EIP-AGRI Focus Group
Robust & Resilient Dairy Production Systems

Mini-paper – Indicators for robust and resilient dairy farming -

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1. Introduction

The dairy sector is a valuable part of the economic structure of many countries, both in the EU and globally. Promoting the economic health of the dairying enterprises is in the national interest. However, dairy farms face challenges at many levels. Farm businesses are exposed to fluctuations in the price of milk outputs and costs of inputs such as feed and labour. Dairy cows are exposed to challenges due to health and disease, thermal stress, poor quality housing and management which may lead to reduced productivity and fertility. For dairy farm businesses to remain viable, these challenges must be managed to create a state of economic stability and health and welfare in the cattle. The terms 'robustness' and 'resilience' are often used to describe this state of relative stability and research has been done to investigate the means by which stability can be achieved. In order to determine whether a system is 'robust' or 'resilient', its stability must be measured or assessed. Characteristics of the system that vary with the 'health' or vitality of the system and which can be quantified are often called 'indicators'. The aim of this paper is to determine whether we have the appropriate indicators available to allow the robustness and resilience of cows and farms to be measured. Definitions of robustness and resilience will be discussed firstly, followed by a discussion of the indicators available.

1.1. Definitions of robustness and resilience

The concept of robustness has been used in a variety of fields. In systems biology, it has been defined as the ability of a system to remain functional despite unpredictable internal or external perturbations. Therefore, robustness does not mean that a system does not change in some way (or is resistant to change), but that it maintains specific functionalities, if needed, by changing its operation in a flexible way (Kitano, 2004). In agronomy, robustness has been defined as the ability to minimize the variability of production or product quality, and it is closely linked with the idea of stability (de Goede et al., 2013). In animal production, robustness has been defined as the ability to express a high production potential combined with resilience to stressors in a wide variety of environmental conditions. In relation to dairy cattle, Ollion (2015) defined robustness as the ability of dairy cows to maintain their performance and their survival in a changing environment. It is therefore a determinant of economic competitiveness, resilience and animal welfare, which are key priorities in dairy cattle production.

Resilience can be defined as the ability of an animal to adapt to stress or to an imbalance in its homeostasis. The magnitude of resilience is determined by the time, the duration and the severity of the disturbances in homeostasis. This can be quantified by measuring variation in the adaptive response whether or not in combination with challenging experimental intervention and the speed of recovery. This offers the opportunity to remedy unfavourable circumstances to prevent animals of becoming ill, as well as insight into the magnitude of effect that certain herd-, farm- or environmental related factors have on production animals.

Resilience applies to individual animals but also to higher organisational levels such as at the farm or system level. In the latter, resilience is the capacity of the system to cope with disturbances, and at the same time maintain its functions. More resilient systems are able to absorb larger disturbances without changing in fundamental ways. Resilient systems are able to adapt, to renew, to self-organize and to learn from change and disturbance. When resilience is lost, vulnerability increases, and the system is no longer able to exert its functions when disturbances occur (Cuijpers et al., 2013).

1.2. The assessment of robustness and resilience – response to challenge over time

Present in all of the definitions of robustness and resilience discussed above, there is the concept that the animal, farm or system has the ability to withstand or 'bounce back' from challenges or stressors. Robustness implies that the animal maintains functionality when a stressor is applied, whilst resilience suggests that the animal responds, but then returns rapidly to the 'normal' state. The ability to observe and compare may be possible for ‘acute’ or ‘short-term’ stressors/challenges. Longer term challenges may require a longer term approach. This implies that to determine the degree of robustness or resilience we must observe the animal or system before, during and after a period of challenge, to allow us to see the 'baseline' or starting values, the response to the stressor and also the quality of the response. This would allow assessing the magnitude and the duration of the response. For instance, assessing the resilience of a cow to heat stress implies the observation of the cow in mild temperatures, exposure to a heat wave and the ability to return to the baseline levels. In the same situation, we would assess robustness by examining the physiological and behavioural mechanisms and regulatory pathways that are involved in the response, and how they responded to the stressor.

As an example, we could consider resilience in cow foot health. We can use a score to assess lameness in cows on two farms. Farm ‘A’ has very good conditions that might maintain good foot health (e.g. regular foot-bathing, good flooring, good cleanliness) and Farm 'B' has poor conditions (no foot-care, cracked concrete, not cleaned). On Farm 'A', the cows mostly have good feet and low lameness scores. Can we say that they are robust in terms of lameness? Strictly speaking, we cannot, because we have not seen them challenged. On Farm 'B', we see cows that are lame and some that are not lame. Are the lame cows robust? Probably not, as they have not maintained functionality when challenged, but we may need to have observed them in good conditions to be sure. Are the non-lame cows on this farm robust? We might conclude that they do show robustness, because they have maintained functionality in a challenging situation. In order to assess the degree of robustness and resilience in individual animals or systems we need to observe their adaptive response to changes in the environment. These changes can be driven by differences in the environment, between two different assessment points or because there is a change over time in a given location. In both cases, the comparison of the outcome is relative to changes in the environment that can inform on the resilient and robust abilities of individuals or groups.

1.3. Assessing robustness and resilience – are there indicators available?

To identify the ability of an animal to respond and recover from challenge, some parameters are needed that can be measured easily, have been accurately validated, can be objectively assessed, and ideally measured at any time point. Large body of research have identified a number of these parameters on farms, ~~abbatoirs~~ slaughterhouses and other situations where the consumer or market requires that standards can be measured and maintained. The assessment methods developed in this research field include those that assess behaviour, physiology and emotional outputs. In addition to this, there are methods that are used within an experimental context. Bodily adaptations can be measured for example, via a variety of changes in biomarkers and parameters, which reflect the capacity of various organ systems to respond and adapt to stress conditions. Potentially, specific stressors could be applied in research, to which allostatic and homeostatic responses of tested individuals might be measured (Wiegant et al., 2013). The metabolic/physiological/behavioural response could be determined by challenging an individual with some form of stressor and by subsequent quantification and evaluation of the coherence in recovery of various physiological indicators. A set of relevant parameters includes metabolic indicators (Ca, NEFA, Glucose, etc.), immune capacity and the activity of the autonomous nervous system. A good recovery towards homeostasis may reflect good health (Huber et al., 2012). However, these phenotypical indicators are typically used as 'snapshot' measures of functioning, health and welfare, whereas to assess robustness and resilience is multiple measures taken across the time course of a challenge. It is likely that these 'snapshot' measures will also fulfil this function, but this should be tested and validated.

Any indicator that is able to measure the ability to cope with a specific stressor (at individual or group level) could be used as a resilience indicator. However, resilience may not be applicable as a general trait but specific for every stressor. For instance, it is possible that a cow that copes well with heat as an stressor may not manage so well with certain diseases, as resilience [j1]to independent traits are not necessarily related one each other. Therefore, it remains unclear whether resilience can be used as general trait in the sense that cows, or systems, are not more or less resilient but this has to be assessed in each particular trait. However, robustness may provide information about the individual or the system that facilitates comparisons. To understand this we should refer to the definition of robustness in dairy cattle, which is the capacity to cope with a persistent exposure[j2] to a challenging environment with production and animal welfare implications. Considering this, robustness should be measured as a trait affecting either the whole animal or system and it makes comparisons between individuals or systems more plausible than resilience as what is measured is the outcome rather than the relative response. Measures able to assess general state of animal welfare as well as performance measures (i.e. milk production in dairy cattle) may be good measures of robustness of a given animal, farm or system.

In the section below, we will discuss the measures that are currently available for assessing health and welfare of animals and consider their usefulness in assessing robustness and resilience.

2. Phenotyping Robustness

Challenges to animals and systems are of different types, and vary in length and in type. A challenge such as heat stress is typically of shorter duration than of poor housing that might last the lifetime of a cow. Therefore, robustness and resilience will have to be adapted to the type of robustness or resilience that is addressed. We have identified four different groups of variables according to the type of challenge: environmental, production, health and comfort and interaction human-animals. Each group includes several indicators that can provide information about the phenotypical response during each challenge. The table below enumerates all the indicators and their characteristics are discussed including individual vs. group level, continuity of measures and the main advantages and disadvantages.

1.1. Production challenges

The robustness functional longevity of a dairy cow in a given production system depends largely on the right tuning of resource allocation towards milk production, body reserves (ie, BCS and/or BW), and reproductive function.

1.1.1. Body Condition Score / Body Weight

The ability to coordinate lactation, intensity of lipomobilization, intake and metabolic health during early lactation, and replenishment of body reserves in late lactation, are major determinants of dairy cattle robustness and functional longevity. Periparturient dairy cows may experience intense mobilization of body reserves, negative energy balance and metabolic diseases such as ketosis. Therefore, management of lipomobilization in periparturient cows has been a major concern for the dairy industry. Continuous monitoring of variations of **body weight** and **body condition score** have been proposed to assess profiles of energy balance and body reserve utilization (Thorup et al., 2013), and to phenotype robustness in large field studies (Berry et al., 2013). The responses (production and physiological) to nutritional challenges, whether spontaneous during early lactation or experimentally induced, have been proposed as proxies to apprehend individual robustness (Gross et al., 2011, Friggens et al., 2016). In fact, intensity of body reserve mobilization and resulting degree of metabolic imbalance vary widely within a given breed in both dairy cows and goats, but the degree of deviation from the "normal" is repeatable for a given animal under physiological (early lactation) and nutritional challenge (nutrient restriction), and depends on individual adaptive capacity ~~(or robustness)~~ (Gross et al., 2011, Bjerre-Harpoth et al., 2014, Friggens et al., 2016). Similar to BCS the body weight can provide information about the nutritional status of individual cows ~~but is also a retrospective value~~. Many factors can influence the body weight what makes it difficult to use it as an indicator for robustness. Nevertheless, losses in body weight can be a sign of metabolic imbalances or welfare problems.

~~(Longer-term approaches of robustness for a breed or strain include the ability to replenish BCS in late lactation, the reproduction outcomes, especially in grass-based production systems with strict seasonal breeding, the cumulated lifetime production . there are good examples from Ireland, NZ and French studies.) link with *Genotype effects and genotype by system interactions.*~~

1.1.2. Pasma minerals and metabolites

Individual plasma mineral and metabolite profiles are commonly used to assess cow adaptation to nutrition and other environmental factors, and for on-farm troubleshooting. Plasma concentration thresholds associated with disease, reproduction outcomes and culling have been proposed, mostly for North-American and European conventional systems. Monitoring of milk composition (milk fat, protein, fatty acids and other components) and mid-infrared spectra may become alternatives for robustness assessment[jp3].

~~*1.1.2. Plasma minerals*~~

~~Individual thresholds for plasma Ca, BHBA, NEFA, and acceptable prevalence in farm troubleshooting. To be developed~~

1.1.3. Milk composition

The occurrence of perceptible changes in BCS is delayed relatively to the metabolic imbalance; therefore, BCS variations provide only a retrospective of physiological status and nutrient partitioning (Chagas et al., 2009, Pires et al., 2015). This time lag highlights the need for easily measurable biomarkers of metabolic status/imbalance during early lactation and under varying husbandry conditions. For instance, when cows are confronted with environmental challenges (variability feed quality or scarcity, thermal stress). Individual real time approaches, via inline measurement of milk biomarkers of ketosis, mastitis and ovarian cyclicity are available commercially. Milk composition analyzed through infrared spectrometry has been proposed to assess negative energy balance and ketosis in early lactation cows (Grelet et al, 2016). ~~Similar to BCS the body weight can provide information about the nutritional status of individual cows but is also a retrospective value. Many factors can influence the body weight what makes it difficult to use it as an indicator for robustness. Nevertheless, losses in body weight can be a sign of metabolic imbalances or welfare problems.~~

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1.1.4. Milk productivity

Dairy breeds differ in their prioritization of milk production and body reserve use, with repercussions on reproduction performance and longevity under Irish grass-based conditions (Dillon et al., 2003a; Dillon et al., 2003b). The progress of dairy potential of NZ Holstein strain and introduction of North-American genetics led to chronic **low BCS**, and impacted reproduction and longevity[jp4] (Chagas et al, 2007) ~~(refs to choose from)~~.

1.1.5. Reproductive performance

The apparent negative relationship between milk yield and reproductive performance (Butler and Smith, 1989) has been extensively explored/debated. The effects are thought to be mediated (at least in part) via altered physiological and metabolic milieu, and consequence of negative energy balance and mobilization of body reserves to sustain the early lactation (Britt, 1991). In fact, reproductive performance is negatively correlated with BCS loss during early lactation, and may be independent of genetic merit for milk yield (Santos et al., 2009, Carvalho et al., 2014).

Strict seasonal calving grass-based systems are particularly sensitive to reproductive failure because peak of lactation needs to be synchronized with grass growth each year. As example, research accessing the adaptability of different breeds, and/or different Holstein strains to these systems consistently show that excessive reliance on body reserve utilization to sustain a high peak of lactation (translated in BCS and BW loss in early lactation), are associated with reproductive failure and impacted functional longevity (Dillon et al., 2003a, Dillon et al., 2003b, Macdonald et al., 2008, Piccand et al., 2013). Furthermore, a recent retrospective study shows that robustness variability

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occurs even within a highly selected dairy breed in conventional systems: the degree of BW loss in early lactation varies across cows, high and low responders are consistent from one lactation to the next, reproductive performance is impacted in cows losing more BW (Zachut and Moallem, 2017).

1.2. Environmental challenges

1.2.1. Body temperature (P)

1.2.2. Thermal imaging (MH)

Infrared thermography (IRT) assesses reflected radiation and uses this to calculate temperature and produces a pictorial representation of the surface temperature of the object or area, with temperature gradients represented by arrays of colour. The body surface temperature of animals reflects the blood flow and metabolic rate of the underlying tissues, and thus IRT can be used to detect blood flow differentials due to infections and inflammation (Eddy et al, 2001). Thermal images can be taken at a distance from the subject, so are a useful non-invasive way to assess blood flow (Stewart et al., 2005). Infrared thermography has been used in a number of contexts to assess disease. For instance, it has been used to detect foot conditions associated with lameness in cattle and horses (Turner, 1998; Eddy et al., 2001; Alsaaod and Buscher, 2012) and changes in udder temperature associated with mastitis in dairy cows (Berry et al., 2003). Detection of systemic infection may be detected by assessing the temperature of areas of the body where blood vessels are near the surface, such as at the inner corner of the eye or inside the ear. However, ambient temperatures will affect the read-out, so careful use is required. There is also increasing evidence that the emotional state of the animal can be assessed using thermal imaging. Nasal temperatures of cows have been shown to rise during negative emotional states and rise during positive states (macaques: Kuraoka and Nakamura, 2011; cows: Proctor and Carder, 2015). This is very recent work and requires full validation in the context of commercial dairy farms.
Little has been done to assess the use of thermal imaging as part of a welfare assessment protocol, but it has great potential. In terms of assessing robustness and resilience, it had not be validated as tool to assess welfare over the timespan of a welfare challenge.

1.2.3. Respiration rate / heat stress (GH)

Although effects such as decreased rumination time, dry matter intake, milk yield and fertility are indicative of heat stress, dairy cows show these signs relatively late. Based on these attributes, it is impossible to achieve immediate control for thermal adaptation and prevent a negative impact on the productivity of cows (Kadzere et al., 2002, Costa et al., 2015b). In contrast, physiological parameters such as heart rate, body temperature, and respiration rate (RR) have been demonstrated as adequate and timely indicators of heat stress in dairy cows (Kadzere et al., 2002, Moallem et al., 2010, Costa et al., 2015a). Among other major physiological parameters consulted in the literature, RR has long been used as a heat stress indicator (Gaughan et al., 2000). RR is considered as a well suited cow parameter for heat stress monitoring, as it is applicable in different weather conditions and because it is easy to monitor without costly equipment (Brown-Brandl et

al., 2005). But on the other hand, to date it is not possible to maesure the RR automatically.
By measuring the temperature humidity-index (THI) it is possible to estimate the thermal stress for the group of cows. But the reactions to an increasing THI can be very individual and should be noted. This variability in the individual reactions of dairy cows is a challenge in identifying an accurate and universally applicable heat stress threshold and heat stress prediction. Kadzere et al. (2002), for example, discussed that high-producing cows are more affected by elevated temperatures than low-producing cows under heat stress because the metabolizable energy used for milk production results in an increased body temperature.

1.3. Health and comfort challenges

1.3.1. Disease prevalence

The number of animals suffering from infectious, parasitic or metabolic diseases is a robust indicator of the cow's health status. Epidemiology has been a critical new influence and tool to describe and quantify the interconnected risk factors that produce disease.
A high prevalence of diseases can be due to two main factors. One is the degree of exposure to certain pathiogen (in the case of infectious or parasitic diseases). For instance, the more presence of a given pathogen in the near environment of cows, the more likely to be infected. There is a second reason why animals can show greater disease prevalence, which is the reduction in immunocompetence. In this case, the decreased ability of animals to protect against pathogens makes them more vulnerable and therefore more exposed to disease. Reduced immunity can be provoked in situations where animals are challenged and the stress response is activated. In summary, changes in disease prevalence over time both at an individual or group level can reflect the degree of stress evoked by a challenging situation, which may differ according to the animal abilities to combat a challenge.

1.3.2. Antibiotic use (C)

The use of antibiotics in farm animals gives insight in the disturbances in health due to bacterial infections. These disturbances are a result of disbalance between the bacterial load and the ability of the animal to cope with such infections. Bacterial infections occur at individual, herd and farm level. Use of antibiotics can be measured at all three levels. The use of antibiotics on farm level can be expressed as the number of daily dosages per animal year taken into account the use in grams of active ingredients per animal year. The differentiation in active ingredients gives insight in the most common problems on a farm due to bacterial infections. Yearly monitoring gives insight in the development of the problems. Antibiotic use per animal can be used as a selection criteria to cull cows.

1.3.3. Milk yield (C)

The milk yield of a cow or herd differs between sample moments. Management is one of the most influential factors. For instance, feed quantity and quality, but also milking technique can cause fluctuations in the milk yield. Also animal related factors as age, calving season and days in lactation have an effect on milk yield. In order to evaluate the production performance of a cow or herd, and the influence management factors have on it, it's necessary that animal related factors are excluded. The 'Farm Standard Cow' (FSC) is such a parameter. The standard daily milk production of a cow is multiplied by a correction factor, thereby correcting for the effect of age, calving season and days in lactation. Herewith the production levels at different sample times can be compared and present fluctuations identified. If cows negatively deviate from their calculated standard production, than this cow has problems adapting to a change in her management or environment, for instance a change in feed, pasture management, milking technique or climate. Or disease is present or parasitic load has reached a certain level. Research at the University of Minnesota has shown that statistical process control analysis of daily milk yield alone detected the onset of disease up to 8 to 10 days prior to the clinical disease (Reneau, 2013). Once a negative deviation has been identified, the farmer should identify what could have caused it. This requires craftsmanship. Adaptation to changing situations is well if these changes don't affect or positively affect production performance. Bottleneck of this parameter could be if the FSC is calculated whilst a cow was already suffering from disease or parasites. For instance, infection with liver fluke causes hardly any symptoms, but can have detrimental effects on milk production (Howell et al., 2015). If the FSC is based on an already with liver fluke infected cow this would not be detected. A liver fluke free cow or herd would show a deviation in the FSC after infection.

1.3.4. Lifetime Daily Yield (LDY) as an indicator of performance (C)

Instead of focusing only on milk yield per lactation, it can be beneficial to also think in terms of volume of milk given over a cow's lifetime. Lifetime daily yield (LDY) i.e. yield per day from birth to culling, can be used as an overall indicator of technical performance at the farm, as it averages out total milk production over every day a cow has been alive. Cows that start milking at a young age, have a short calving interval and are healthy enough to last several lactations, will have a much higher LDY than those who are older at first calving, do not get back in calf very quickly and have poor longevity. A high yielding cow that doesn't make it to the third lactation because of poor health or fertility will have a lower LDY than a cow that reaches fifth lactation but with a lower average yield per day.

The four things to take into account when calculating lifetime daily yield are milk yield, age at first calving, calving interval/lactation length, and involuntary cullings/number of lactations. Gathering this information will draw attention to problem areas, and might over time help to change the mentality of only focusing on yield per lactation.

LDY is not an indicator of profitability, as the farmer milking his cows for many lactations may be spending a fortune on vet bills, but it is a very good indicator of performance. And it puts the cow's health and fertility in the centre.

http://www.milkproduction.com/Global/PDFs/Cow%20Longevity%20Conference%20Proceedings%20.pdf

1.3.5. Average herd age (C)

The higher the average age, the better the resistance of the animals and the less wear among the animals. The animals can thus properly adapt to their husbandry system and farm environment. However, average age should not be seen alone. Average age only tells something about the farm or about the adaptability of a herd if it comes along with a high lifetime daily yield, low antibiotic daily dosages and low feed costs per kilogram of milk produced.

1.3.6. Involuntary culling (P)

Involuntary culling is when a cow leaves the herd for reasons that are not of the farmer's choice like for example reproductive problems whereas at voluntary culling, a farmer chooses to sell a cow to obtain the cow's beef value. Voluntary culling can have different reasons such as age, low milk production and/or to maintain a herd size, but all aiming at maximizing returns. However, involuntary culling is a cost to the farmer. One of the factors attributed to involuntary culling is the deterioration of fertility in dairy cows which is a negative correlated response to selection for higher milk (Lãvendahl & Chagunda, 2006). The major reported reasons for culling in dairy herds include fertility, lameness and udder health (Chiumia et al., 2013). Therefore, the rate of involuntary culling can provide information on whether cows from a certain herd or group are dealing with the environment or the production system. For instance, a high rate of involuntary culling due to fertility failure, may suggest that cows cannot afford the level of production that is requested.

1.3.7. Cow longevity (C)

High rates of involuntary culling on a dairy farm because of illness or reproductive problems occur because of poor cow welfare and reduce the profitability and sustainability of dairy farms. Removing the main causes of involuntary culling will lead to improved animal welfare, improved longevity of cows and improved farm profits. Calf illness and mortality are contributors to reduced longevity or a low average herd age. Poor calf management also has a negative impact on the cow's later productivity. Lameness, injury and illness in dairy cattle, mainly resulting from poor indoor housing conditions, have also been identified as contributors to involuntary culling rates. However, there are producers with low involuntary culling rates, which shows us that there are housing and management practices that improve the cow's well-being and control the prevalence of the underlying health problems.
http://www.milkproduction.com/Global/PDFs/Cow%20Longevity%20Conference%20Proceedings%20.pdf

1.3.8. Circadian rhythms in behaviour (MH)

Animals show movement or locomotion in characteristic daily patterns, organised by the circadian (light/dark) cycle, but for dairy cows also by events such as the delivery of food and milking. It has been suggested that in free-ranging animals, the degree to which the individual's daily activity pattern shows synchronisation between the internal rhythms and external 24-h photoperiod. If we consider that activity is the ultimate external expression of the internal rhythms in the motivation to feed, rest, drink etc., then activity

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can be used as an overall indicator of the internal state. Studies in a range of species has shown that a lack of synchronisation is shown in animals that are disturbed or unhealthy (e.g. Scheibe et al., 2010; Berger et al., 2011). This level of synchronisation can only be assessed when activity can be measured over a number of days. Using technology such as pedometers or GPS devices allow this data to be collected. For dairy cattle, the availability and use of accelerometers in dairy herds to detect oestrus means that the data to assess these measure in activity are readily available.

1.3.9. Changes in feeding, activity and resting behaviour (MH)

As stated in the previous section, the activity patterns of an animal are ultimately the outcome of the internal physiological processes and external influences. In the dairying situation, cows can show quite consistent activity and resting patterns, with periods of activity around feeding and milking. However, research has shown that changes in resting and activity patterns can be used to detect health and welfare issues. Lame cows spend longer lying down (Chapinal et al., 2009; Blackie et al., 2011) than healthy cows. Cows with mastitis also have increased lying times (Kester et al., 2015) compared to healthy cows. Changes in feeding patterns have also been shown to occur when animals are experiencing health issues. Cows with lameness issues show alterations in their feeding patterns many days before the issues is detected by farm staff (Gonzalez et al., 2008) and cows experiencing a difficult calving ate less prior to calving (Proudfoot et al., 2009). Studies have also shown that overstocking and depth of bedding affect lying times (Tucker et al., 2009; Winckler et al., 2015). Although it has not been validated, this type of assessment could be used to compare welfare across farms.
Accelerometers were originally designed to detect oestrus in dairy cows. However, the use of these devices to detect health issues has been recognised (van Nuffel et al., 2015) and currently many companies are developing algorithms to analyse standing and lying patterns to detect health problems such as lameness.

1.3.10. Locomotion scoring (MH)

Changes in locomotion or gait characteristics are often the first detectable signs of foot disease. Visual gait scoring methods have been developed to assess lameness (e.g. Manson and Leaver, 1988; Sprecher et al., 1997; Flower and Weary, 2006). Locomotion scoring is a skill that can be taught to researchers and farmers, and has been widely used. Locomotion or gait scoring has been incorporated into welfare assessment tools such as Welfare Quality® because of its ease of use.

1.4. Economical and social challenges (to be developed)

1.4.1. Feed self sufficiency

1.4.2. Excretions in environment

Conclusion

A large number of parameters exist, particularly for assessing production, health and welfare in dairy cattle at the individual and group level. However, the majority of these indicators have been designed as 'snapshot' indicators for experimental or on-farm welfare assessment use and require validation for use across the longer time-course needed to assess robustness and resilience. We also largely lack indicators that inform on the resilience of systems or relate the robustness and resilience of animals to that of the system.

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