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EDITED BY
Cameron Clark,
The University of Sydney, Australia

REVIEWED BY
Christine Janet Nicol,
Royal Veterinary College (RVC),
United Kingdom

*CORRESPONDENCE
Albert Sundrum
Sundrum@uni-kassel.de

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Why has animal science not led to improved farm animal health and welfare?

Albert Sundrum*

Department of Animal Nutrition and Animal Health, University of Kassel, Witzenhausen, Germany

To sustain the economic viability of a livestock farm in a global market, characterised by a price undercutting competition, farmers are forced to adapt to what the market demands. At the same time, they have to care for the functionality of the farm system as a whole and of the subsystems, such as the farm animals, so that they for their part they can contribute to an economic success. Now, that animal health and welfare (AHW) has become an increasingly important issue for citizens and consumers, not only the decision makers but also the disciplines of animal science are challenged to improve an unsatisfying AHW level that has been neglected for long. However, to reduce AHW problems requires a quite different approach than to increase productive efficiency. A common sense can be assumed concerning the need to strive for an optimal cost-to-benefit ratio while balancing positive and negative impacts of production processes on economic and AHW target figures. However, what is often not adequately considered is the fact that economic and biological demands have to be balanced within a living system, e.g. in the individual animal and farm system. These function as the relevant reference systems in all cases where measures to reduce AHW problems are considered. Furthermore, there is a large gap of scientific knowledge, however, not in the traditional sense. While the predominant approaches, scientists generate context-invariant, and thus generalisable disposal knowledge in diversified subdisciplines, problem solving requires contextualisation, orientation and action-guiding knowledge within transdisciplinary approaches. The reason is that AHW problems are highly context-sensitive as well as multifactorial. They develop within the farm specific interconnectedness of manifold and highly varying factors, emerging a complexity that does not allow predictive statements via inductive approaches but requires an iterative procedure to approach to a farm specific AHW level, which is balanced with the overarching goal of economic viability. Recommended action guiding knowledge has to be of high external and ecological validity, before farmers might consider it to be implemented in farm practice. From the reflection about the discrepancy between the knowledge needed to reduce AHW problems and what is offered by animal science, it is concluded that not only the farm systems but also the predominant approaches of animal science have to be transformed. Otherwise, there is not a big chance to considerably reduce AHW problems in farm animals.

KEYWORDS

animal health and welfare, animal science, costs and benefits, external validation, knowledge transfer, production diseases, system science, transformation

1 Introduction

To survive economically, farm systems have to follow economic principles. In a global food market, competition primarily revolves around cost-efficiency in primary production and in the following agri-food supply chains. The economic framework leaves little scope for actions that are not focused on economic efficiency and hampers all those efforts in farm management from which a financial return appears unlikely. A persistent high level of animal health and welfare (AHW) problems in livestock farms indicates that many farmers fail to provide what farm animals need to be able to cope, and what an increasing portion of citizens and consumers demand (Sundrum, 2020a). With the focus on productive efficiency, negative side effects are often out of scope of perception and thus are not adequately considered with regard to the conflicts of interests and the negative impacts on farm animals, food quality, consumers' expectations or public interests. This can apply even for the negative impacts of AHW problems on the economic viability of the farm system, which can be undermined by substantial financial losses without being adequately realised (Hoischen-Taubner et al., 2021). Thus, AHW problems are not only a threat to the survivability of the farm animals and the economic viability of the farm system, but are also responsible for a decrease in the demand for animal sourced foods (ASF) in many European countries (European Commission, 2021). In the long run, this development poses a threat to the business model of livestock farming. The negative image not only decreases the demand for ASF, but raises questions about the societal support and the continuance of the generous public subsidies. Livestock farms characterised by a very poor AHW level might even lose the social licences for producing ASF (Barkema et al., 2015; Duncan et al., 2018; Hampton et al., 2020).

Animal science has historically accompanied the development of animal production by providing adequate knowledge to foster the intensification processes and to hedge the proliferation of negative side effects; the first with great, the latter only with limited success. While there has been tremendous progress in livestock farming concerning productivity, previous efforts have failed to achieve substantial improvements concerning AHW. As consumers are increasingly concerned about the insufficient AHW level, farmers and animal scientists are challenged to find solutions that correspond with market demands without overly compromising the economic viability of the farm system. To address these partly contradicting demands, farmers must strive for an optimal cost-to-benefit ratio, balancing positive and negative impacts of production processes on economic and AHW target figures. The objective of this paper is to reflect on the weak points and obstacles which stand in the way of solving or reducing AHW problems at the farm level due to tensions created by differing interests. Furthermore, from a scientific perspective, the question arise as to how the various disciplines of animal science might be able to transform livestock systems towards improved AHW and support more balanced decision making.

2 Animal health and welfare

Safeguarding the health and welfare of farm animals and preventing animal diseases serves to protect public health, animal production and rural economies. When considering AHW as a public good (Appleby et al., 2003; Degeling and Johnson, 2015), it cannot be left to the interests of single groups of stakeholders or single scientific disciplines on how to define AHW. Currently, the principal source of an international definition of animal health and welfare for farm animals with a scientific basis is the OIE Terrestrial Animal Health Code, adopted in 2008. It has been ratified by 174 countries and thus can claim to represent the highest level of common sense that so far has been achieved in terms of AHW. It was agreed that "*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*".

Although AHW encompasses a very complex issue, the definition is insofar operationalizable as it refers to the freedom of severe perturbations and diseases as an essential although not sufficient prerequisite. While the presence of severe perturbations and diseases allows a valid statement about poor AHW, their absence does not demonstrate that AHW is good. This is in particular due to the fact that a varying, but on average, high proportion of farm animals are suffering from inapparent disturbances and disorders which only become apparent when making efforts and use of appropriate diagnostic tools. In the case of laying hens, a striking example is the very high prevalence of sternum fractures in laying hens. In a full post mortem investigation, fracture prevalence in the range 53% - 100% was observed in flocks from non-caged systems, whereas the prevalence in flocks from enriched cages ranged between 50% - 98% (Thøfner et al., 2021). In a longitudinal study based on a radiographic evaluation of keel bone damage in laying hens revealed that even 99% of the animals showed at least one keel bone lesion during the study and 97% of the animals had at least one keel bone fracture (Baur et al., 2020).

Another example of generally undetected but nevertheless important health and welfare problem in various species is gastric ulceration. This applies above all for fattening pigs and sows as well as veal calves. In a comprehensive study, over 79% of stomachs of pigs had either an oesophago-gastric ulcer or visible pre-ulcerative changes. The frequency of severe ulceration (Grade 3) was 6%, and mild ulcers (Grades 1 and 2) 73%. In the case of veal calves, the prevalence at slaughter ranged from 70 to 93% (Bus et al., 2019). Other subclinical inflammatory processes often occur in the respiratory tract. For example, cranioventral pulmonary consolidation was the most frequent lung lesion (31%) detected in fattening pigs at the abattoir, followed by dorsocaudal infarcts with pleurisy (12.5%) and pleurisy alone (6.3%) (Pallarés et al., 2021).

When assessing the prevalence of subclinical production disease of dairy cows on organic farms, the prevalence of the assessed indicators varied widely between farms and countries (Krieger et al., 2017). The median prevalence was 51.3% for subclinical mastitis, 10% for risk of ketosis, and 3.2% for risk of acidosis. Furthermore, a more or less large proportion of animals within a herd fail completely in their efforts to adapt to the living conditions and collapse or have to be killed in an emergency slaughter without being recognised in occasional surveys (Compton et al., 2017). These given examples of single scientific surveys are far from providing a comprehensive overview about the occurrence of inapparent disturbances and subclinical diseases in farm animals. They indicate only some of the often disregarded but nevertheless severe AHW problems in farm practice that occur in addition to the obvious behavioural disturbances and clinical diseases, not addressed here. The high prevalence of "hidden" AHW problems together with easily visible disturbances and diseases indicate that AHW problems are not the exception but rather the rule in livestock production.

The focus on the absence of apparent perturbations has been the starting point of scientific welfare concepts. In 1965, the Brambell Committee outlined the five aspects of animal welfare, giving rise to the "five freedoms" framework. These, however, were restricted to freedoms of movement (in response to intensive housing practices) e.g. freedom to turn around, freedom to lie down. It was Webster who took the phrase and developed it into something far broader (Webster, 2013). The concept is globally recognized as the initial concept in farm animal welfare and includes freedom from hunger and thirst, discomfort caused by husbandry, pain, injury and disease, fear and stress, as well as the freedom to act out the species behavioural patterns as the essential prerequisites for the state of physical and mental health. An advanced approach is followed by the Five Domains Modell (Mellor et al., 2020). It was originally formulated in 1994 for animal welfare assessment with the specific purpose of assessing and grading the negative impacts of research, teaching and testing procedures on sentient animals. It separates out the aspects that can be measured (e.g. injuries, inflammatory processes, level of performance of normal behaviour) in 4 of those domains, from the possible subjective consequences for the animals (pain, frustration) which cannot be directly measured, but only inferred. The domains of the most up-to-date model are: nutrition, physical environment, health, behavioural interactions and mental state, including not only negative but also positive welfare impacts. Irrespective of which concept is finally preferred, it is important to acknowledge that there always is a continuum in the state of the animals, ranging from negative to positive.

What matters to animals in welfare terms is their subjective experience (Dawkins, 1980). Animals perceive and process the incoming information from the internal physical/functional state via their nervous system as well as the external factors of their living conditions generated by sensory inputs individually and thus differently from each other. They weight the importance of these factors according to their own judgement with respect to their own well-being (Boissy, 2019). Accordingly, well-being is an animal-individual computation result of the brain, which is subject to dynamic changes even in the course of the day. Each disturbed or disrupted feature generates sensory inputs which are processed by the brain to form specific negative affective states, which are associated with physiological and behavioural reactions that act to restore the body's internal stability as an essential prerequisite for self-sustaining. Negative and positive affective states provide orientation concerning the actual situations as well as the estimation whether objects are attractive or should be avoided in order to improve the chance to survive (Gygax, 2017). Thus, farm animals are self-referential with regard to their perception and their reactions towards stimuli. The individual operates as an integrated whole entity, organised to avoid, solve or compensate dysfunctions and disturbances as 'survival-critical negative affects' (Mellor et al., 2020). From this perspective, AHW expresses the capability of the individual to cope with the living conditions, whereas dysfunctions indicate that the respective animals are overstressed in their ability to cope (Sundrum, 2015). AHW is the result of a successful and ongoing process of adaptation. Impaired adaptation processes are indicated by dysfunctions, disturbances, disorders or diseases, caused by discrepancies between what is needed by the individual animal and what is provided by the living conditions.

What matters to farm animals to be able to cope is the availability of appropriate resources and protection against overstraining stressors and disorders. Managing livestock as flocks, groups or herds, widely ignores individual variation in animals' requirements. In contrast, individuals rarely behave uniformly within a population but rather display complex combinations of different strategies in a variable environment. As a consequence, individuals in the same environment can differ in their trade-offs between such selective forces leading to varying combinations of characteristics regulated at different levels (e.g., genetics, physiology, neurobiology, or behaviour) (Sih et al., 2004). Thus, individuals of the same species differ in their ability to cope and may handle a threatening situation differently when having different resources to their disposal. For instance, a better and more profitable group composition of pigs in intensive husbandry can be realized when based on the behavioural characteristics of a pig (Hessing et al., 1994). Also tail biting is to a high degree related to general behaviours at the individual level, which should be considered when trying to reduce the prevalence of tail biting (Bagaria et al., 2022). Expert opinion about the best indicators to use for flock-level assessment of hen welfare, with and without consideration of practical issues, is rating plumage score as the most important indicator of all (Rodenburg et al., 2008). Other work suggests that the experts' rankings does not correlate with the birds' own integration of their experiences in different housing systems as different types of birds show different environmental preferences (Nicol et al., 2009).

In the case of dairy cows, large inter- and intraindividual variation refers not only to the nutrient requirements but also to the intake and the disposability of nutrients as exemplified in the case of dairy cows (Rumphorst et al., 2022; Habel and Sundrum, 2023). Correspondingly, an indifferent nutrient supply to a feeding group of cows as in the case of a total mixed ration inevitably leads to a situation where a relevant part of the animals is either undersupplied or overfed, whereas only the minority of individual is fed closely according to their daily requirements. The capacity to cope with nutrient imbalances is not only depending on the degree of the gap between supply and demand and the time it lasts but underlies also a large variation between farm animals living under the same conditions (Kessel et al., 2008). The same applies for the capacity to deal with biotic and abiotic stressors in order to prevent pain, suffering and damage (Hansen and Aréchiga, 1999; Chebel et al., 2016). Thus, the degree of AHW problems within a livestock farm system is reciprocal to the ability, capacity and skills of the farm management to provide appropriate resources and protection services against biotic and abiotic stressors according to the individual needs. The wider the gap between individual needs to maintain the body's internal stability and the corresponding supply, the more are animals exposed to the danger of dysfunctions and disturbances that overstress their ability to cope. In face of the generally high but highly variable AHW problems in livestock farms, it is obvious that many farm animals do not receive what they need in order to cope.

3 Healthy agroecosystems

The term "healthy" is not only attributable to animals and humans but also to ecosystems (Costanza and Mageau, 1999). The authors developed the concept of ecosystem health as a comprehensive, multiscale, dynamic, hierarchical measure of system resilience, embodied in the term 'sustainability' and representing a desired endpoint of environmental management. The term implies the system's ability to maintain its structure (organization) and function (vigour) over time in the face of external stress. Accordingly, a healthy system must be seen in light of both its context (the larger system of which it is part) and its components (the smaller systems that make it up). The same applies for agroecosystems as defined by Conway (1987) as an ecological system modified by human beings to produce food or other agricultural products. It involves making trade-offs between productivity, stability, and sustainability. The farm manager is part of the agroecosystem and at the same time belongs to a superordinate societal and market system, which is used for more or less extended exchange of various inputs and outputs (Deutsche Forschungsgemeinschaft, 2005). While the farm management is challenged to steer and transform the agroecosystem towards inner stability, it has to consider also the internal and external influences and demands. A certain degree of AHW is an essential sub goal for both internal and external demands. From the scientific perspective, questions arise about the appropriate knowledge to be transferred to the farm management to contribute to the transformation of farm systems towards an improved AHW level. Such knowledge must fit not only to the economic considerations of the farmers, but also to the needs of the individual animals and thus to the context, in which the interactions between the individual farm animals and the living conditions occur.

3.1 What matters to livestock farmers

Farmers rely on their daily experience and practical knowledge of how their livestock will optimally produce, which is something they positively relate to AHW (Balzani and Hanlon, 2020). Productivity and AHW status of farm animals are seen as a means to ensure economic viability of the farm system. Thereby, farmers are confronted with a high degree of complexity, which emerges from the interactions between manifold factors on different scales within the farm system and from interactions with the external world. In particular, livestock farmers have to deal with volatile market prices for raw goods and production tools such as feed, which they can hardly influence but have to adapt to. Sales prices are the result of a price competition on a global level, forcing livestock farmers to produce raw goods to the lowest possible costs. Although being concerned about the economic viability of the farm, livestock farmers are not necessarily guided by rational thinking and evidence. Especially negative side effects of the production processes such as production diseases and the economic consequences are often disregarded (Hogeveen et al., 2019).

The whole farm is the reference system when it comes to decisions about the allocation of resources. From the perspective of farmers, investments in the AHW issue are only justified when a return of investment can be expected to directly pay off, whereas it cannot be expected from them to operate against their own interests. Correspondingly, limitations in the availability of relevant resources (e.g. high-quality feed, labour capacity, investments, know how) are causing profound trade-offs when decisions have to be taken regarding their allocation between partial goals. On the one hand, there is a large extend of overlap between the goal of productivity and the success in protecting farm animals against severe AHW problems. On the other hand, an excessive and unilateral pursuit of productivity can be counteracted by negative side effects and failure costs, particularly due to AHW problems (Farm Animal Welfare Committee, 2011). It is also possible that measures to improve AHW are so costly that the overall productivity diminished. While the state of physical and mental health is an end in itself for the individual animal, it is only a means to an end for the farmer. He/she is not well recommended to strive for the highest possible level of AHW but for the farm specific optimum that balances the failure costs due to AHW problems with the costs to prevent losses by appropriate countermeasures (Hogeveen et al., 2019). The same applies for strategies to increase the productivity of farm animals, e.g. by enhancing the performance level. When expenses exceed the optimum level of the cost-to-benefit ratio for the individual animal, farmers yield a negative marginal profit.

3.2 What matters to improve the level of AHW in the farm system?

To improve the level of AHW, appearing dysfunctions, disturbances, disorders or diseases have to be treated and modifications in the allocation of resources have to be made. The expertise to meet the comprehensive challenges is not aggregated in one but divided up over different disciplines. Concerning the treatment of diseased animals, veterinarian surgeons are the trained specialists from which is expected that they are able to contribute to substantial improvements. However, to do so, some preconditions must be fulfilled. Inter alia, they have to be consulted at the onset of diseases, charged to identify the causes of diseases, enabled to exploit the possible treatment options and to assess treatment success, and last but not least enabled to eliminate the farm specific weak spots and main causes of recurrent diseases. Not only the consultation but particularly their recommendations are a relevant cost factor. To improve treatment success, veterinarian surgeons have to be charged, paid, and finally, farmers have to implement the recommendations. According to a study, aimed to qualitatively and quantitatively describe farmers' reasons for adherence and nonadherence with veterinary recommendations, trust, feasibility, and priorities were identified as the main themes (Svensson et al., 2019). However, there is a lot more at stake than the adherence and nonadherence with the recommendations of experts.

A systemic perception of the need for alterations requires a farm management that focuses on shaping the environment (Wells and McLean, 2013). From the recognition of animals failing to cope follows the operational requirement to design an environment that is better adapted to the needs of the animals. This can only be achieved effectively if the causes of dysfunctions are identified and repaired. However, it is also necessary to consider the individuality and self-referentiality of farm animals and their context-variant interactions with the living conditions. This is illustrated in further detail by different examples of AHW problems in dairy farming, but applies in a modified form also to other species in livestock production.

Mastitis is a main production disease of dairy cows. Its aetiology is complex and multifactorial as are the options to treat or prevent mastitis effectively and cost-efficiently (Vliegher et al., 2018). Factors with explanatory power are inter alia the time interval between infection and treatment, knowledge about the pathogenicity of the pathogen germs, the degree of parenchyma alterations, the frequency of previous treatments, and the energy balance with respect to the nutrient supply. Success to reduce mastitis is above all depending on the implementation of a surveillance programme and an appropriate treatment strategy. An on-farm survey revealed that therapeutic success ranged between 18% to 59% while the total costs of mastitis per cow and year varied between € 158 to € 483 (Doehring and Sundrum, 2019). The large variation between and within farms indicates that average figures risk giving misleading information about effective and cost-efficient measures. Due to a lack of profound data, failure costs of mastitis and investments to prevent them are seldom estimated appropriately (van Soest et al., 2019).

Another example is given by metabolic disorders. They are a key problem in the transition period of dairy cows and often appear as onset of further health problems (Sundrum, 2015; Webster, 2021). They mainly derive from varying gaps between nutrient supply and demand and cause variations in activity and feeding behaviour patterns (Jawor et al., 2012; Itle et al., 2015), collectively called "sickness behaviour" (Harden et al., 2015). Metabolic disorders indicate an overstressed ability to balance input, partitioning and output variables and to adapt to imbalances in the supply with nutrients. The earlier endangered and diseased animals are identified and treated accordingly, the lower are the impairments and the higher the probability that countermeasures succeed. A low prevalence of metabolic disorders can most likely be achieved when the farm management gets an overview of the nutritional status of the single animals, e.g. by making use of balance sheets, for example with respect to energy balance (Thorup et al., 2018). By this means, endangered animals can be identified and modifications of the individual supply or demand side engineered. Such an approach suggests a more effective and cost-efficient procedure than strategies that primarily rely on the adjustment of a diet which is fed to all animals of a feeding group while disregarding the intra- and interindividual variation of nutrient requirements (Sundrum, 2020b).

Culling of farm animals indicates the ultimate failure of adaptation. This applies for both, the farm animals and the farmers who were not capable to adjust the living conditions to meet the individual requirements of the farm animals. Culling of dairy cows is primarily due to infertility or production diseases (Compton et al., 2017; Rilanto et al., 2020). Often, more or less extended phases of pain, suffering and damage preceded the way towards the final end. Time and circumstances of culling are not only associated with severe AHW problems, but are also main drivers of economic results (Dechow and Goodling, 2008). Farmers often tend to underestimate costs of disease, culling and replacement (Jones et al., 2016). Individual cows can only contribute to farmers income, if their individual revenues from milk and slaughter override their individual costs for rearing, feeding and their share of the fix costs of the farm. Thus, culling is not economically desirable before cows reach their productive zenith. The cow-specific calculation of individual income over service life cost (^{i}IOLC) regards the individual cow as both the basic biological and the basic economic unit of a dairy farm, which allows for allocation of all costs and revenues of the dairy branch to single cow's service lives (Habel et al., 2021). In a comprehensive study on 32 dairy farms, lifetime profitability of individual cows varied considerably between farms as well as between the culled cows on the same farm. Median ^{i}IOLC was negative for 59% of the investigated farms and varied largely between farms. The majority of the investigated farms failed to take appropriate decisions to better sustain the lives of their animals and to generate sufficient profit from the investments.

There is no doubt that it costs efforts and money to solve AHW problems. Although there is growing literature on farmer decision making and 'barriers to uptake' with regard to the different production sectors (Palczynski et al., 2016; Svensson et al., 2019; van Klompenburg and Kassahun, 2022), it often remains unclear for the farmer where investments and efforts could prove essential to survival, where they might be effective and worthwhile, and where they seem counterproductive. Correspondingly, farmers may be prevented from acting because of the complexity at hand. Only few costs are obvious: e.g., the reconfiguration of pens, and administration of improved feeding, hygienic and treatments strategies. Some interventions may require ongoing additional personnel costs or additional veterinary expertise. Not less problematic is the fact, that the projected benefits are less certain than the costs, and are more difficult to assess in financial terms (Fernandes et al., 2021). In a review, various financial benefits of good AHW through, for example, reduced mortality, improved health, improved resistance to disease and reduced medication, and lower risk of zoonoses and animal-borne infections have been outlined (Dawkins, 2017). Although these parameters might directly affect the profitability of the livestock farm businesses, they are neither expressed in economic terms nor in terms of cost-to-benefit ratios. While it is widely recognized that animals with poor welfare are unlikely to produce at optimal levels, the cost-to-benefit ratio of investments are seldom known, because they are highly context-variant. What makes it even more complex and confusing for the farmer is the fact that investments are underlying the general law of diminishing marginal utility.

Due to the heterogeneity of farm conditions, to reduce AHW problems, farmers cannot rely on general recommendations. They have to find a farm centric approach to organise and regulate the processes within the farm system. In their role, farmers are both observer and part of the farm system, primarily guided by a self-referential perspective. To strive for a balance between the goals of a high productive efficiency and a low rate of dysfunctions, e.g. in terms of AHW problems, they could learn from perceiving their farm as an agroecosystem. Concerning the characteristics of self-organizing autopoietic systems (Razeto-Barry, 2012), the structure of agroecosystems can be described as a hierarchy of scales as illustrated in Figure 1.

Cells as autopoietic systems of 1st order are interacting with available material and elements in their environment in a self-referential way with respect to what they need to sustain and function when organised with other cells in tissues and organs. Furthermore, they fulfil demands of the individual organism as the autopoietic system of 2nd order. Individual animals are part of a herd and subsystems of the agroecosystem. In this way, each superordinate system acts as the environment for the subsystem, which cannot exist or be sustained without the resources and the protection provided by the superordinate system. Autopoietic systems continuously produce the components, which constitute it by itself, while these components steadily sustain and regenerate the superordinate system (Varela, 1997). Individual animals are an integral and functional system and represent an entity with a functional integrity. In striving for maintenance, the uptake of external material is regulated following own purposes when integrating and transforming the material within the system. They select components from the environment and give them a meaning of incentives, objects of perception, and interests.

Because the requirements and needs of farm animals and their ability to cope vary considerably even in largely homogenized groups, it is of high importance to consider the individuality of farm animals, interacting within a superordinate system based on the functionality and integrity of its own subsystems. The more supply and allocation of nutrient resources and protection against biotic and abiotic stressors are adapted to the individual requirements, the higher the chance that the individual is able to cope. Thus, when striving for a reduction of AHW problems, farmers are well recommended to recognise the farm and the subsystems as autopoietic, being self-referential in what they need to cope, in order to be able to support the functionality the superior system in which they are embedded.

4 The role of animal science

In general, it can be assumed that the generation of knowledge by the various disciplines of animal science on how to make use of intensification, specialisation and technical progress has considerably contributed to the increase in productivity within livestock production. For instance, from 1957 to 2005, broiler growth increased by over 400%, with a concurrent 50% reduction in feed conversion ratio (Zuidhof et al., 2014). In dairy production, the annual milk yield per cow increased over 4-fold in the last 75 years with no evidence of nearing a plateau (Baumgard et al., 2017). On the farm level, higher efficiencies for milk synthesis are associated with a dilution of maintenance requirements and are suggested as a main reason for the strong increase in productivity. On the cow level, the primary source for the gains in efficiency relate to inter-animal variation in nutrient partitioning. This potential was exploited particularly by breeding strategies, and accompanied by an increased scientific knowledge about what is required to exploit the increased genetic performance capacities by providing adequate nutrient supplies and environmental conditions.

While the variation between animals is the starting point of the tremendous increase in performance, it is at the same time the cause of many AHW problems. These derive inter alia from a mismatch of nutrient allocation between different subsystems when animals are not receiving what they need to prevent dysfunctions and to

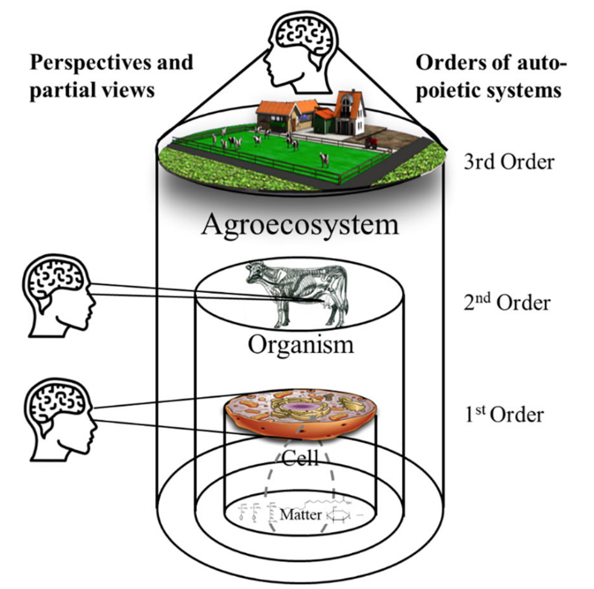

FIGURE 1
Hierarchic structures of living autopoietic systems and their perception from different self-referential perspectives.

cope (Habel and Sundrum, 2020). The ambivalence of variation between farm animals is exemplary expressed by the results of a 2 × 2 × 2 factorial arrangement, where the effects of genotype (G), environment (E), and G×E interactions were assessed (Beerda et al., 2007).Whereas high milk production levels per se do not compromise the health status of cows, high yield will increase allostatic load. The high genetic merit for milk yield is intrinsically connected to increased risks for disorders and underlines the negative impacts of an inappropriate nutrient supply. In a recent review, scientists from the discipline of animal breeding acknowledge that progress in milk production has been accompanied by deterioration of key biological mechanisms (e.g., health, resilience, robustness, welfare, longevity) in the most common dairy cattle breeds (Brito et al., 2021). Despite the great betterment in production efficiency, strong drawbacks have occurred along the way. The authors concluded that the genetic progress achieved in high-yielding dairy cattle, closely related to dairy farm intensification, reaches its limits. Jointly responsible for the limits might be that feed intake (Hristov et al., 2005) as well as digestive (Ledinek et al., 2019) and hepatic efficiencies (Loncke et al., 2020) do not increase proportionally to increases in milk production of high-yielding dairy cows. Studies also indicate that increases in milk yield require progressively greater marginal increases in nutrient supply, which leads to decreasing marginal feed efficiencies in high yielding herds (Bach et al., 2020). Because marginal feed costs increase progressively with milk production, profits associated with improving milk yield might be considerably lower than expected.

What applies on the animal level is also valid on the farm level, where the high intra- and interindividual variation of the gap between requirements and supply are jointly responsible for dysfunctions, disorders, subsequent diseases and increased culling rates (Rumphorst et al., 2022). These are also a relevant cause for negative marginal profits in farm systems where the management fails to ensure that at least the majority of cows in the herd become a 'profit cow' before being culled and thus contribute to the economic viability of the farm system (Hoischen-Taubner et al., 2021). Focusing on a reduction in production costs, such as costs for high-quality feedstuffs, skilled farm labour or disease prevention, can have adverse effects on the productivity and the efficiency of the dairy herd (Põldaru and Luik-Lindsaar, 2020). In contrast, improving disease and fertility management have been shown to also increase feed efficiency and lifetime productivity of individual cows and dairy herds (Knapp et al., 2014). The outlined relationships make it reasonable that it is not the general ability of dairy cows to further increase the annual milk yield that is nearing a plateau, but the capacities of farm management to deal appropriately with the individual requirements and needs of the farm animals.

Since decades, reflexions on undesired side effects of intensification processes in the various animal species on the issue of AHW have been part of animal science (Rauw et al., 1998). Although research work on the AHW issue has created an enormous amount of relevant scientific knowledge by various disciplines, there is no evidence of a substantial progress in solving many AHW problems of farm animals. Instead, comprehensive data sets suggest a lack of general improvements, for example in the case of mortality rates (Compton et al., 2017; Kielland et al., 2018; Ritter et al., 2019), or production diseases (Sundrum, 2020a). Also where the implementation of substantial improvements in housing conditions are evident, as is the case in organic livestock farming (Sundrum, 2014), no fundamental differences have been identified between organic and conventional farms in the AHW level, applying more or less to all farm animal species that have been addressed in a systematic mapping of current knowledge (Åkerfeldt et al., 2021). Of course, this does not mean that improved housing conditions have no effect on the AHW level. The data from the large-scaled field trial of organic livestock production show, however, that living conditions in their impacts on the AHW level comprise far more than defined husbandry system. Above all, capacities, skills and knowledge of the farm management are decisive for what is achieved in farm practice with respect to the AHW level. At the same time, the farm management is embedded in a market system that offers only marginal incentives to improve AHW while simultaneously forcing livestock farms into a price undercutting competition.

Within the overall context, the role of animal science is to support farmers with information not only with regard to productive efficiency but also on how to be effective and efficient to improve AHW within the farm specific context. What has been offered in the past by animal science is obviously not sufficiently adequate to solve AHW problems in farm practice to a considerable degree. Thus, the question arises, why an increase in scientific knowledge is not accompanied by an increase in the capability to solve AHW problems in farm practice? While the reasons are manifold, and often beyond the area of influence and responsibility of animal science, two aspects are considered to be of particular relevance from a scientific perspective.

4.1 Animal science in search of knowledge gaps

The enormous growth in scientific activities and knowledge has inevitably led to a fragmentation of scientific knowledge. Differentiation of disciplines and specialisation of research areas are still considered as a recipe for success. By answering key research questions, new questions arise and generate a self-sustaining momentum, not unlike the path dependency in farm business. The focus on disciplinary research programs entail that large parts of the real world complexity are disregarded, associated with a vague expectation that these are covered by other disciplines (Krohn et al., 2017). Each discipline follows its own goals and problem framing, encompassing the definition of system boundaries, the role of actors and the selection of design tasks. They refer to different reference systems such as different groups of animals, housing systems or production methods. Differentiation and specialisation of scientific approaches have resulted in what Alrøe and Noe (2011) called perspectival knowledge asymmetries. Scientists have their own discipline-born perspective and see complex matters differently. Experts perceive knowledge gaps from within their professional paradigms and are widely incapable of forming judgements beyond their specific expertise (Millgram, 2015).

According to Fraser (2008), “different scientists adopted the different value-based views of animal welfare - basic health and functioning, natural living, and affective states – as the rationale for different scientific approaches to assessing and improving animal welfare”. The different approaches are associated with “a dilemma that threatens to throw animal welfare science into disarray”. This is particularly the case, when different scientific approaches arrive at opposite conclusions as exemplified in the case of housing sows in gestation stalls. Fraser (2008) identified the reason for contradictions in the fact that tools of science are used within a framework of values and that the understanding of animal welfare and its scientific assessment is both values-based and science-based. Thus, scientists are self-referential when choosing a specific perspective on the AHW issue or apply specific methodological tools they have taken ownership of in their specialist discipline. While the disciplinary focus through the inherent methodological lenses provides a deeper insight in the interconnectedness of processes within sub-areas, the focus becomes even more narrowed in search for further gaps beyond the knowledge that is already available. The drivers of specialisation in animal science like in other scientific areas have inevitably led to a reductionist approach while the whole picture is becoming more and more lost out of sight, leading to a decline in the skills to solve complex problems (Deutsche Forschungsgemeinschaft, 2005). This applies above all for problems that develop beyond the boundaries of disciplinary specialities, which is particularly the case for most of AHW problems. Such can only be solved when the underlying causes are understood not only from the ankle of single disciplines and from a focus on single factors. To grasp the outcomes of complex interactions of various factors involved on different scales, these have to be examined from different perspective. Understanding the multifactorial genesis of AHW problems and contributing to their mitigation requires an integrative and thus inter- and transdisciplinary solution approach. This is most likely to be achieved when funding bodies specify schemes to encourage inter- and transdisciplinary thinking. However, this alone is not sufficient. As scientific findings always have some generality and some specificity, it is of high importance for the chance that solution proposals are implemented in farm practice to know more about the ambiguity and context dependence of methods and measures. Consequently, there is an urgent need to extend tests on the external validity of measures and results obtained under specific conditions.

4.2 Animal science in striving for publishable results

Scientists are not only self-referential concerning the research subjects but have to consider also their own benefits when conducting research work. When striving for a scientific career they will not be able to avoid relying on publications in scientific journals. According to the guide for authors of many scientific journals, studies may be considered for publication only if the results are likely to be of international interest, i.e. it must be possible to generalise the findings using scientifically based approaches (Elsevier publisher, 2023). Of course, this applies not for all scientific journals. However, the Impact Factor of the journals that make the such demands tends to be higher, and thus are of higher attractiveness for scientists. As scientists compete for research funding and for comparatively few permanent positions, promising scientists only have a chance to pursue a career when they are careful to demonstrate their publishing skills. The general framework of research work affects the areas where scientists are looking for gaps of knowledge suited to generate generalisable and therewith publishable results. In contrast, scientists are not often rewarded for translating their results to be useful to end-users.

Publications must satisfy the major scientific criteria of validity and reliability. Validity describes how well an instrument does what it is supposed to do. Reliability describes the consistency with which results are obtained (Andrade, 2018). Concerning validity, it can be distinguished between internal, external and ecological validity. Internal validity examines whether the study design, conduct, and analysis answer the research questions without bias, and allows trustworthy answers to the research questions in the study. For example, improper randomization, inadvertent unblinding, or missing data can all undermine the fidelity of the results and conclusions of a randomized controlled trial (RCT). External validity examines whether the study findings can be generalized to other contexts, for example other patients. Ecological validity refers to the degree to which research findings reflect real-life related functions and examines how closely an experiment aligns with real-world phenomena (Fahmie et al., 2023). Ecological validity is evaluated within a given study, external validity of single-case research is evaluated across a collection of studies.

While standardisation of experimental conditions is of high importance when striving for a high internal validity and for generating publishable results, study results can become increasingly determined by the specific experimental conditions in which they are conducted. Thus, environmental standardisation is a cause of, rather than a cure for, poor reproducibility of experimental outcomes (Richter et al., 2009). To reduce within-experiment variation, experimenters are usually advised to standardize the conditions of their experiments as rigorously as possible. Standardising the experimental conditions is believed to render the animals’ responses to experimental treatments more homogeneous, thereby reducing within-experiment variation and increasing test sensitivity. As a consequence, study results might appear as generalisable and context-invariant from a disciplinary perspective, whereas they can appear as highly context-specific when being examined with regard to external validity. Not less important is the fact, that highly standardised conditions can be very different from what is found on commercial farms. The degree by which farm animals pay for the pursuit to increase productivity with limitations in the availability of resources and in the protection against a large variety of biotic and abiotic stressors vary considerably. The variety of disruptive factors includes high stocking density, provoking conflicts with other animals, high concentrations of microbiological pathogens, parasites or toxins, and harmful gases. In addition, the variety of the interactions between these factors are subject of dynamic changes, whereas the combination of the respective factors affects the animals not separately but jointly.

In contrast, it is inherent for a disciplinary perspective to focus on selected effects, necessarily implying that other aspects are disregarded. The focus on single aspects or the selection of specific criteria touches upon a core problem of biology (Cassirer, 1974): the 'part-whole-problem'. Within an organism, the different parts and subsystems are not separate from each other but are self- and mutually reinforcing and work together towards the same goal: to keep the organism alive. There is no part that does not need the support and cooperation of nearly all other parts. A living system cannot be fully understood without considering the purpose behind the biological processes. This applies particularly for adaptation as a functional and target-oriented process. Whether the whole organism responds adequately to challenges cannot be deduced from single parts or by indicators. Whether adaptive measures and processes are beneficial or not depends primarily on the context in which they take place. They do not follow a one-size-fits-all approach as is for instance conducted in randomized controlled trials, but require an external validation with regard to the effectiveness in farm practice (Krauss, 2018).

Different scientific disciplines prioritise different indicators to assess the state of physical and mental health of farm animals. While partial views reveal only partial insights, assessments based on partial results and on an inductive approach are at risk for misjudgements and inductive fallacies. The piecemeal approach of animal science blinds actors to the possible larger conflict constellation for AHW problems. Whereas in experimental studies scientist are striving for the greatest possible narrowing of the variation, variation between animals can be quite extended in farm practice. What is statistically valid for a group of farm animals under highly standardised conditions does not necessarily work for individual animals, deviating from what might be supportive when assessed in terms of means values. This applies for instance when providing feeding rations formulated to meet the average nutrient requirements of a group of farm animals, although animals show a high degree of variation in their requirements (Rumphorst et al., 2021). Nevertheless, effects of nutrient supplies are often validated against the mean effects revealed in relation to a control group, but not against the state of physical health of individuals, being the valid reference system in the AHW context. The state of physical and mental health refers to the individual animals at any point in their lifetime. Thus, the state cannot be averaged.

Possible counter-examples are epidemiological studies which are analysing on-farm risks for AHW problems (e.g. lameness, mastitis, pecking, fractures, abnormal behaviour) and explore real-world variation, although they seldom consider individual animals as the reference unit. Benefits and limitations of epidemiological studies are exemplified with a study investigating risk factors for lameness in dairy cows (Dippel et al., 2009). The results revealed that lying comfort and nutrition were identified as key risk areas for lameness across regions, breeds, and farming systems, therewith providing information about the priority of factors that have to be considered. However, the farm-level factors in this study, as is the case in many other studies (Rittweg et al., 2023), were restricted to few easily detectable indicators, whereas many of those factors that are also relevant for the development of lameness, such as the quality of the floor, hygienic conditions and preventive hoof trimming (Sogstad et al., 2005), comorbidities (Daros et al., 2020) or the energy balance of the individual animal (Collard et al., 1999) have been disregarded. In addition, a priority of risk factors that might be valid for the majority of dairy farms is not necessarily true for a specific farm situation. The multifactorial genesis of lameness varies not only between farms but first of all between the individual animals. While epidemiological results offer some orientation about the most probable risk factors that should be considered with regard to possible preventive measures, they seldom lead to concrete options for action. These would require a sufficient persuasive power towards the farmers to convince them that the recommended measures can be expected to be effective and cost-efficient in the farm-specific context. Above all, epidemiological results do not save the efforts of a thorough diagnostic procedure to identify the main causes in the farm and animal specific situation when it comes to the foremost task to treat the suffering animals in due time.

While many scientific studies, technologies and practices claim to result in positive AHW (Bertenshaw et al., 2008; Cronin et al., 2014; Westerath et al., 2014; Rentsch et al., 2023), without physiological and behavioural evidence from the individual animal, we have no way of knowing whether these claims are valid (Fernandes et al., 2021). Thus, what is target-oriented when striving for a scientific career is not necessarily suited for solving AHW problems that emerge from highly context-dependent dysfunctions. Striving for generalisable and publishable results widely disregards the inherent goals of organisms and the inner logic of farm systems. Thus, a fundamental trade-off is seen in the discrepancy between what animal scientists are striving for and what is required to grasp the complexity of processes within the farm systems. The outlined considerations explain why the predominant approaches in animal science primarily deliver piecework. Not unlike puzzle pieces, new findings generated from a disciplinary focus under specific experimental conditions are to the disposal of all who have access to scientific journals and are in search of information that might be of interest for them. This knowledge about tools, causes and effects which has emerged under specific condition can be classified as disposal knowledge (Mittelstraß, 2001). Disposal knowledge seems like a missing puzzle piece in search of a gap within a large mosaic picture where it might fit. Here again, a trade-off becomes obvious. To be generalisable, the shape of the disposal knowledge should be rather unspecific, whereas envisaged effects can be expected in particular, when the impetus fits to a high degree to the needs in a specific dysfunctional situation.

5 Transformation knowledge

To solve AHW problems, it is necessary to transform a dysfunctional state of a farm system into a functional and healthy state by promoting adaptive systems in their capability to regenerate. Therefore, the main causes of dysfunctions have to be identified and meliorated. This requires both an overall overview to locate parts according to their relevance for the whole system as well as what is demanded from the individual animals in their inherent efforts to cope. Problem solving expertise is expressed by the capability to perceive and classify problems and dysfunctions appropriately. Beside the requirements of the individual farm animals, the external demands of competitiveness have to be considered. At the same time, farmer should not lose sight of the demands of consumers with respect to the quality of ASF and the societal demands with respect to public goods. To support decisions makers, there is need for a scientific approach that adequately accompanies the transformation process.

The transformation of a farm system should not be launched without appropriate knowledge. Knowledge about an issue can be defined as the capability to solve problems connected with this issue (Renn, 2012). This is enabled by connecting information about the issue with cognitive structures, which are relevant for understanding its behaviour, and based on encoding experiences, enabling individuals to solve problems as part of their adaptive behavior and capacity. Farmers are the key figures in their dual role as part of the system and as control agent of the whole system. They exert influence on inputs as well as outputs and interactions within the system. They are not only in charge of the farm animals but have to take decisions concerning the primary goals of the farm system, how the system is organised and regulated, and how the internal and external resources available are allocated. With the farmers, functioning as an interface, the areas of technology, economy and society act upon the overall system (Deutsche Forschungsgemeinschaft, 2005). The same applies for scientific knowledge which has to be attractive for the mindset of the farmers when trying to take the right decisions in the allocation of limited resources and to implement measures which deem to be effective and cost-efficient with regard of the envisaged goals. The persistent high prevalence of inapparent and apparent disturbances and diseases in farm animals can be seen as evidence for a poor translation of the enormous scope of scientific knowledge about the background and the possibilities to mitigate AHW problems available in the literature.

The complexity of AHW problems goes far beyond the scope of any given discipline of animal science. In general, they are multifactorial and thus interdisciplinary in nature, context-variant, ambiguous and rich in contradictions. Solutions to AHW problems require a combination of scientific, technological, economic and sociological expertise. Thus, there might be some merit in assembling scientifically informed experts who collectively can provide detailed input on species-specific biology, ethology, ecology, physiology, pathophysiology, health and management. The project WelfareQuality® (Blokhuis et al., 2013) is an example for the involvement of a wide range of scientists from different disciplines. The ambitious efforts to set up an aggregation system for on-farm assessment of animal welfare gave, however, rise to some disagreements. Inter alia, it has been concluded that animal welfare should not be understood as a simple additive function of negative or positive states whereas there are significant differences in the perceived validity and importance of different kinds of welfare indicators (Sandøe et al., 2019). Considering the distinction between intra- and inter-individual aggregation, the authors concluded that the Welfare Quality® concept lacks transparency, allows important problems to be covered up, and has severe shortcomings when it comes to the role assigned to experts. From the results of a comprehensive on-farm study based on the implementation of the Welfare Quality® protocol, it was concluded that various challenges, combined with the lengthy assessment time, were too great for its use as a certification tool (Heath et al., 2014). Obviously, to solve AHW problems, it does not help to convene representatives of various disciplines and "put them in a room" for a solution to emerge. What is fundamentally wrong with this approach is the failure to recognize that different mindsets sitting together will not come to much (Elkana, 2012). The author concluded that we should get used to the fact that all knowledge must be seen in context: not only when looking at its origin, but even when trying to establish its validity and even when looking for its possible application for solving burning problems. To raise questions about context is first and foremost to raise questions about meaning with all its flexibility, plasticity, ambiguities, and contradictions.

AHW is the outcome of complex interactions of farm animals within the causal network of a farm system and as such an emergent property which cannot be deduced by single indicators. Widely disregarding the individuality of farm animals when striving for generalisable statements in a one-size-fits-all approach can be seen as one of the most crucial blind spots of animal science. This applies as well for the dynamic changes within farm animals, living conditions and the interactions between both over time. These interactions form the context in which apparent dysfunctions and diseases occur to a more or less large number of farm animals, whereas other animals of the same production unit suffer from inapparent disturbances and diseases and others are able to cope without any signs of AHW problems. From the interactions between individual animals and the specific living conditions a complexity emerges that cannot be reduced to generalizable cause-effect relationships agreed upon by a number of scientists from various disciplines. In contrast, a more promising approach for the transformation of scientific knowledge into the complexity of agroecosystems might be represented by scholars with knowledge in multiple disciplines and capable of an interdisciplinary way of thinking (Deutsche Forschungsgemeinschaft, 2005). These are also the most likely persons to provide what is most urgently needed when dealing with complexity: orientation.

5.1 Orientational knowledge

In the past, the overarching goal of livestock production has been to increase productive efficiency. Often this goal is equated with a continuous increase in the performance level and with benefits created by economies of scale. Disposal knowledge deemed suited to contribute to this goal was perceived with a high priority, explaining inter alia the high attractiveness of breeding strategies (Baumgard et al., 2017). In general, breeding strategies follow an inductive approach, moving from specific phenotypic traits to broader generalisations, and being widely context-invariant, i.e., a progress in relevant traits is expected to occur independent from the farm specific conditions. Some counter-examples of shifts in the approach, e.g. considering social factors (Ellen et al., 2014), try to ensure that selection takes place in farm environments and that the antagonisms between productivity and AHW is more considered than has been the case in the past (Brito et al., 2021).

The goal to reduce AHW problems is quite different from the predominant breeding approach. It requires a deductive and iterative approach, respectively. In addition, it is not an end in itself but a means to the overall goal of the sustainability of the farm system, setting a farm specific framework for all options of action. The reference systems are the individual animals and the respective farm system. Being a subordinated goal, the envisaged level of AHW is farm specific. Knowledge to transform a farm into a healthy agroecosystem must be designed to realise a win-win-win situation which conflates the interests of the farmer with those of the farm animals and public goods. However, before the relevance of reducing AHW problems for the economic viability of the farm can be estimated, various questions arise for the farmer, e.g.: Where are we now and where do we want to stand in the future? What has to be changed? How do we proceed and how can we assure that the implemented measures are effective and cost-efficient? And last but not least, how can improvements be measured?

Orientation concerns what is needed for an appropriate functionality of the subsystems, and what is provided by the superordinate system in terms of resources and what is demanded from the subsystem to contribute to the functionality of the superior system (see Figure 1). Correspondingly, both an external and internal benchmark system has to be considered. Being a relative parameter ranging from a low to a high grade, the AHW level can be benchmarked against the AHW levels of other farms, therewith classifying the farm's own rank position in comparison to other farms. An example for an external benchmark is provided by a monitoring system for the assessment of cattle health in Dutch dairy herds based on routinely available data (Brouwer et al., 2015). This can be extended and combined with other dates, e.g. pathological meat inspections findings for a more comprehensive cattle health surveillance (Veldhuis et al., 2021). It is beyond the scope of this article to refer to the assets and drawbacks of surveillance systems and the use of iceberg variables (Farm Animal Welfare Council, 2009) for the assessment of the AHW level in further detail.

In the current context, it is emphasized that it is generally possible and already implemented in several countries to benchmark farm systems according to their degree of fulfilling public interests in relation to the AHW issue. In this respect, animal science has considerably contributed to the development of benchmarks (Mullan et al., 2016; Sandøe et al., 2020; De Luca et al., 2021). Benchmarking provides orientation. This applies in the first place for the farmers, who get to know where their farm system is classified concerning the AHW issue. Furthermore, this knowledge is essential in guiding farmers to define future target values with respect to the AHW level. Farm specific target values are the lighthouses for a reorientation and realignment of the farm practice and also relevant for designing transformation knowledge. Due to the general law of diminished marginal utility, the current rank position as well as the gap between the current and the envisaged rank position have a considerable influence on the cost-to-benefit-ratio of measures. Furthermore, benchmarking provides orientation for superordinate institutions with regard to the degree of variation between farms and the identification of those farms that are particularly in need of a transformation process.

The internal benchmark refers to the position of the AHW issue within the farm system and in relation to the overall goal of economic viability. For the farmers it should be of high importance to know, how far the current economic losses through AHW problems undermine the economic viability of the farm system. This also includes knowledge about the degree of AHW problems, the additional expenditures needed to solve AHW problems and to create a win-win situation that corresponds with both, the own economic as well as the public interests. While it certainly goes beyond the scope of the capacities of the farm management to deal with all farm animals in a comprehensive individual manner, the starting point when trying to reduce AHW problems should not rely on average figures but should focus on those animals, which are affected with the most severe AHW problems. In a similar way, preventive measures should first be addressed to those animals being exposed to the greatest risks in failing to cope due to the largest gap between what is required and what is provided by the living conditions. Thus, it is the variation and the animals at both ends of the distributional width that count both in relation to AHW problems and cost-to-benefit ratio.

These hints may suffice to understand that solving AHW problems on commercial livestock farms is above all an economic question. However, generalizations of economic effects may be fallacious for the individual farm (Jarvis and Valdes-Donoso, 2018). The economic impacts associated with differences in productivity often remain hidden under average figures. The various types of data from a farm, e.g. economic and biologic data, commonly lack connectivity and compatibility at animal level (Habel et al., 2021). Thus, neither agronomists nor other specialists, let alone the farmers themselves generally have adequate knowledge to their disposal to take appropriate decisions to strive for an optimal cost-to-benefit ratio with respect to the AHW level. What makes the situation even more complicated is that being aware of the core AHW problems on the farm and having defined new AHW target values does not necessarily mean the reasons and causes behind the problems are known, let alone the most effective and cost-efficient measures to reduce them.

5.2 Action-guiding knowledge

Farmers will only agree in the implementation of measures to solve AHW problems, when they see a chance to benefit from such investments (Jansen et al., 2010). Measures can only be expected to be effective when they consider the individual gap between what is required and what is offered by the farm management and what is needed to support the individual animal to cope. Thus, the first step to improve the AHW level from a systemic perspective and by making use of deductive knowledge (from general to particular) is to get an overview of the possible shortcomings and AHW problems in the herd and to identify the most threatened animals. In the past, there have been tremendous efforts to develop technical options, e.g. by the use of 'smart' sensors and the principles and technology of process engineering, to identify possible deviations of numerous indicators from reference values (Berckmans, 2022). However, identifying deviations is not equivalent with a profound interpretation about their meaning. Interpretation is, among other things, aggravated due to a more or less extended overlapping area between false positive and false negative diagnostic results. Not all animals without obvious deviations are without AHW problems and not all deviations indicate an AHW problem. Above all, the information deriving from such techniques seldom generates knowledge about the causes behind the deviations.

Abnormal behaviour, symptoms of a clinical disease or deviations from physiological reference values indicate the need for further diagnostic procedures to assess the possible causes behind the disturbances and the degree of severity and potential threat for the recovery or survival of the animals. Diagnosis in individuals is deductive and goes from general signs to specific aetiologies (Slenning, 2001). When faced with a sick individual, the practitioner begins by making a list of "normal" comparisons. Each "abnormality" is a clue to the cause of the illness. Thus, a deductive process can be depicted as a series of questions. The answers to each question take the examiner down an increasingly branching decision process. Finally, a process of pattern recognition leads to a clear diagnosis when the disease pattern matches with official definition of the respective disease.

Dealing with all possible dysfunctions and disturbances that might affect farm animals in an appropriate diagnostic and treatment procedure up to a state of *restitutio ad integrum* is very time-consuming and costly and thus beyond what the farmers think is affordable. Instead, when striving for effort and cost saving strategies, a reductionist approach has been created. This tries to narrow AHW problems to main factors in relation to the affected animals within a group of animals while widely disregarding the individuality of AHW problems. Thus, diagnosis in herds or groups is in general inductive and goes from the specifics in a few individuals to generalities about the group (Slenning, 2001). Herd-based testing is done by subsampling a number of cows, representative of the animals at risk and then evaluating the proportion of cows above a certain cut-point. However, the signs are rarely precise. All the possible aspects which might have caused the current prevalence rate of AHW problems on the herd level will probably lead to a long list of factors. However, the list of factors does not provide certainties or probabilities with respect to the ranking of these factors in relation to the occurrence of AHW problems in the farm specific situation. To reduce AHW problems, disposal knowledge has to be contextualized. However, this does not work by the predominant inductive approach but requires an iterative approach that alternates between deductive and inductive conclusions, thereby strengthening synergies and resolving trade-offs.

Reducing efforts as part of a reductionist approach is not promising when simultaneously considerable negative side effects are disregarded, and particularly when these expand to a degree that undermines the economic viability of the farm system. Often, these become only assessable when biological and economic data are connected with the individual animal as reference system. Many farmers save themselves the effort of a time-consuming data acquisition and rely only on average figures. A study about the economic losses in connection with mastitis in dairy cows showed that it may be worthwhile to invest in a comprehensive documentation and analysis of data, so that it is clear where action is required and which investments can be expected to be financially feasible (Doehring and Sundrum, 2019). In contrast, average or incomplete figures risk giving the wrong impression and leading to false conclusions. As there is no general pathway to reduce AHW problems, also the detail depth of data acquisition underlies a context-specific cost-to-benefit ratio. The farm-specific degree and nature of AHW problems determine the efforts needed to overcome a negative marginal utility. The same applies for the disciplinary expertise needed to identify the main causes of AHW problems and to support individual farm animals in their ability to cope.

The trend in farm practise following the general idea of economies of scale when striving for the overarching goal of productive efficiency coincides with the reductionist approach and trend towards specialisation in animal science. Having widely lost sight of the whole farm system, animal science in its current alignment is neither able to provide orientation nor appropriate action-guiding knowledge. When focusing on selected sub-aspects from a mono-disciplinary perspective, the context in which AHW problems emerge as dysfunctional outcomes of the interactions between the individual animals and their living conditions is largely disregarded. Based on a reductionist approach, large quantities of detailed information have been accumulated with little attempt to incorporate it into a broad view of the whole subject and integrate it into a coherent understanding of complex systems. Thus, one of the biggest challenges for animal scientists is to interpret findings in a meaningful fashion in relation to the overall functionality of an agroecosystem. Otherwise, it is difficult to provide estimations about the effectiveness of measures in reducing AHW problems. On the other hand, these estimations are the starting point in finding the optimal cost-to-benefit ratio of measures. The options to improve this ratio is a main financial source and at the same time a main driver that might encouraged farmers to engage in efforts to reduce AHW problems.

5.3 Validation

It is a truism that conditions that require improvements need to be assessed, measured and the success of implemented measures whenever possible validated. Otherwise, it will not be possible to act against the barriers of established ways of thinking, of production processes or clashing interests within or outside the farm system. As AHW is a very complex issue, where substantial progress has not yet been adopted in many areas, possible improvements are associated with fundamental challenges, requiring systemic changes as well as an orientation towards external yardsticks. In light of the necessity to follow a context-variant approach when trying to solve AHW problems, it could be argued that the transformation of livestock systems is not a task for animal science but for advisory services in the first place. These have the most nearly access to the conditions on the respective farms and might be able to link what is available from animal science as disposal knowledge with the specific living conditions. The fact is, however, that the transformation of livestock systems to healthy agroecosystems cannot succeed when it is not evidence based, being a core area of science.

Concerning the validation of progress in reducing AHW problems, benchmarking does not only provide orientation but functions as a yardstick, by which a possible progress can be assessed. Any changes in the rank position serve as feedback for the farmers whether they are on the right track or have to realign their efforts. Thus, the previous suggestions in the literature on how to benchmark farm systems in relation to the AHW level (Brouwer et al., 2015; Nienhaus et al., 2020) need to be developed further and to be transferred to all farm animal species. Concerning the manifold options and strategies that might be considered when trying to reduce AHW problems, it should not be left to the primary producers and the advisory services to find solutions in a trial and error approach. This could be very expensive as well as inefficient and might prevent many farmers to walk the path towards improvements. With respect to the effectiveness of measures to reduce AHW problems, it is not the internal validity within highly standardised studies that counts in the first place but the external and ecological validity of scientific results.

External validity refers to the robustness of a causal relation outside the narrow circumstances in which it was established and thus defines the extent to which a scientific result can be generalised (Richter et al., 2016). A low reproducibility of results calls for research into practicable and effective ways of systematic environmental heterogenization. Concerning AHW problems, it should not be the primary research question whether various parameters show a significant difference in mean values when compared in a *ceteris-paribus* approach, but if the strategies are successful in reducing the portion of animals with AHW problems or in increasing the portion of animals that are able to cope, respectively. Future research should aim to collect longitudinal data on single animals and single farms concerning a wide range of AHW problems to be able to follow individual animals and farms and to identify possible patterns over time.

Ecological validity is aligned to real-world phenomena. In light of the complexity of AHW problems within farm systems, it is the whole system that functions as a reference system. Instead of large-number trials, focussing on single interrelationships in cross-sectional studies (Rittweg et al., 2023), single case studies are suggested to advanced understanding of systemic interactions (Teixeira de Melo et al., 2020). This approach does not only fit to the complexity of farm systems and the development of multifactorial AHW problems but also to the fact that many dysfunctions and problems by which farmers are challenged have a number of equivalent solutions (Sundrum et al., 2016). In order to capture and reduce the complexity of AHW related factors on farm level, a farm centric and equifinal approach is suggested to reduce AHW problems by making use of a participatory approach (Krieger et al., 2017). Such a concept was developed to enable farmers to identify effective measures and to invest resources more efficiently. Case studies can be the basic to subdivide systems and subsystems according their starting and their boundary conditions and according to their needs and regarding the effectiveness of measures to improve AHW. In a further step, the external validity of single-case research should be evaluated across a collection of comparable studies in a meta-analysis to examine whether study findings can be generalized to other contexts. Outcomes from a meta-analysis may include a more precise estimate of the effect of treatment or risk factor for disease, or other outcomes, than any individual study contributing to the pooled analysis (Lean et al., 2009).

While farmers are striving for the most cost-efficient measures when considering to reduce AHW problems, there is little knowledge to be gained from traditional animal science. Those studies that linked animal health measures to farm level economic outcomes reveal a heterogeneous body of evidence in terms of both methods, animal health measures and economic outcome measures used. In a recent review, none of the included studies made explicit causal claims between AHMs and economic outcomes (Sandeberg et al., 2023). From an economic point of view, farmers can select between different options to deal with AHW problems. E.g., they can treat animals according to their individual AHW problems and support them in their ability to cope. It is also possible, to abandon them to their fate, or to slaughter them ahead of schedule. Furthermore, they can take the occurrence of specific AHW problems as a reason to rearrange the living conditions and management strategies and to change the allocation of available resources in order to prevent or reduce the re-emergence of AHW problems. In this context, regulatory authorities as well as food processors and retailers play an important role to provide feedback and make clear that decisions about the farm specific degree of AHW problems are not completely left to the self-referential estimations of the farmers.

How such decisions are made is seldom a careful balancing between the different options and their respective cost-to-benefit ratio. To do so, farmers would need data, which they in general don't have and a perspective that differs considerably from a strategy that seeks for productive efficiency primarily by measures going along with reduced efforts. Those enclose, among other things, a limited willingness to invest in comprehensive data collection and processing as well as in diagnostic procedures on the animal and farm level to gain knowledge and insight into the animal and farm specific background of AHW problems. Instead, it is about considering the alternatives. It would request a change in the mindset to focus on the disadvantages, farmers will face if they don't implement what would be appropriate in the case at hand, as opposed to the disadvantages they will face if they do. Instead, farmers often apply rules of thumb, which they seldom change over the years, for instance when considering a culling strategy regarding the most common reasons for culling (Kulkarni et al., 2023).

On the other hand, regular veterinary visits might be seen as an obvious strategy to provide opportunities for constructive conversations between veterinarians and farmers and for shifting management from a reactionary approach to proactively optimizing health and welfare. However, a recent research study in dairy farming revealed that veterinary visits intended to improve herd health and production management are not necessarily effective in questioning predominant management strategies (Ritter et al., 2021). In a study, a mean of 51% of the visit duration was dedicated to transrectal pregnancy and fertility diagnostics, and a considerable amount of time (30%) was spent on visit preparation, transitions between tasks, and leaving. Mean length of discussions was 2 minutes, and only 17% of the visit duration was spent discussing dairy-specific topics. Such insights in the relationship between farmers and advisory services suggest that it cannot be left to the practice alone to deal with AHW problems, when they are at the same time considered being of public interests.

Instead, a retrospective approach seems a promising option to understand the background behind the processes. For instance, raising the proportion of 'profit animals' seems a suitable strategic goal to provide orientation for the farm management and validation for implemented measures that consider heterogeneous farming conditions (Habel et al., 2021). While retrospective analyses exclude the possibility to react in real-time for individual cows, the monetary valuation associated with service life characteristics can help to prioritize when choosing between different options of investments. E.g., a retrospective examination might conclude that the living conditions need to be shaped according to the individual requirements of the animals to allow for a desired outcome, rather than to strive for measures that generalize animal and farm performance. Evaluation of the overall lifetime profitability along with identification of economically poor farm-specific herd characteristics can help to pinpoint problems, optimize herd management, and prioritize investment necessities. Joining economic results and AHW of individual animals is a way to change the perception of AHW problems from collateral damage to a cause for severe economic losses. The corresponding knowledge might foster farm individual, iterative change processes, aiming for less AHW problems and for a higher cost-to-benefit ratio to the benefit of all stakeholders involved (Hoischen-Taubner et al., 2021).

6 Conclusions

Livestock farms are increasingly challenged to meet the demands with respect to the issue of animal health and welfare of their farm animals. Animal science is called upon to support them in reducing AHW problems. However, the predominant reductionist and mainly mono-disciplinary approach of animal science with the main focus on the internal validity of scientific approaches to generate generalisable and therewith publishable results is ill-suited to solve AHW problems. These are context-sensitive as well as multifactorial. They develop within the farm specific interconnectedness of manifold and highly varying factors, emerging a complexity that does not allow predictive statements via inductive approaches but requires an iterative procedure to approach to a farm specific AHW level. Efforts and expenditures to solve AHW problems have to consider a balance between failure costs, caused by AHW problems, and preventive costs to reduce them while simultaneously striving for the economic viability of the farm system.

To face and meet the challenges, it is important to open animal science for a transdisciplinary research in the handling of complex, real-world problems that occur within the context of agroecosystems, which as a whole create the animal protection service and AHW level of a farm. Transformation knowledge is equivalent with problem solving knowledge that has proven to be effective in the context in which it is applied. Consequently, scientific knowledge needs to be more accessible and understood by the decision makers. Trade-offs have to be addressed on the scale where they emerge (principle of subsidiarity), following a bi-directional approach which simultaneously reflects upward and downward causation. Beside an adequate expertise expressed by the access to the various facets of disposal knowledge, orientational and action-guiding knowledge is required, duly substantiated by evidence. Thus, the primary goals should be to generate results with sufficient external and ecological validity. Otherwise, the effectiveness of measures to reduce AHW problems cannot be assessed with the necessary validity to convince farmers to implement them.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

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