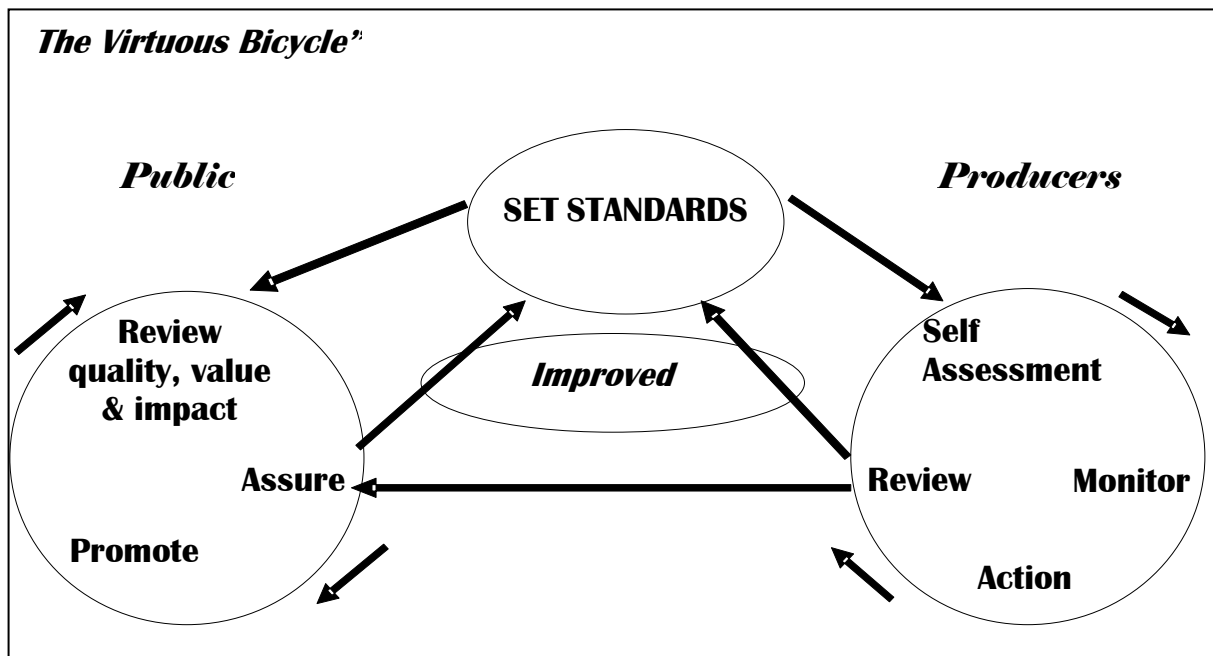


Figure 13 The characterisation of measures and criteria used for the basis of on-farm monitoring of animal welfare and possible routes for the integration of these measures for conveying information to farmers and consumers (Botreau et al 2007).

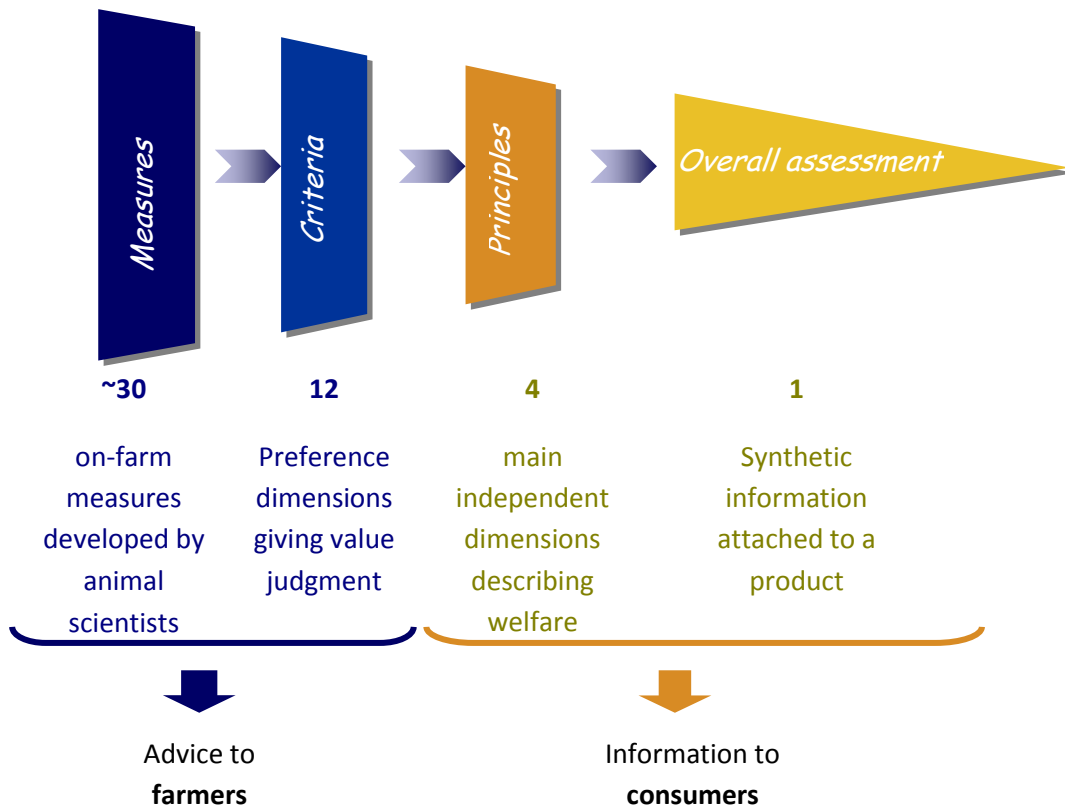


Figure 14 The characterisation of measures and criteria used for the basis of on-farm monitoring of animal welfare and possible routes for the integration of these measures for conveying information to farmers and consumers.

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GLOSSARY / ABBREVIATIONS

Agonistic behaviour

A form of social interaction that is associated with aggression, including threatening and submissive behaviour.

Anaesthesia

Loss of feeling or sensation produced by an agent. In cattle, local or regional anaesthesia, blocking peripheral conduction of sensation is far more common than general anaesthesia.

Analgesia

Relief of pain without loss of consciousness; absence of pain or noxious stimulation.

Calf

A calf is a young bovine which is not reproductively active. There is a gradual transition from a newborn animal, dependent on milk, to an animal with many adult characteristics. In this report, calf is used for animals of up to 8 months.

Claw

One of the two digits of a cow's foot.

Cope

Have control of mental and bodily stability or maintain control of mental and bodily stability in the face of a challenge. This control may be short-lived or prolonged. Failure to be in control of mental and bodily stability leads to reduced fitness.

Cubicle

A place for a single cow to stand or lie, which is separated from other cubicles by walls or dividers. The cows are not tied in the cubicle and can enter and leave at will. Such cubicles or stalls are usually in a building that includes many such places, each with access to a passage and areas for walking, feeding, dunging and social interaction (a cubicle house or free-stall barn).

Drylots

Loose housing in outdoor, open or sheltered corral, normally with an earth floor and feed bunk.

Dystocia

Difficult parturition to the point of needing human intervention.

Exploration

Any activity carried out by an individual in order to acquire new information about its environment or about itself.

Foraging

Behaviour of animals moving around in such a way that they are likely to encounter and acquire food.

Free-Stall

See cubicles.

Grooming

The cleaning of the body surface or rearrangement of pelage by licking, nibbling, picking, rubbing, scratching or application of aqueous liquids. Grooming may be performed by the animal itself (auto-grooming) or by a social companion (allogrooming).

Heifer

A young cow from 8 months until her first parturition.

Hierarchy

An ordered sequence of individuals or groups of individuals in a social system which is based upon some ability or characteristic, most often to act aggressively towards or displace group members or to have priority of access to some resource.

Hock

The ankle joint and tarsus of a cow.

Multiparous cow

A cow from the end of her first lactation onwards.

Need

A requirement, which is part of the basic biology of an animal, to obtain a particular resource or to respond to a particular environmental or bodily stimulus.

Nurse

The process by which a mother mammal allows a young animal to obtain milk from its teats.

Pasture

Field for grazing.

Peri-natal mortality (PM)

Death of calves at birth or during the first 24 hours after delivery.

Robustness

The extent of the possibility for a population of animals to have the capacity in its gene pool to deal with a wide range of circumstances.

Slatted Floor

A combination of solid parts (slats), which would support the lower surface of the claw of the cow, and gaps (slots) which would allow manure and other liquids to pass through. (Also called slotted floor.)

Solid floor

A continuous flat surface which might be made of various materials and which allows full contact with and support to the lower surface of the claw of the cow.

Somatic Cell Count (SCC)

Number of cells per unit of milk (usually ml). Since the majority of cells are leucocytes, milk SCC is now a standard indicator of udder infection. A level over 100,000 cells/ml is often considered as a sign of mastitis. The usual measures are the individual cell count and the bulk milk cell count.

Space allowance

The area of animal accommodation per animal or per unit of weight of animals. In some studies the term space allowance also takes account of the volume of the building.

Space allowance at feeder

The length of feeding space per animal or per unit of weight of animals.

Stanchion-Barn

A building containing tie stalls.

Stereotypy

A frequently-repeated, relatively invariable sequence of movements which has no obvious function.

Still-birth

Delivery of a fully formed dead neonate.

Stocking density

See space allowance.

Straw yards

A building housing cows with a strawed lying area and usually with unstrawed feeding and dunging areas.

Stress

An environmental effect on an individual that over-taxes its control systems and reduces its fitness or has the potential to do so.

Suckle

The process by which a young mammal obtains milk from the teat of its mother or another lactating female by sucking.

Thermoneutral zone

The temperature range within which metabolic heat production and energy expenditure are minimal, most productive processes are at their most efficient level and an animal is thermally comfortable without the need to change heat production. The zone is limited by the lower critical temperature (LCT) and the upper critical temperature (UCT); above and below there are energy costs of thermoregulation.

Tie-Stall

A lying and standing place in which a single cow is tethered to a stanchion.

Weaning, weaned

In mammals, weaning is a gradual process during which the young animal receives less and less milk from its dam and consumes more and more solid food. It is accompanied by changes in the dam-offspring relation. In dairy farming, calves are often separated from their dams soon after birth and receive milk (or milk replacer) from humans or a machine. Although separated from the dam, calves are considered as un-weaned as long as they are fed milk and the term weaning is used to refer to the process of removing milk from the calf's diet.

Zero-grazing

Feeding cattle with pasture plants or other food in a system that does not involve any time at pasture.

Abbreviations

BVDV: Bovine Virus Diarrhoea Virus

EC European Commission

EFSA European Food Safety Authority

EU European Union

LCT Lower critical temperature

MS Member State

SVC Scientific Veterinary Committee of the European Commission

UCT Upper critical temperature