Chapter

Nutrition and Health-Management in Dairy Production

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Abstract

The 'barrel model' of an organism's resource allocation pattern represents the basics for feeding regimes in farm practice. Several objections can be raised against the underlying theoretical assumptions, the generalizations derived from them, and the application of the model in practice. The concept particularly neglects the role of glucose and the increased competition for it between lactocytes and immune cells. It also fails to recognize the large variation between and within dairy herds. Lack of success in reducing production diseases calls for a modified approach – one which not only deals appropriately with the large variation between and within the dairy herds but also strives to balance the existing productivity/animal health/financial trade-offs. Instead of following general procedures, nutrient supply and outflow via milk have to be adapted to the individual requirements and health risks. To do so, the percentage of dairy cows affected by production diseases and failing to cope is a key criterion. Benchmarking of production diseases could act as an orientation point for farmers to compare their own position to other farms and thus set realistic target figures. Furthermore, means and measures to achieve goals have to be validated in the context in which they are used.

Keywords: complexity, energy balance, glucose deficits, production diseases, target figures, role of animal science, reductionist approach

1. Introduction

Various field studies suggest that dairy farming in general has up to now failed to substantially reduce the prevalence of nutritional disorders and associated comorbidities [1–3]. According to LeBlanc [2], dairy production is challenged by the fact that 30–50% of dairy cows are affected by some form of metabolic or infectious disease around the time of calving. The knee-jerk reaction which insists we still do not know enough to considerably reduce the undesired side effects of production processes is not valid as long as the current knowledge is not adequately implemented. On the contrary, it could be argued that the seemingly never-ending search for further knowledge in the same direction can be blamed for preventing reflection and discussion about a possible need for fundamental changes in the strategic orientation of dairy farming. However, as long as research emphasis is placed on finding technical and genetic solutions for current problems, the impression is created, and will remain, that there is no need to consider modifying the actual dairy systems. Yet in light of the lack of success, the question arises whether the high prevalence of production diseases (Pds) is not in fact an inherent problem of the production processes across the dairy industry. In raising this basic question, it is not the intention of the following script to repeat or summarize the general recommendations found in literature and text books that claim to provide options for reducing these serious problems. Instead, the objective is to question predominant thinking patterns and to reflect on the weak points and driving forces that might be responsible for preventing effective progress in the reduction of Pds in dairy farming.

2. Nutritional disorders and production diseases

Production diseases are a negative side effect of the production processes. They are not merely a peripheral phenomenon, although often mistakenly dealt with as such, but are related, amongst other things, to the issues of animal welfare and food safety. Pds adversely affect productivity and reproduction and can have severe economic implications due to related failure and prevention costs [4]. Moreover, products of diseased animals are of inferior quality, a fact recognized by consumers, who are aware of the problems in animal production. Thus, the high prevalence of Pds gives rise to questions and discussions about production processes and what responsible management actually entails. Pds have been under discussion in animal science since the first Int. Conference on Production Diseases in Farm Animals in1968, an event which has occurred periodically ever since [5].

Disturbances of one or multiple metabolic processes related to the regulation of a particular metabolite in the body fluids are known as metabolic disorders [6] and are a manifestation of the cow's inability to cope with metabolic demands [7]. Clinical diseases closely related to a suboptimal nutritional management are, amongst other things, ketosis, milk fever, metritis, mastitis, and lameness [8]. The known interactions between various metabolic stressors, and their relationships to other diseases, particularly infectious and inflammatory diseases of early lactation, have become "a central focus of interest in the study of metabolic diseases in dairy cattle" [9]. Nutritional disorders and comorbidities have been comprehensively discussed elsewhere [10]. In the following, they are considered as production diseases.

Pds occur throughout the lifetime of dairy cattle but are never so pronounced than in the transition phase, the 6 to 8-week period centered on parturition, and which is known as the most challenging and critical period for a dairy cow during the lactation cycle [11]. Within this period, major physiological, nutritional, metabolic and immunological changes occur. The production cycle of the cow shifts from a non-lactating state to the onset of extensive milk synthesis [12, 13]. Cows have to adjust metabolically to the sudden increase in energy and nutrient requirements and supply. Gaps between nutrient demand and supply can coincidentally occur with substantial variations in the nutrient content of the diet and in the daily intake of dry matter (DMI). Dealing with this requires comprehensive adaptation and regulation of the metabolism. Desirable outcomes for farm management are: cows that are successful in adapting metabolically to challenges inside and outside of the organism with minimal to no disease events and a reduction in avoidable culling as well as cows with efficient productive and reproductive performances. Past intensive research conducted into nutritional requirements, physiological adaptation and metabolic associations with periparturient diseases of cows has not led to any substantial reduction in the prevalence of Pds. Despite the fact that solutions are still not clearly evident, most in the dairy industry continue to believe that there are tremendous opportunities to improve the health and reproductive performance of transition cows without compromising milk production [14].

3. Allocation of nutrients by the farm management

It is beyond dispute that allocation of nutrient resources to the farm animals by farm management is of high importance for the realization of both a high level of productivity and a low level of Pds. However, in farming practice the nutrient allocation is not always demand- and target-oriented. In general, the diet offered is either in the form of a total mixed ration ad libitum or in a combination of a feed mixture ad libitum, both supplemented with an assigned amount of concentrate via an electronic feeder. The allocated amounts of concentrate are deduced from a more or less accurately estimated level of milk performance of each individual dairy cow, while the total or partly mixed rations are generally formulated according to the average performance level of a herd or feeding group of dairy cows.

This approach, however, neglects the large variation in the requirements of the animals due to, amongst other things, inter and intra-individual variation in milk yield, body weight and, last but not least, variation in feed intake. Grouping strategy and feeding behavior as well as social rank between the animals have a considerable impact on the competition between them for space and feed, and thus on feed intake [15]. Accordingly, a large inter and intra-individual variation of feed intake is observed in farm practice [16]. The amount of daily nutrient and energy intake is a result of the interactions between the composition of the diet itself, the environment in which a diet is offered and various intrinsic processes [17]. On the other hand, the same dry matter intake (DMI) per cow and day can be achieved by altered frequencies and durations of eating time and meal sizes. Nutrient and energy intake can change dramatically in response to changes in diet composition or metabolic state. Feeding regimes on a farm might appear to be regular but hidden variations in the nutrient and energy supply can occur to a greater or lesser degree. Furthermore, the feeding rations offered can be quite variable in their composition, for example in the portion of roughage and concentrate, throughout the course of time, thus correspondingly in the availability for the animals within the digestive tract [18]. Furthermore, the proportion of single components can vary considerably due to imprecision in mixing and/or in allocation procedures.

In light of the numerous sources of variation, feeding rations offered in farm practice cannot precisely meet the requirements of an individual cow within a feeding group or herd. The gap between demand and supply underlies a considerable variation between the animals. In general, farm management lacks insight into the degree of the inter and intra-individual variations and discrepancies. Knowledge about the impacts of nutrient supply is often restricted to the outcomes of feeding regimes in terms of the individual milk yields and content on a monthly, seldom on a daily, basis. Many farmers have knowledge about the composition and ingredients of the feeding ration and they can base estimations about the required feed intake on the analyzed portions of the diet [19]. However, these estimated equations are only valid for one virtual cow but represent the average of a feeding group. Considering that the interactions between the numerous influencing factors, of which only few have been mentioned, create a virtually unlimited number and variety of combinations (even within one single cow, let alone a herd), the discrepancies between demand and supply can only be poorly predicted by traditional models of feed intake regulation [20].

4. Resource allocation within dairy cows

Available energy is used by animals during biological processes (chemical, active transport, mechanical, electrical and thermal work) which are essential for building, sustaining and enhancing biological structures [21]. To grasp the complex processes within the organism, Weiner [22] proposed the 'barrel model' of an organism's resource allocation pattern, defined as the partitioning of available energy and substrates into various essential life processes, and into body structures and tissues [23]. According to Rauw [24], "input constraints (foraging, digestion and absorption) are engaged in series, whereas outputs (maintenance, growth and production) are parallel and independently controlled. If the sum of the output rates does not match the input, the balance is buffered by the storage capacity of the system" (**Figure 1**).

Feeding regimes in farm practices are generally based on this model when trying to meet the estimated requirements of cows with an adequate nutrient and energy supply, and to assess the amount of milk that can be expected from the ingredients offered by the diet. The 'barrel model' seems to be quite plausible in explaining the balance between input and output variables, and in offering options for farm management to react to increasing demands in the course of increasing output of energy via milk by inducing an increase in feed intake, digestibility and absorption of nutrient resources, and thus an increase in the availability of energy for the intermediate metabolic processes. However, when viewing this approach from different angles, several objections can be raised against its underlying theoretical assumptions, the generalizations derived from them and the application of the model in farm practice. The objections relate to the issues of self-maintenance,

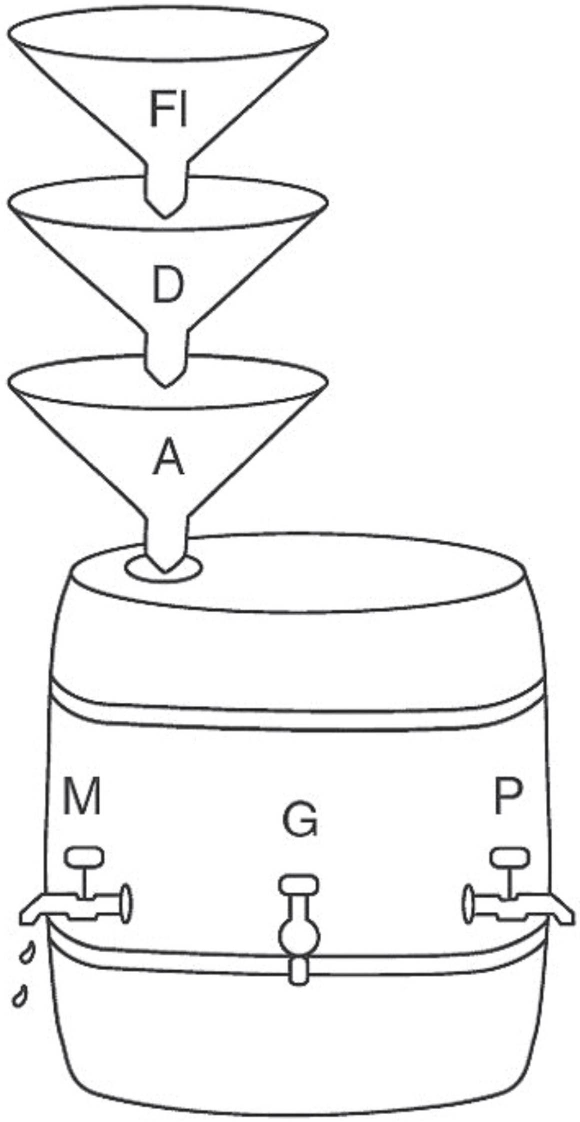

Figure 1.
The 'barrel model' of an organism's energy balance. The first spigot always leaks basal metabolic rate. FI, feed intake; D, digestion; a, absorption; M, maintenance; G, growth; P, (re)production [24].

storage capacity, regulation of allocation, intra and inter-individual variation, lack of evidence and the impacts on animal health and welfare. These issues are discussed below.

5. Available resources for (self-) maintenance

Not only a producing but also a non-producing animal expends nutrients to maintain its life processes. Every animal assures these expenditures have been met before allocating ingested nutrients to any other use. When comparing species of differing size and body weight (BW), it is known that smaller animals have a higher demand for maintenance energy than larger animals. The percentage ratio of regression to BW is approximately 0.75 and this is the accepted common base for the expression of maintenance requirements for nutrients across species [25]. Theoretically, it is an easy approach for calculating energy requirements of farm animals. It requires only reliable information on BW. Given the large variation in BW between dairy cows within a herd, and due to substantial changes which occur during the lactation period [26, 27], gaining reliable BW figures would demand a regular recording of individual BWs. This however is seldom consistently carried out in dairy farming.

Furthermore, cows of similar BW, size and breed may vary considerably in their requirements for basal metabolism. For example, locomotion activity is often considered as part of the 'maintenance requirement' even though the extent of activity, e.g. foraging, can differ extensively between cows. This also applies to the requirements needed to maintain the body core temperature because metabolically busy animals do not need additional energy to maintain body core temperature at the same ambient temperature as metabolically less busy animals. Much more significant is the fact that meeting the energy requirements for the basal metabolic rate and its variation due to differences in BW, activity level or cold and heat stress does not cover the requirements that are needed to ensure self-maintenance of the animal when faced with the various threats they have to cope with. McEwen [28] coined the term "allostatic load" within the concept of allostasis to describe potential permanent overburdening of homeostatic processes. One can imagine allostatic load increasing due to the rising energy expenditure required to fuel regulatory processes. Accordingly, allostatic load is the sum of the energy required to maintain basic homeostasis and to acclimate to changing environmental conditions.

The immune system, as one of the body's sensory organs for controlling interactions with the environment, is integrated into the physiological regulatory mechanisms that maintain the integrity of the host in the face of diverse environmental threats. Immune responses are not only influenced by the nature of the pathogen but also by characteristics of the host: age, gender, passive immunity, prior exposure to the pathogen, concurrent infections, physiological status, micro and macro-nutrient status as well as the presence of concurrent stressors [29]. The author identified demands on the immune system related to, amongst other things: "increased metabolic activity - systemically during fever, locally during activation of immune system cells; reduced nutrient availability due to anorexia and/ or other sickness; altered priorities for nutrient utilization due to changes in the gradient during immune activation that reduce the capacity of many non-immune tissues to utilize nutrients".

Whatever their origin, e.g. the accumulation of pro-inflammatory processes in dairy cows around parturition, disorders and diseases implicate the need of energy and substrates. These are needed to adequately meet the requirements of the immune response to prevent severe health problems of dairy cows and to support the overall goal of self-maintenance. According to Aitken et al. [30], "many aspects of the bovine immune system are compromised around the time of calving, especially the inflammatory responses". Immune suppression in the periparturient dairy cow is a commonly observed phenomenon and has been linked to poor metabolic status and negative energy balance [13, 31, 32]. Thus, attenuation of the immune response to the various challenges is, in the first place, the result of limitations in the availability of energy and substrates.

Besides energy, the organism requires protein, vitamins, minerals and trace elements in appropriate amounts in relation to the individual needs. Here the role of glucose must be emphasized: this substrate is used by the highly energy-demanding immune cells as a main source of fuel for immune defense and should therefore be considered the quantitatively most important fuel to fulfill the energy requirements of immune cells [33]. According to Ingvartsen and Moyes [34], "as glucose is the preferred fuel for immune cells, its low concentration during the transition period may partly explain the naturally occurring immunosuppression at this time". Another study [35] shows that ketones are not utilized by immune cells and in fact primarily act as inhibitors to immune responses when concentration is relatively high. In comparison with healthy controls, ketotic cows have increased circulating LPS prior to calving, and post-partum acute phase proteins such as LPS-binding protein, serum amyloid A and haptoglobin are also increased [35]. Endotoxin stimulates the immune system and activated leukocytes switch their metabolism away from oxidative phosphorylation to rely more on aerobic glycolysis [36]. The energetic cost of immune-activation is substantial but the ubiquitous nature of the immune system makes precise quantifying of the energetic demand difficult. Kvidera et al. [37] estimated approximately 1 kg of glucose is used by the immune system during a 12-hour period in which lactating dairy cows were challenged by LPS. This amounts to 2 kg of glucose per day for the immune system alone. This is more or less equivalent to the amount of glucose a cow withdraws in the form of lactose when producing an amount of 40 kg of milk per day [38]. In this context, it has to be considered that the synthesis of lactose alone utilizes 65–70% of the cow's total glucose turnover [39].

An increased immune system glucose utilization occurs simultaneously with infection induced decreased feed intake. This coupling of enhanced nutrient requirements with hypophagia further decreases the amount of nutrients available for the synthesis of milk. In the face of limited availability, glucose is allocated preferentially to a selected function at the expense of other functions, resulting in trade-offs and increased competitive pressure. Immune responses are context-specific and the costs vary considerably depending on the pathogen, the environment and defense capacity of the host. Immune defense activities create highly individual outcomes depending on the initial and boundary conditions, and on the degree of the mismatch between demand and supply. The context-specific and individual nature of immune activation suggests that quantitative estimates of the costs of immune activation can be neither readily generalized nor predicted. This might explain why the costs of immune defense are not a prioritized issue of animal science. Apart from striving for an easy approach to asses energy requirements of farm animals, it is quite astonishing and disturbing to realize that the costs of self-maintenance for farm animals are largely disregarded by the scientific discipline of animal nutrition. This may be due to the fact that feeding trials are generally conducted under standardized experimental conditions and usually on healthy animals which probably do not require high levels of additional energy and other substrates for the immune defense. Therefore, the results of feeding trials under experimental conditions enclose a high degree of uncertainty when transferred into practice on dairy farms where production diseases are frequently found.

The 'barrel model', with its focus on energy demand and supply, considers neither the requirement of glucose for adaptation processes nor the need for a glucose buffer to fuel a short-term activation of the immune defense. Furthermore, it is obvious that the allocation of nutrients and energy resources for the various needs is not regulated independently, as assumed by the 'barrel model', but is highly interconnected. In the past, it may have been rational for the diet formulation to consider maintenance, growth and production as separate singular outputs. In face of increased knowledge, it is not justified to maintain these assumptions any longer.

6. Storage of energy and glucose resources

Once nutrients are absorbed, they belong to the total energy and substrate pool and the stores of the body which make up the overall pool of resources. Metabolites in the form of carbohydrates, protein and fatty acids which are not needed in current metabolic processes are transformed and stored in the adipose tissues of the organism to serve as a reserve in periods of deficiencies. Fatty acids in the adipose tissues represent the main source of energy which the organism can fall back on when the supply does not meet the current needs. The 'barrel model' suggests that the energy balance is in general buffered by the storage capacity should the sum of the output rates not match the input [24]. Whenever intake is insufficient to support production – as in early lactation – energy is mobilized from body fat via the liver causing cows to milk off their backs and lose condition.

According to Friggens et al. [40], "high-yielding dairy cows have been genetically selected to partition even more glucose into milk production with the effect that reliance on body reserves has dramatically increased". Patton et al. [41] stated: "Even in the case of higher dietary intake, the increased input will primarily result in greater milk production while having little effect on energy imbalance and no beneficial effects on body condition and reserves at all". Although the storage capacities in the adipose tissue may seem to be abundant, the mobilization of fat can cause problems if the lipolysis is accelerated too fast. Metabolic changes, e.g. the process of uncontrolled lipid mobilization in response to excessive negative energy balance, increase the risk of ketosis, hepatic lipidosis and infectious diseases [42, 43]. Sordillo and Raphael [13] addressed the possible connections between fat mobilization and dysfunctional inflammation responses that may contribute to increased morbidity and mortality in the transition phase. Failing to adapt physiologically to an increase in nutrient requirements needed for the onset of milk synthesis is equivalent to metabolic stress and a major underlying factor in the development of transition cow disorders [44]. The authors conclude: "The combined effects of altered nutrient metabolism, dysfunctional inflammatory responses and oxidative stress can form destructive feedback loops that exacerbate metabolic stress and cause health disorders."

As mentioned above, dairy cows have a high demand for glucose. The storage form of glucose is glycogen and although widely distributed throughout the mammalian body, quantitatively the liver and muscle account for most of the body's glycogen stores. The liver glycogen depot plays a central role in intermediary metabolism, by storing and mobilizing glycogen during the metabolic states, with these responses modulated during pregnancy, lactation and exercise [45]. Metabolizable energy intake is the key driver. The glycogen depot in the muscle on the other hand is particularly important for local energy homeostasis. Compared with simple-stomached species, the rate of glycogen synthesis within ruminants is relatively low. Because ingested carbohydrates are efficiently fermented to short-chain fatty acids in the rumen, ruminants are required to meet the largest part of their glucose demand by de novo genesis [46]. A de novo generation of glucose by gluconeogenesis from non-carbohydrate precursors (e.g., lactate, glycerol, and amino acids) supplements the exogenous supply of glucose. Propionate is by far the predominant substrate for gluconeogenesis in ruminants [47]. The authors state that "the quantitatively most important adaption of metabolism to support the increased glucose demand in the immediate postpartum period is endogenous recycling of glucogenic carbon through lactate. This is mediated by a dual site of adaptation of metabolism in the liver and in the peripheral tissues, where the liver affinity for L-lactate is increased and glucose metabolism in peripheral tissues is shifted towards L-lactate formation over complete oxidation". Furthermore, the amino acid alanine is likely to contribute to liver release of glucose. If these adaptations fail, lipid metabolism may be altered. Increasing feed intake and provision of glucogenic precursors from the diet are important to ameliorate these disturbances. This applies in particular for an efficient gluconeogenesis because it is the major pathway for maintaining an adequate glucose supply. Glucose is, however, not only dedicated to the lactocytes in the udder, as emphasized by many animal scientists [39, 46], but is also as an essential fuel for many other cells and tissues of the organism. Thus, glucose needs to be permanently available at a sufficient level in the blood stream, and at the disposal of all cells which depend on it for their unimpaired operability. According to Bell [12], "daily requirements of glucose, amino acids, fatty acids and calcium for an early lactation cow are, respectively, more than 2.7, 2.0, 4.5 and 6.8 times greater than those needed for pregnancy. These differences represent changes in nutrient requirements over a short period of only one to two weeks, highlighting the tremendous metabolic alterations necessary to adequately support lactation." An imbalance in the glucose supply of high yielding cows in early lactation is unavoidable. The intensity of the imbalance is influenced not only by the level of milk yield and the degree of endogenous glucose provision but also by the demand of other essential tissues, inflammatory responses and, last but not least, by the immune defense.

In cases where dairy cows fail to cope with their living conditions due to the exceeding demands on their adaptation capacities, it is obvious that this is probably not only due to a lack of energy but also in particular to a lack of glucose. The concept of energy balance as represented in the 'barrel model' seriously neglects the role of glucose and especially the increased competition for it between the immune cells and the epithelial cells in the mammary gland. Furthermore, the 'barrel model' fails to consider that unpredictable events, including many biotic and abiotic stressors, need to be dealt with through immediate physiological and behavioral adjustments which can lead to situations in which the availabilities and the promptness of mobilization are overstressed.

7. Regulation of resource allocation

Biological regulation of the glucose balance within the organism involves a series of orchestrated changes; increased hepatic rates of gluconeogenesis, decreased glucose uptake and use by adipose tissue and muscle, a shift in whole-body nutrient oxidation so that less glucose is available as an energy source. First and foremost, the mobilization of essential resources requires well-functioning regulatory capacities to enable an efficient exploitation of resources to orchestrate a release of nutrients matching the requirements to a high degree and to deal with possible bottlenecks in metabolic pathways.

According to Baumgard et al. [39], the priority objective of the regulation is to ensure an adequate glucose supply to support lactation. A cow in a state of negative energy balance is considered "metabolically flexible" because she can depend upon alternative fuels (NEFA and ketones) to save glucose. In high yielding cows, the utilization of body energy reserves and the mobilization of body fat in the first month postpartum can be energetically equal to over one-third of the milk produced [48]. From a different perspective, the objective of regulation is to continually adjust the milieu to promote survival. Sterling and Eyer [49] introduced the term "allostasis" to refer to "changing regulatory systems ("stability through change"). Allostasis can be considered as the process of maximizing fitness in the face of environmental change and other unpredictable challenges. Regulatory mechanisms must change in order to maintain or achieve a state appropriate for the time of day or year and also in response to disturbances." From the perspective of the dairy cow, milk secretion is accompanied by substantial losses of energy and nutrients, particularly glucose from the body pool. A marked increase of cell differentiation and tissue hypertrophy in the udder is the starting point of an increase in milk yield [50]. According to Stefanon et al. [51], "the number of vital mammary epithelial cells control the initial conditions for the amount of milk produced as well as the amount of glucose needed for the production and secretion of lactose." Cows with a high genetic performance capacity for milk production are characterized by the ability to perform intensive gluconeogenesis and partitioning of the glucose into the udder while its contribution as a fuel source to extra-mammary tissues is decreased [12]. Because the uptake of glucose by the epithelial cells in the mammary gland is not insulin dependent, the cells have priority access to the glucose in the blood stream. According to Bauman et al. [52], "the productivity of this biological factory is extensive and in terms of the use of nutrients and energy, the cow should be viewed as an "appendage to the mammary gland" rather than vice versa."

Due to a sudden increase of nutrient requirements for milk production postpartum, a time when dry matter intake and nutrient supply lag behind, nearly every high yielding cow faces the challenge of shortages in energy and nutrients. According to Eastridge [53], "increases in genetic merit for milk yield go together with increases in feed intake but the latter does not fully compensate for the extra energy demands during early lactation. This results in a more or less extended negative energy balance and increased mobilization of body reserves." In order to sustain the various life-preserving functions, a limited availability of glucose provokes severe competition between different tissues in their need for glucose. It follows that "limitations require partitioning, and partitioning requires prioritization in guiding the nutrient flow to ensure that the demands of other cells, tissues and organs within the organism are not completely neglected" [48]. Accordingly, there is a need to avoid ruinous competition between sub-systems to prevent them from being swamped by unwanted side reactions which affect the viability of the system. Parasitic reactions by single organs at the expense of other organs may cause the whole organism to collapse. The question is, how and to what degree the regulation capacities are able to balance the trade-offs in their demands for glucose.

According to Lucy [54], "nutrient prioritization in early lactation to favor milk production over fertility is a reasonable strategy in biology. As nutrition becomes scarce, the lactating dam will preferentially invest the limited resources in the survival of living offspring rather than gambling on the oocyte that is yet to be ovulated, fertilized and cared for during an entire gestation. Selection for high milk yields takes advantage of the genetically programmed readiness of the dairy cow to enter into a negative energy balance at the onset of lactation and to mobilize resources from its body tissues." What is a natural biological process to ensure the maintenance of the offspring, however, might prove to be a self-harming trap when the selection process advances into dimensions that are far beyond the initial intention to ensure nutrient supply to the off-spring via milk. Dairy farming, and particularly breeding measures, takes advantage of the vulnerability of dairy cows in their self-defense against an excessive load by the demands of the mammary gland. However, milk production to safeguard the off-spring on the one hand and self-preservation of the dam on the other can come into life-threatening conflicts. This is the case when the gap between demand and supply gets to the stage where metabolic regulations are at risk of failing to balance the capacity of gluconeogenesis with the secretion of lactose, and of failing to mobilize the body resources needed to compensate for the deficits between nutrient output and intake. In general, the partitioning of resources within the organism is an excellent example of how cooperation works as long as there are enough resources available and as long as one part of the whole does not make unlimited demands at the expense of other parts. Shortcomings and problems can occur within several steps of the adaptation process, particularly those involving the adipose tissue and the liver. Further details have been explained elsewhere [10].

Generally, three options exist to alleviate the frequency and effects of these shortcomings and problems: (i) promote the absorption of resources to enhance availability or (ii) increase efficiency in the use of resources by partitioning the resources to those tissues and organs with the highest priority for the overall objective of self-maintenance or (iii) reduce the use of resources from the body pool as far as possible to sustain essential body functions. As absorption and partitioning have been optimized through a long-lasting evolutionary process, the major weak point lies in the limited capabilities to restrict nutrient losses via milk when it is necessary for the prevention of exhaustion due to overwhelming demands, and for self-maintenance. While the liver and muscle tissue have glycogen stores at their disposal, the mammary gland and the immune system rely completely on the body glucose pool. The body pool allows efficient trade-offs, that is, the organs grant each other short-term loans. If each organ were independently self-regulated, they would require their own reserve capacity, and thus more digestive capacity, to support an expensive infrastructure rarely used [55]. Efficiency in the use of limited resources requires organs to trade-off resources, that is, to grant each other short-term loans. However, milk secretion does not have an underlying central counter regulation which would enable a throttling of energy and nutrient losses via milk to prevent the dams from exhaustion and emaciation which subsequently weakens their adaptation capacities and risks their self-preservation.

The 'barrel model' illustrates that milking opens the flood gate for the loss of energy and nutrients, particularly glucose, from the body pool. However, energy and substrate losses, particularly glucose losses, can be so high that the minimum level required to sustain essential functions of the organism for self-maintenance is not maintained. The model is lacking possibilities to detect the filling state of essential resources in the body pool and thus those who are in charge lack information to throttle the outputs via milk to a degree necessary to leave enough resources for the processes of self-maintenance.

8. Dealing with inter- and intraindividual variation

The average milk yield per cow has increased considerably over the last decades, primarily as the result of genetic selection based on the moderate to high heritability of most production traits and the corresponding improvements in feeding regimes. Although animal breeders have accomplished a great deal in the past, they are not satisfied with these accomplishments. Accordingly, it is no surprise that the partitioning of energy within the organisms has also raised their interest. For animal breeders, options that emerge from the fields of genomics, proteomics, etc. to incorporate genetic differences between animals into nutritional models represent an area of exciting opportunity to improve nutrient partitioning and productive efficiency [39, 56]. According to Baumgard et al. [39], it is in fact only when the coordination of nutrient use is inadequate or an imbalance occurs that animal well-being and performance are compromised. However, in contrast to the underlying assumptions that inadequate coordination and imbalances in nutrient supply are exceptions, there is profound evidence suggesting that this is in fact the rule. The reasons are multi-layered and encompass the degree of supply, the processes in intermediary metabolism, the total requirements, and their coordination at the farm and animal level. The main reason, however, is inherent in the production process and lies in the large variation in the living conditions within and between dairy farms and in the intra and inter-individual variation at the animal level.

Dairy cows live under quite heterogeneous nutritional and environmental conditions and the individual animals themselves differ highly in their condition, their reaction and adaption capacities and, therefore, in their adaptive success. For example, while calculated energy balance is typically most negative within the first 12 days postpartum [57], differences amongst cows in time and extent of nadir and total energy deficits are large. In their study, the authors revealed that "over the course of 122 lactations mean values of total energy deficits during early lactation amounted to 1451 MJ NEL with a standard deviation of ±1062 MJ NEL. The postpartum interval to nadir of the estimated energy balance averaged 48 ± 29 days." Moreover, cows differ considerably with regard to the partitioning of energy and glucose between different physiological systems. Thus, cows with similar energy intakes and expenditures via the milk may actually experience differences in the burden of NEB and the shortage of glucose. This is not only based on genetic make-up (e.g. high v. low genetic merit) or the stage of lactation but varies greatly between individuals of the same genotype or in the same stage of lactation [58]. In their study, which allowed "discrimination between the roles of genotype (G), environment (E) (e.g. feed caloric density and milking frequency) and GxE interactions, the effects of genetic merit and milking frequency were significant only in the groups that were fed rations with high caloric density. However, signs of severe deficits in the availability of energy, poor protein balance and low body condition scores were not concentrated in the highest producing cows." Regardless of genotype, a reduced energy supply and extra milking had strong unfavorable effects on both energy and protein balance.

Large variations exist not only in terms of input and output but also in the availability of the various nutrients within the body pool. Substantial day to day variations in digestion and fermentation processes in dairy cows cause considerable variations in the relative quantities and supply of essential nutritional elements from the intermediate metabolic processes. This variation in the size of supply represents a real challenge for the metabolism in the face of demands for milk production and self-maintenance. Animals kept under highly standardized conditions on a research farm showed remarkable differences in changes in the concentrations of metabolites and hormones during the postpartum period [59, 60]. These findings indicate that the ability to cope with metabolic stress varies considerably between individual cows. On the other hand, energy partitioning between milk and body tissue can be altered considerably by diets that differ in lipogenic and glucogenic nutrient content [61, 62]. In addition, animals show enormous differences when confronted with various biotic and abiotic stressors and pathogens. In their reactions to changes in the environment, animals are not only influenced by the specific initial and boundary conditions, they also react self-referentially [63]. Unlike machines, their individual reactions cannot be predicted due to the interconnectedness of the numerous variables interacting with each other in a way that can switch from a more synergistic to an antagonistic relationship and vice versa.

In light of the large variation in biological processes and the deriving high level of complexity, the "barrel model" approach seems to be comparatively too simple and thus is not suited to be used in breeding and system biology to deal with differences between animals in the partitioning of nutrients. The approach lacks appropriate options to assess and deal with the intra and inter-individual variation of animals in their ability to cope with the highly variable internal and external challenges. The large amount of data harvested by "omics" techniques are noncausal. Nevertheless, representatives of "omics" research claim to demonstrate functionality and to develop a more comprehensive understanding of the regulation of the physiological processes and their role in animal productivity and animal health while applying the descriptive information gained from their research [39]. However, without accounting for either the large intra and inter-individual variation at the animal level or the variation in the living conditions at the farm level, it seems rather over-ambitious and presumptuous to claim accurate interpretation of the correlated changes.

A recent study [64], conducted on rabbits, provides some interesting observations and conclusions. Observing the resource allocation in different maternal rabbit lines revealed that the so-called "generalists" were able to appropriately allocate their resources to production, reproduction and health under suboptimal environmental conditions. The so-called "specialists" with high prolificacy were not able to allocate sufficient resources into health and reproduction. The authors concluded that the environment in which the animals are selected clearly drives the interplay between functions within the organism. If the objective of a selection program is to improve the overall fitness of animals without impairing productivity, a strategy is required that strives to establish a line of generalists.

9. Need for facts instead of assumptions

While the success of breeding programs in increasing the performance of dairy cows is obvious, their contribution towards improving the capacity of the animals to cope with unbalanced metabolic situations and challenges remains questionable. Breeding follows a single-sided approach that does not cover the multifactorial development of disorders and diseases, i.e., the approach does not consider why some animals are able to cope better than others. Nor does the approach take into account the context in which the animals are challenged. This applies not only to the respective conditions in which they live but also to the resources they can rely on or are lacking. In general, an external validation is not carried out because within breeding programs it cannot be assessed whether failures of animals in coping with the challenges are related to the genome or to the respective living conditions or to the interactions between both. Due to the lack of casual relationships, breeding programs can provide correlations but not explanations. Breeding programs do not demand, and cannot provide, a solution for the problems in the here and now. However, focusing and counting on breeding has the unbeatable advantage that it requires a fundamental change neither in the living conditions nor in the willingness to accept responsibility for the living conditions of the animals.

Primary causes and disturbing influences which contribute to the development of production diseases are manifold. They vary considerably between farms and animals. Some farms do well whilst others fail quite markedly in reducing clinical and subclinical problems, irrespective of average milk yields [11]. However, little is known about the causal network between the various factors involved in the uptake, partitioning and excretion of energy and nutrients [10]. Compounding the problem is the fact that variables such as feed intake, body condition, postpartum health and performance vary so widely amongst individual cows. Disturbances like change in diet, climatic conditions (heat stress), pathogen pressure, access reduction to trophic resources caused by competition with other individuals, injuries, diseases and other challenges can occur slowly or abruptly. The effects are disruptive and may be cumulative over hours or days or weeks. Additionally, factors such as an animal's current state of health and social status etc. may influence how it goes about its routines and how it responds to disturbances. Despite the highly heterogenous situation on dairy farms and the inter and intra-individual variation between dairy cows, the dairy industry still anticipates more robust and mechanistic models for predicting supplies and requirements of absorbed nutrients and available energy. Such models are expected to be useful in allowing for increased efficiency in the use of feed resources. Given the numerous influencing factors, the meaningfulness of models based on a few quantifiable variables is questionable, particularly when it comes to predicting the real outcomes. As adaptive success depends on the interactions between the level and type of threat, and on the current individual responsiveness of the cow, modeling this process is barely an option, let alone it providing information that allows for dependable prediction of outcomes. Nevertheless, modeling is suited to providing orientation towards possible outcomes (see explanations below).

High producing dairy cows are at a high risk of losing the capacity to cope with disadvantageous keeping and feeding conditions [58]. Diseases in animals are an indication that their physiological condition is out of balance [10]. This is often due to limitations and mismatches of resource allocation. Ingvartsen et al. [65] pointed out that evaluations found in literature on the relationship between performance and incidence of Pd are in all probability meaningless as inherent biological correlations – besides within and between-herd confounding effects – exist. According to Mulligan and Doherty [7], the hypothesis that high yielding cows automatically have higher levels of production diseases is likely to be as false as the hypothesis that lower yielding cows have lower levels of production diseases. Health problems are context-variable and need to be addressed in the context in which they emerge. Often, the degree of the clinical signs of disorders and diseases is neither assessed comprehensively nor monitored consistently, let alone always tracked down to the possible causes [66]. Achieving a low prevalence of production diseases is rarely considered as an independent production goal as it is easier to simply perceive them as being an unavoidable negative side effect of production processes. The multifactorial background of production diseases as the result of overstressed adaptation capacities hinders easy identification and solving of health problems. Commercial farms can seldom provide conditions that allow observations to be performed on a ceteris paribus basis as under experimental conditions. In contrast, impacts of the various influencing factors on the ability of farm animals to cope are not constant and do not emerge separately from one other. Adaptation is a functional and target-oriented process involving the whole organism and thus cannot be narrowed down to single factors [10].

Instead of following general assumptions and mental associations about possible relationships between single variables and the impacts of management measures on these variables, an obvious step when striving to solve health problems in the here and now is to estimate the degree of metabolic disorders and associated comorbidities at an individual farm level. Doing this requires regular monitoring, an indispensable component of any serious attempts to develop context-specific strategies regarding the improvements of production diseases. This alone, however, is not enough. It needs to be supplemented with the acquisition of further data on individual cows, particularly the degree to which the energy and nutrient supply correlates to the individual needs of an animal according to its specific stage of life and living situation. Yet, generally speaking, even when available, farm management is often not able to correctly interpret data regarding the negative energy balance of the individual cows and thus cannot know which animals are at a higher or a lower risk, which animals are able to cope with the NEB and which ones are showing disorders as a sign of adaption stress due to whatever reasons.

10. The role of farm management

Modern animal production is mainly based on economic principles; neither animal health and welfare nor ecological issues are taken much into consideration. However, the high morbidity and mortality in dairy production associated with poor welfare conditions necessarily questions modern industrial farming practices. In the past, politicians, agronomists and animal scientists have appeared to assume an ability in the markets and in science to drive technological changes which will enable the economic-environment system to both satisfy increasing global food demands and simultaneously solve problems of animal health and welfare. These key assumptions, however, have turned out to belong to the category of wishful thinking, lacking as they are in any profound evidence. They generally neglect, on different scales, the biological basics, particularly the complexity of physiological processes as well as the ambivalent nature of productivity and the resultant trade-offs. Whether processes are beneficial or non-beneficial very much depends on the context in which they take place and the level at which the situation in question is being analyzed. The same is also true for the possible options of balancing the trade-offs between economic interests and animal health and welfare in a cost-effective manner. Thus, the frequent attempts to formulate one-size-fits-all general recommendations for a successful implementation of measures are often misleading and contradict the actual context-specific nature of biological processes and the subsequent need for context-specific solutions at all levels of dairy farming.

10.1 Lack in orientation

For the farmers, it is often very important to know where they stand in relation to other farms. Data from a representative number of farms could be used to create a scale ranging from very low to very high prevalence of Pds per farm unit thus giving farm management an idea and orientation as to whether the individual farm belongs to the category of farms with a low, a middling or a high level of health problems. However, as long as data on production diseases is not sufficiently solid, it has little practical value for farmers and they can basically disregard it. Thus, a diagnostic procedure is essential for the assessment of the prevalence of Pds as well as for the identification and implementation of measures appropriate for the farm specific situation and for the need to balance partly contradicting goals. Both the rate of productivity and the prevalence of production diseases on dairy farms emerge from very complex processes. Focusing on single aspects without taking into account both the context and the conflicts between achieving productivity and the development of production diseases does not allow any truly valid statements and can be said to be overly narrow.

In contrast to zoonotic and epizootic diseases, productions diseases are not yet a matter of public concern. Although accompanied by pain, suffering, distress and longer persistent harm, they are not even fully recognized as a severe animal welfare issue. Being primarily treated as an internal affair of the farm, Pds are not regulated by legislation but left in the hands of the farmers and their individual readiness to act. Generally, personal economic concerns are a greater deciding factor than concern for the health of animals. Indeed, it is often said that farm management is interested in reducing Pds solely due to economic reasons. Indeed, there is no doubt that Pds can cause severe economic losses. However, there is still a lack in valid data about the degree of failure costs, and particularly on the effort in terms of labor time and investments required to reduce the prevalence of production diseases in the farm specific context [4]. To reduce production diseases in a cost-effective way and to maintain production at a competitive level is not only highly contextual and thus requires appropriate farm-specific measures but also relies on a function of margin utility. This applies to the use of resources e.g. high-quality feed, labor time, investments to reduce production diseases as well as to the intensification occurring in the increased use of inputs. Additionally, the conditions outside the system boundaries (in terms of the price of products sold, availability and price of resources needed to reduce production diseases) have to be considered. Cost–benefit relationships not only depend on the status quo for both productivity and production diseases but also on the gap between the status quo and the envisaged target figures.

10.2 Need for profound data

Optimization of the relationship between productivity and the prevalence of Pds to the benefit of both the farmer's income and the health and welfare of farm animals requires access to reliable farm-specific data. Thus, a major question is how to increase the availability of valid data and how to create an overview that can support decisions of management regarding an efficient allocation of available resources. Records of milk performance at an individual level – either through daily milk yield measurements or official milk recording – are valuable tools, and not only for performance monitoring. They also reflect the individual requirements of the dairy cows in the course of lactation and are thus essential for implementing a target-oriented nutrient supply. Often this data may be considered unnecessarily costly or time-consuming for flat rate concentrate feeding or TMR systems. Lactation curves plotted for individuals or groups of animals provide a very graphic illustration of performance. Since it is always one of the first things to be affected by the diet, milk components are an essential element for monitoring the impacts of energy and nutrient supply on dairy cows. Fat and protein levels are especially valuable indicators of diet adequacy. Furthermore, feed intake is a critical factor in providing the right degree of nutrition. Given the wide impact, dietary problems and imbalances can have on productivity, monitoring specific aspects of dairy health and fertility can be very valuable in feeding management. However, appropriate techniques for the assessment of feed intake at the individual level are not yet fully developed for use in farm practice. One sophisticated and cost-effective technology which is available but seldom implemented on dairy farms is measuring equipment which can continuously determine the body weight development. More often in use is the tool of Body Condition Scoring which provides information about the measure of a cow's energy balance. However, one disadvantage of this tool is that long temporal delays can occur in receiving the information on discrepancies and thus in subsequent responses to the information. The time delay between cows receiving too little energy in their feed rations and any resulting pregnancy rate problems often go unrecognized until it is too late to do much about them. This is compounded by the fact that fertility is not given sufficient prominence within rationing programs although fertility, like lameness, is now recognized as being caused by a number of factors, including inadequate nutrition. Furthermore, disorders like acidosis, ketosis, displaced abomasum and fatty liver are clear signs of dietary problems, especially if they affect a number of animals rather than just the odd individual and occur regularly rather than occasionally.

10.3 Dealing with complexity

Due to the fact that being confronted with the complexity of production diseases for a long time, farm practice is unswervingly in search of simple approaches to deal with unintended side-effects. This contradicts with the major challenge, namely variation, in dairy farming: variation in the energy and nutrient supply of the individual cow, variation in the utilization and partitioning of energy and nutrients and the differences in the requirements needed for the essential tasks of regulation and immune defense, resulting in a large variation in the gaps between supply and demand. Without feeding control measures, it is left to the animals to cope with the occurring discrepancies. In this respect, an apparent "survival of the fittest" selection occurs at the farm level. However, it is not necessarily a selection between farm animals based on comparable initial and boundary conditions but on a highly variable situation in terms of performance level and additional demands by fluctuating internal and external stressors. Consequently, the selection might occur to a high degree by pure chance.

The prevalence of production diseases on farms indicates the degree of shortcomings of farm management at two levels. Firstly, regarding the degree of a demand-oriented supply with energy and nutrients according to the individual requirements, and secondly, regarding protection against stressors such as pathogens, crowding effects or heat stress which lead to a need for additional resources. Production diseases are always context specific. The context is characterized by the specific farm conditions, the individual cow situation and the interactions between both. Dairy farms vary widely when it comes to the living conditions of the animals. Thus, health problems require a diagnostic procedure at the farm level. This diagnosis needs to include the most relevant influencing factors involved in the multifactorial processes as well as estimations about the most effective and efficient strategies in the farm-specific context [3, 67, 68].

10.4 Assuming responsibility

An important prerequisite for any improvements, however, is related to the need to assume responsibility not only for the results of efforts to increase productivity but also for the negative side effects of the production processes. The farm management designs the living conditions of farm animals and organizes the allocation of resources but it is also, to some degree, responsible for the resource partitioning processes within an organism. This applies to breeding for a high number of lactocytes in the mammary gland, which is responsible for a prioritized skim of glucose from the body pool, and to sucking away every last drop of milk via milking. Metabolic disorders indicate an imbalanced trade-off between the original goal of sustaining the offspring via milk and the goal of self-maintenance of the dam. Farmers are challenged to reduce the degree of trade-offs by adapting the breeding practices to the quality of available nutrients and, at least, temporarily, decreasing the amount of milk extracted during milking, perhaps also the frequency of milking. To increase milk production, it is not uncommon in intensive dairy systems to increase milking frequency to three times daily. Reducing milking frequency is much less common. In doing so, it is in fact possible to improve the overall energy balance of cows during early lactation with once-daily milking [69]. Furthermore, this procedure can entail an improvement in the metabolic profile [70] and immune function [71] of dairy cows. In contrast, Soberon et al. [72] reported that cows subjected to an increased milking frequency are 1.4 times more likely than the control cows to be classified as sub-clinically ketotic. Depending on the stage of lactation, breed, and parity, the reduction in milk yield losses in the course of short-term alterations to milking frequency in early lactation varies considerably and can amount up to 22% [73]. This figure has been revealed as an average milk loss across 30 different international short-term studies. While it is comprehensible that short-term alterations to milking frequency may provide a tool to better manage the metabolism and energy balance of cows during early lactation [74], many farmers fear that the losses in milk yield could be too high. All the more is it necessary not to go for a general strategy but to develop a farm specific strategy that suits the situation of the individual cows, thereby also considering the fears of farmers. The aim should be to throttle the withdrawal of milk by adapting the quantity to the estimation of risk for the individual cow. This practice would be suitable under certain infrastructural farm conditions, including the availability of valid data on dairy systems where an emphasis is placed on animal health rather than on milk production per cow.

10.5 Unfair competition

Finally, the crucial question is, at which rate of disturbances and Pds should an intervention by farm management take place. Currently this is determined solely by individual farm management, often to the detriment of the animals. Farm management, however, would be well-advised to show an interest in reducing the prevalence of production diseases. A high prevalence of production diseases represents a low health performance by farm management. Farms with a high prevalence of Pds are not only disregarding their obligation to prevent suffering of the animals but are also delivering inferior products to the market. Thus, low levels of Pds should be seen as a significant production goal which carry as much weight as productivity goals. However, setting low disease levels as a production goal will only occur when farmers realize that they can gain an advantage over competitors who have higher levels of Pds. On the other hand, farms behave unfairly when they cause, and/or basically ignore, a high level of Pds and related welfare problems and therefore produce an inferior level of product and process quality while simultaneously achieving the same market prices as those who invest time, money and effort in product and process improvements. Moreover, farm associations, like those of organic agriculture, should be more concerned about unsatisfactory health performances amongst member farms and doing more to raise the lack of concern shown by their consumer clientele as this defies general consumer expectations and any efforts to justify the premium prices [75]. Whether it is intrinsically motivated or forced by economic reasons or the demands of retailers to improve the current unsatisfactory situation regarding the prevalence of production diseases, farm management needs to know how and where to direct its efforts. Benchmarking would offer an appropriate methodological approach to deal with the issue of unfair competition and also with the uncertainties in the assessment of Pd data as these methodological uncertainties affect all farms, if not exactly to the same degree. Benchmarking allows target figures to be deduced from the average levels obtained from assessing a sufficient number of comparable farms or from an estimate of the optimum balance between productivity and disease related loss and failure costs. While farmers are generally hesitant in their readiness to extend control to others, farm management lacks orientation regarding its own position in relation to other farms and regarding the target figures it should aim for in the future as long as benchmarking is not established. The lack of benchmarking for Pd values in relation to the product quantity of products from animal origin can be seen as one of the main barriers in the fight to reduce nutritional disorders and related Pds in dairy production.

11. The role of animal science

Due to the lack of sustainable success in reducing production diseases, or at least the lack of evidence of a general improvement in animal health and welfare in dairy farming, the various disciplines of animal science are challenged to reflect on the possible reasons and on their own role in the overall process.

11.1 Predominant focus on performance

Increasing the milk performance of dairy cows is still the predominant goal in dairy production, primarily driven by economic considerations and supported by various disciplines of agricultural and animal science. Particularly the discipline of animal breeding continues to embrace this strategy, even though scientists make efforts to integrate functional traits in the breeding programs, so far with no truly convincing success. The traditional approach of animal breeding indirectly evokes the impression that it is the animals and/or the genome rather than the living conditions which are the real weak points in the system and, consequently, it is the former rather than the latter which needs to be further improved. It is obvious that a unilateral focus is not appropriate for dealing with problems that emerge from the interactions between various components within the organism, and between the organism and its respective living conditions. Dealing with the issue of animal health and welfare in dairy production cannot just be left to the predominant paradigms and interests of single disciplines. Instead, there is a need to first gain an overview and to identify the predominant weak points in the farm-specific context. A unilateral objective of increasing milk performance, together with a one-sided disciplinary focus are probably at the heart of the ignorance surrounding the negative side effects which accompany the production processes. On the other hand, what is being ignored cannot be solved.

In light of the farm-specific challenges, particularly the large inter and intra-individual variation of the gap between nutrient demand and supply, the scientific discipline of animal nutrition is not yet able to offer adequate tools to balance energy and nutrient input/output figures on an individual base. When the supply level is tailored to suit one virtual cow whose average values of nutrient and energy requirements act as the reference for a whole feeding group, then the variability in the requirements between the individual cows of a feeding group is widely disregarded. This also applies to the requirements an individual animal needs for regulation (allostatic load) and immune defense activities in relation to the supply of energy and nutrients, particularly glucose. The additional requirements are hard to predict and are thus blind spots in the discipline of animal nutrition. However, they cannot be disregarded any longer when the reduction of the prevalence of production diseases on the farm level is on the agenda.

While some scientific disciplines are engaged in furthering increased performance in animal production through, for example, breeding or feeding methods, other disciplines, e.g. veterinary science are trying to deal with the negative side effects of the intensification processes, also with no truly convincing success. The different disciplines seldom work together to find common strategies to deal with contradictory goals and the uncertainty regarding their effects. Instead, there is an enormous temptation for animal scientists to gain a scientific reputation by becoming a specialist who focuses on single areas at the risk of losing sight of the whole picture. This focusing by the numerous experts on their respective topics has led to a dissociation of the generalist approach. The re-integration of the subcomponents into a well-functioning whole requires an enforced interdisciplinary effort to focus on the performance of the whole system rather than on the separate optimization of individual components. It goes without saying that this is easier said than done.

11.2 Reorientation

In the future, it will not be sufficient for dairy production only to produce a high amount of milk in a cost-effective way. Milk production has to be carried out also in an animal and environmentally friendly manner, therewith considering the values of common goods. Realizing a comparable low prevalence of productions diseases is equivalent with the animal protection service of a farm system [76], which can be offered as a quality service on the food market. This approach allows the alignment of animal protection and production services of the farm system, appearing as a new production goal. The balance between animal protection and production services result from the entirety of processes which take place within a farm system. To succeed in this effort requires more than relying on a general scientific knowledge base, but needs a systemic, functional and result-oriented approach.

The traditional tools of improvements when dealing with complex issues are: problem analysis, defining a short-term and/or long-term goal, developing promising strategies, implementation of most appropriate measures, and finally adequate control and monitoring of success. This roughly sketched approach parallels with the deductive approach of veterinarians when examining, diagnosing and treating single diseased animals except that its focus is not on the recovery of individual animals alone but extends to the recovery of individual farms. Certainly, such an approach requires continuous acquisition of information on the nutritional status of the individual animals, the capacities of the living conditions and, last but not least, the resulting outcomes of the interactions between individual animals and their respective living conditions in terms of clinical and subclinical diseases. These indicate that animals are currently not able to cope. The percentage of dairy cows not being able to cope should be the key criterion for all subsequent activities.

11.3 Providing orientation and 'action knowledge'

Different kinds of internal regulations are required on the farm level. Animal science is asked to provide orientation and to develop 'action knowledge' to create strategies for management to sustainably allocate the relevant resources within the farm system, particularly considering the trade-offs in resource flows through various sub-systems. To formulate concise working hypotheses regarding the most effective and cost-efficient means that are at the farmer's disposal and to organize an appropriate allocation of resources within farm-specific contexts requires the determination of target figures in relation to the envisaged prevalence of Pds.

At the same time, the impacts of tools and means intended to reduce Pds have to be context assessed to establish whether they work effectively and whether they provide a positive cost–benefit ratio. Many technical tools and measures to reduce production diseases have been proven in scientific studies but nearly solely under standardized conditions. The results of these studies are at the farmer's disposal via mediation by advisory services and thus belong to the category of 'disposal knowledge' [77]. However, trying to find general solutions for the mitigation of negative side effects, e.g. in offering general recommendations in the field of breeding [39], technical developments or precision farming [78], might be blamed for oversimplification. By predominantly focusing on the development of 'disposal knowledge' in relation to single traits, animal science fails to grasp the complexity of the challenges at hand. This inductive approach distracts the focus from the problems occurring in the here and now and related to the farm-specific context. Simultaneously, it makes farmers believe that this might make the need to implement fundamental changes within the production processes seem unnecessary. 'Disposal knowledge' can claim to be valid only for the specific conditions under which it has been proven. When implemented in a specific farm context, it functions only as a working hypothesis for 'action knowledge'. The impacts that might occur in the use of generally recommended means and tools require external validation to assess whether they are able to contribute to the envisaged end and to deliver what they promise. This includes proving their suitability in contributing to alleviating the conflict between productivity and animal health on individual farms. Without external validation, general tools to reduce production diseases seem to be an end in themselves rather than a means to an end.

The extent of the outlined complexities explains why it is so difficult to improve the unsatisfactory situation regarding animal health and welfare in dairy farming. Too many partly diverging interests of different stakeholder groups, including the interests of animal scientists, are involved. However, if general enlightenment belongs to the crucial tasks of scientists, as they themselves maintain, this stakeholder group is under a particular obligation to consider animal health and welfare as belonging to the common good and are therefore obligated to contribute to improvements therein. However, as long as animal scientists claim to be able to offer simple solutions based on a reductionist approach without providing convincing evidence, they could be considered as part of the problem rather than part of the solution.

12. Conclusion

An oversized gap between nutrient requirement and nutrient supply in the transition period is a major cause for nutritional disorders and associated comorbidities in dairy cows. Due to the large inter and intra-individual variation in relation to feed intake, output of glucose via milk and metabolic adaptation capacities, the risk for the development of production diseases is a matter of the individual animal in the farm-specific context at a given time. Consequently, the risk cannot be predicted and solved by an inductive approach. The individual animal is the reference system for the appropriateness of nutrient and energy supply as well as the need for protection against biotic and abiotic stressors. Different animals need different supplies and a different kind and degree of protection. Correspondingly, the approach to deal with dairy cows that belong to a feeding group as a homogeneous unit and addressee of management measures is misleading.

Feeding regimes in farm practices are generally based on the concept of energy balance as represented in the 'barrel model'. However, it has become obvious that the allocation of energy resources for the various needs is not regulated independently, as assumed by the model, but is highly interconnected. But above all, the model neglects the role of glucose and the increased competition for it between the immune cells and the epithelial cells in the mammary gland. The model does not create a sufficient predictive power. Therefore, it is not justified to adhere to the model any longer.

The real challenge of nutrient management is to organize an efficient allocation of the available nutrient and labor resources closely related to the individual needs of the animals. Certainly, farm practice does not allow to feed dairy cows individually. However, there are various options - on the one farm more than on others - that should be taken into account when striving for a low level of Pds. Amongst other things, the implementation of feeding phases should be highly adapted to the corresponding requirements. The appropriateness of allocation of the animals to the existing feeding groups needs a continuous controlling. In the case of combined feeding, allocation of concentrate should be controlled and the successive adaptation process improved. Last but not least, animals which show clinical or subclinical signs of diseases and thus an overstressed capacity to adapt to the specific living conditions should be separated into a risk group given special attention and care. Nutrient and energy supply of endangered animals should be improved as well as their protection against biotic and abiotic stressors. Where appropriate, a temporary reduction in the outflow of glucose via the mammary gland should be considered to increase the availability of glucose in the body pool.

The overall production goal of farm management should be reoriented in striving for a prevalence of productions diseases that lies below the average of comparable dairy farms while simultaneously keeping the performance level on a level that does not compromise health and welfare of the farm animals. This goal cannot be achieved by general recommendations in relation to breeding and/or feeding. The history of Pds in dairy farming has proven that the predominant approach of animal science, based primarily on 'disposal knowledge' has failed to improve the long-lasting problems in relation to metabolic disorders and associated comorbidities. To solve problems which derive on different scales from very complex interactions between various factors and being to a high degree context-dependent requires also orientation and 'action knowledge'. Currently, many dairy farmers place their hopes in the development of further tools in precision dairy farming. This may certainly extend the options for acquiring more data but simply acquiring more data is not synonymous with gaining better 'action knowledge'. Before data can become farm-inherent knowledge for practical implementations, data need to be interpreted and transferred into valid information. Expectations, not least promoted by animal scientists, that the elaborate process can be automatized have failed so far. Not that there will be no further developments in the future and possible improvements but farm animals have already suffered too long. Farm management should not continue waiting for what might have little chance of effectiveness due to the underlying complexity of the processes. Whatever the future holds, there is first and foremost the necessity to solve problems in the here and now and to provide evidence of success in reducing production diseases, i.e., the implementation of measures in the farm-specific context together with external validation.

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