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Resigning protein concentrates in dairy cattle nutrition: a problem or a chance?

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Abstract Based on the assumption that the reduction of the use of imported protein concentrates, such as soybean from overseas, is a goal of ecologically sustainable livestock production, this paper is discussing significant aspects of dairy cows' demand for dietary protein. These aspects are put in a general context of rumen fermentation efficiency. The main question is, whether new perspectives on optimal rumen functioning could be found, which allow to develop low-input feed evaluation systems for dairy cattle, especially in organic livestock systems. It is argued that besides the reduction in concentrated feedstuff, such systems should base on aspects of feeding behaviour and feed diversity. Such approaches are expected to avoid nutrition-based metabolic disorders of the cattle and to generate advantageous side effects regarding food quality and ecology coming along with low-concentrate feeding. An approximate outline of topics for research and development in order to achieve such systems is presented with this paper.

Keywords Dairy cattle · Feeding concepts · Protein concentrates · Feeding behaviour · Rumen fermentation

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Introduction

Global needs for soybean as livestock feed are constantly increasing and are considered as a serious environmental and social problem (von Witzke et al. 2011). Generally, and in particular related to soybean production and nitrogen emissions from livestock, the global land requirements for animal products increase and are prospected to go far beyond the ecological capacity of the earth within the few next decades (Pelletier and Tyedmers 2010). Especially animal production in European countries relies to a very large degree on soybean imports as the main vegetable protein source for almost all livestock species. Whereas for monogastric species, the possibility to resign dietary concentrates is limited, the nutritional physiology of ruminants might allow for considerable reductions in this field. Due to their digestion physiology, which combines fermentation, chewing and particle sorting, ruminants, in particular cattle, are able to degrade plant fibres very efficiently (Clauss et al. 2010) and to gain metabolizable energy from roughages which are poor in soluble carbohydrates like sugars or starch. This is the big advantage of ruminants compared to monogastric animals. Correspondingly, ruminants developed a metabolic pathway to reuse blood urea as a nitrogen source by secreting it into the rumen instead of renal excretion and are thus also able to use dietary nitrogen very efficiently (Van Soest 1994), especially when the supply is low. Based on these considerations, sustainable livestock systems should aim at reducing the use of protein concentrates (soybean) in ruminants' feed rations. Given that goal, it appears necessary to reassess the need of dairy cows for dietary protein in high-roughage feeding systems and to indicate the potential and constraints for resigning or at least reducing dietary protein concentrates.

Protein demands in dairy cow nutrition

The demand of dairy cattle for dietary protein is mostly defined in the national feeding recommendations for livestock. It is usually separated into requirements for maintenance and for milk production and, for example, based on usability (German system; GfE 2001) or absorbability (Swiss system; Agroscope 2013) at the abomasum and duodenum. By this, the ruminal conversion of feed into microbial protein is taken into account, usually based on models which thoroughly consider the contribution of the different feed components to microbial fermentation and degradability of the diet. Thus, the *ruminal* protein demand is defined in dynamic and complex models. The endogenous part of the protein demand is not described in such a dynamic way but more or less fixed per kilogram of metabolic body weight and kilogram of milk yield. These systems allow calculating accurately the dietary demands for given milk yields or—vice versa—the milk production potential of a given diet.

In practice, the farm extension programmes tend to recommend rather too high than too low protein balances in order to be safe in maintaining high milk yields. One indicator for appropriate protein supply of a dairy cow is the urea concentration in the milk, where minimal thresholds are defined (Westwood et al. 1998), beyond which a cow is expected to develop metabolic disorders.

However, recent experiences in concentrate-free dairy herds in Switzerland show that cows being fed below their theoretical demands in dietary protein may have clearly higher milk yields than calculated but, at the same time, less veterinary cases than comparable cows which receive protein concentrates according to the system demands (Furger et al. 2013). These cows showed low milk urea concentrations (<15 mg/dL), and a low ruminal N balance, which both should indicate deficiency in protein supply. The performance was however significantly higher than estimated, and no signs of metabolic disorders appeared in these cows. In several other recent studies comparing different dietary forages, the diets with the lowest crude protein concentration led to the highest partitioning rate of feed protein into milk protein (Leiber et al. 2006; Kälber et al. 2011, 2012; Staerfl et al. 2012), accompanied by the lowest milk urea concentrations. It can be assumed that under the specific conditions of the cited research work, the cows reused a larger share of their blood urea via secretion with saliva and directly into the rumen (rumino-hepatic cycle; Van Soest 1994). This implies an efficient use of nitrogen, meaning lower dietary demands and lower excretion via urine into the environment and, at the same time, higher partitioning of feed protein into milk (Kälber et al. 2012). Furthermore, a lower dietary N level leads to a lower metabolic need for endogenic detoxification of rumen-derived ammonia (urea production) which improves the metabolic status of the cow (Westwood et al. 1998).

Summarizing, it appears that under optimal conditions in low-concentrate feeding systems, a low dietary protein supply can be less a problem but rather an advantage for the cow's metabolism and the environment. These *optimal conditions*, however, have to be determined. Forage quality on the one hand and rumen physiology on the other hand are of course the main factors, as in the conventional feeding systems.

Rumen fermentation: is the maximum the optimum?

Contemporary feeding systems for dairy cows are usually aimed to achieve the maximum efficiency of rumen fermentation and, at the same time, the maximum of protein (amino acids) reaching the duodenum for absorption. However, there are a number of issues which might serve to question whether the maximal rumen function is really the optimum for the ruminant itself, for the product quality, for the environment and thus, finally, for the production system. The above considerations about the *optimal protein supply* indicate that the conventional feeding philosophy aiming at a maximum rumen fermentation and microbial growth rate might cause metabolic and environmental loads with N, which are avoidable if the dietary protein is reduced. This evokes the question whether a maximal rumen fermentation rate is really the right goal in ruminant nutrition or not.

There are other aspects supporting this question. One should be given here as an important example:

If the rumen fermentation and microbial modification of nutrients would be 100 % efficient, all native plant polyunsaturated fatty acids, which are essential for any mammal (Sinclair et al. 2002), would be lost in the ruminal biohydrogenation process (Chilliard et al. 2007). If no polyunsaturated plant fatty acids reach the endogenous metabolism of a mammal, no nervous system and no cell membranes could be developed. After mobilization of all endogenous depots, the animal would develop disorders and could finally not reproduce any longer. Therefore, mechanisms must exist to steer the ruminal fermentation process and to avoid too high rates of biohydrogenation. One of these mechanisms might be rumination (mastication): it not only has the function of physical fibre degradation but it also brings the material from the rumen in contact with oxygen in the cow's mouth during chewing. This inhibits the attached rumen bacteria which are strictly anaerobe and thus impairs the fermentation process. The chewing process further activates plant enzymes like the polyphenol oxidase (PPO) via the contact with oxygen. The PPO is described to inhibit bacterial activity in the rumen, thus protecting essential polyunsaturated fatty acids from being degraded by rumen bacteria (Buccioni et al. 2012).

A further way of inhibiting ruminal bacterial processes is the ingestion of plants rich in secondary metabolites, which therefore play an important role in ruminant diets (Jayanegara et al. 2011; Bodas et al. 2012; Piluzza et al. 2013). One effect of the plant secondary metabolites is, again, the protection of polyunsaturated fatty acids from biohydrogenation and their increased transfer into the animals' tissues (Kälber et al. 2011; Willems et al. 2014).

Ruminants have been repeatedly demonstrated to be able to select or avoid plants with specific secondary compounds in fast and differentiated response to their metabolic needs (Villalba et al. 2010; Lyman et al. 2011). The conclusion from these examples is that (1) if ruminants are in need of protecting themselves from maximal rumen fermentation in order to save certain plant essentials and (2) if ruminants are able to steer their own rumen metabolism via mastication and via feed choice, complex interactions between the animal, the feed-plant environment and the rumen microflora must have developed evolutionary. A key factor in these interactions is the steering of the rumen processes by the feeding behaviour of the animal. This implies an optimum which is clearly below the maximum concerning fermentation rates.

Intensive feeding strategies aiming at maximum fermentation rate ignore this ability of the ruminant and they further ignore a probable need for feed choice in the behavioural properties of the animal. The possible implications for animal health are scarcely investigated, yet (Villalba et al. 2010).

Further side effects of plant secondary compounds are important for livestock systems: The protection of polyunsaturated fatty acids in the rumen not only is essential for the ruminant itself but it also enhances the quality of milk and meat, which may contain higher concentrations of omega-3 fatty acids if the animals are fed with forages rich in PPO or phenolic compounds (Vasta and Luciano 2011; Willems et al. 2014). Also, the mitigation of ruminal methane production can be achieved by the same phenolic substances in the diet, which, however, also implies a partial inhibition of rumen efficiency (Jayanegara et al. 2013).

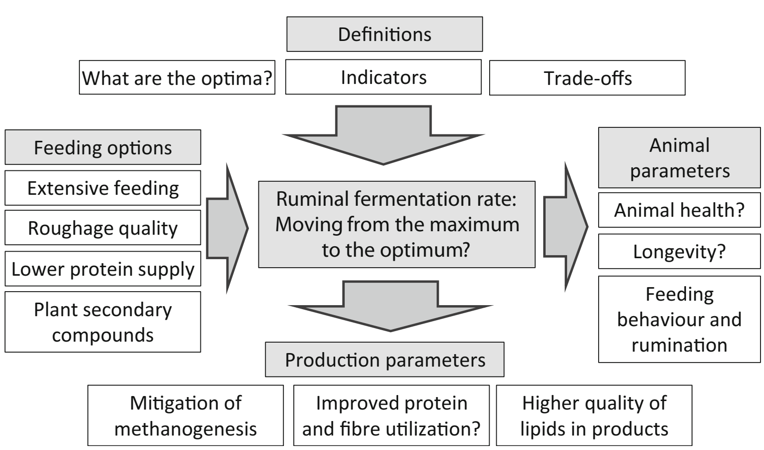

Fig. 1 Possible framework of a research and development agenda for optimized low-concentrate feeding systems for dairy cows

Finally, dietary protein can build complexes with tannins, thus being protected from degradation in the rumen. This reduces ammonia concentrations and can, in optimal conditions, lead to a better protein utilization and lower excretion of urea into the environment (Piluzza et al. 2013).

These examples should introduce a perspective, in which not a maximal but rather a reduced rumen fermentation would be the goal to achieve an optimum in animal health, product quality and environmental impact. Also, a *low* dietary protein supply, which might impair maximal microbial growth in the rumen, could be justified and reasonable in this context. However, it is necessary to note that this is only one perspective and many other aspects like the degree of fibre utilization and the metabolic animal health have to be kept in mind to achieve a sustainable system.

Defining optimal rather than maximal rumen function as a goal in organic livestock systems would require large and manifold research activities under controlled as well as under practice conditions in order to find the real optima and the management options to achieve them. The target could be to develop new feeding recommendations for dairy cows in low-concentrate feeding systems. Figure 1 displays important aspects for the development of such an organic or forage-based feeding recommendation system. These aspects would have to be addressed in future research for low-input ruminant systems.

Conclusion

On the background of the global challenge concerning the reduction of protein concentrates for livestock and of the indicated ability of dairy cattle to cope with protein supplies which are lower than recommended, it appears to be necessary to reassess the dietary protein needs of dairy cows fed on high-roughage diets. Further, it seems to be promising to investigate the specific conditions under which dairy cows can cope with low dietary protein supplies. This should be done in the context of a general investigation about the optimal rates of rumen function, which might be below the maximum, if animal behaviour and health, environmental impacts and product quality are considered. In this sense, the resigning of protein concentrates from dairy cows' diets in organic farming could be a chance to reconsider the feeding paradigms for ruminant production in a broad perspective.

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