How low can you go? The importance of protein in the dairy cow diet

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- The modern dairy cow's nutritional requirements are highly complex due to the microbial population of the rumen and the demand for efficient and high-yielding animals.
- Protein is an essential component of the ruminant diet and correct levels can support fertility and productivity, however, too much protein can cause health problems and increased environmental pollution.
- Targeted feeding of specific amino acids could present a solution to the problem of under or overfeeding protein.

The nutritional requirements of the dairy cow are continually being refined and developed due to the importance of efficient and sustainable milk production. In the dairy industry, feed costs represent one of the largest expenses, so it is essential that feed efficiency is enhanced and waste feed decreased in order to optimize production and profit. As milk producing capacities of high-yielding cows continue to increase, so will the difficulty in meeting their nutritional requirements.

What is it and why is it important?

Proteins are large molecules which consist of long strings of amino acids (AAs) which contain high levels of nitrogen (N). Protein is essential in all aspects of body maintenance, reproduction and most importantly in the dairy industry, milk production.
The cow receives all of her protein via the diet, this protein can be categorized into rumen degradable (RDP) and rumen undegradable (RUP) protein.
RUP is *not* digested in the rumen and passes through to the intestine (Figure 1).
On the other hand, RDP is broken down by the rumen bacteria which can be used by other rumen microbes to generate their own bodily protein (Figure 1). Some microorganisms then end up being washed down to the cow's intestine where they are digested. This bodily protein is of high quality and is extremely important to the animal as it accounts for up to 80% of the cow's total protein.

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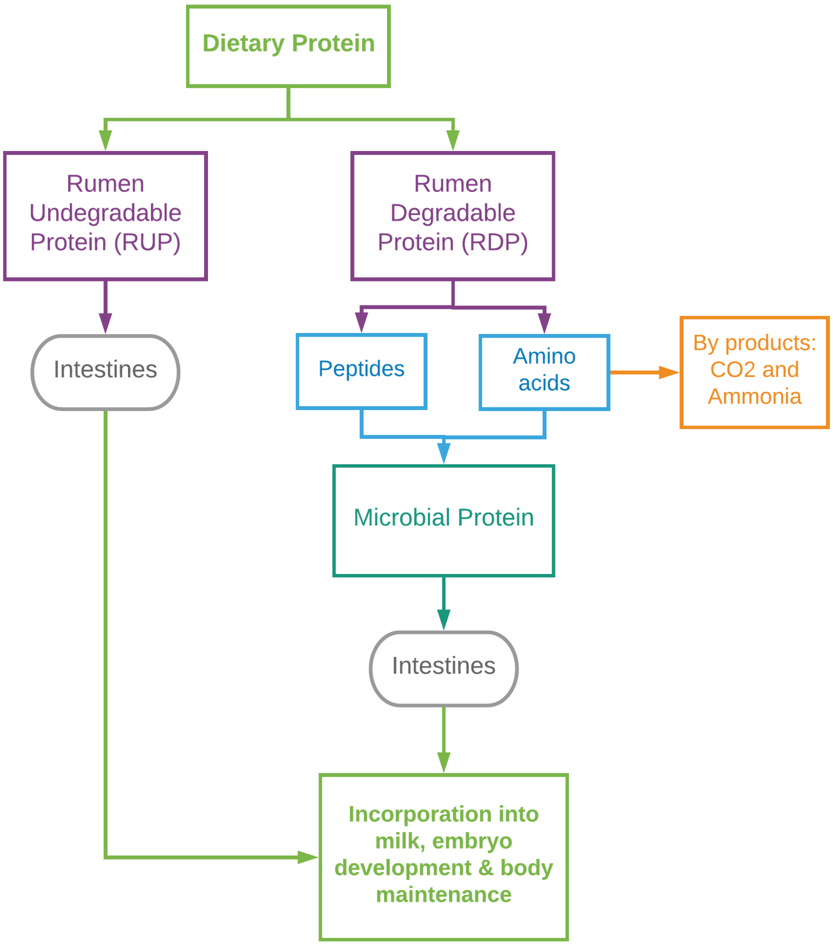

Figure 1: Diagram showing the fate of incoming dietary protein.

RUP and RDP complement one another and although RDP contributes the majority of protein, RUP is also important, especially for high-yielding cows. With too little RDP, rumen fermentation is negatively affected leading to significantly reduced feed use and decreased supply of microbial protein. If too little RUP is provided (protein that escapes ruminal degradation) the microbial population of the rumen must work overtime to try and make up for the deficit. Experiments have examined different balances in RDP and RUP and have found that the ratio can affect the type of casein that comes through in the milk, as well as levels of zinc and some fatty acids.

As such, the complexity of protein nutrition in the dairy cow becomes clear, mostly because we are feeding two systems: the animal and the microbial population of the rumen.

Protein requirements of the dairy cow

The nutritional requirements of dairy cows vary depending on their stage in lactation, whether they are spring or autumn calving and their current body condition score (BCS). It is important to maintain an optimum BCS as overweight cows are more likely to have issues calving whilst underweight cows will likely suffer from metabolic disorders (*e.g.* negative energy balance) after calving.

Table 1: Crude protein requirements (%) of dairy cows at different stages in lactation and when dry (Taken from Moran (2005)).

Milk production	Crude protein requirements (%)
Early lactation	16-18
Mid-lactation	14-16
Late lactation	12-14
Dry	10-12

When assessing the protein content of the diet, crude protein (CP) is the figure to look at – this value represents the total amount of protein in a given feed. This value is calculated by determining the amount of nitrogen in a feed and multiplying it by the factor 6.25. This is based on the assumption that protein contains 16% nitrogen (100/16 = 6.25). Where CP requirements are exceeded, nitrogen emissions increase but milk yield does not– indicating reduced nitrogen efficiency (Table 1). By balancing CP intake in a well-formulated diet, nitrogen excretion can be reduced with limited effects on milk yield or composition, meaning that nitrogen use efficiency is improved.

The problem with high protein diets

In the past, overfeeding protein was common practice – to ensure that the cow has more than enough protein to produce large quantities of high-quality milk. Indeed, rations high in protein do stimulate milk production and can increase dry matter intake (DMI), however,

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this strategy comes at a cost: economically, environmentally and biologically for the cow.

In biological terms, diets containing high concentrations of protein have been shown to have a negative effect on reproductive performance and fertility. Fertility is one of the major factors affecting the efficiency of any dairy herd and can account for one of the main costs of production. Research has found that in cows fed high-protein diets, urea levels in the blood increase and uterine pH changes, both of which are detrimental to embryo establishment and development. This can lead to an increased rate of pregnancy loss in the first 10 days. Of course, an overabundance of protein must also be broken down and excreted, doing so requires additional energy and can exacerbate energy deficits in the cow.

Naturally, excess protein must be eliminated from the body via faeces and urine which can contribute to environmental pollution. The results of protein breakdown include nitrogen which is then excreted as ammonia. Ammonia deposition can lead to soil acidification and excessive nitrogen levels which can impact natural habitats and subsequently biodiversity. When ammonia comes into contact with other air pollutants, tiny toxic particles are formed which can lead to poor air quality and health problems.

Feeding excess protein also reduces profit margins, as feed costs increase but productivity remains the same (or even decreases). In addition to increased waste levels (undigested feed containing high levels of unused nitrogen), this renders high-protein diets a costly and ineffective nutritional strategy.

Strategies for optimising dietary protein

High RUP diets

The effects of a high RUP diet are well debated, with some studies suggesting that it does not enhance lactation performance whereas others have found that milk contains higher total levels of protein and ovarian activity can be enhanced. It has been suggested that these inconsistent results stem from differences in protein degradability of the supplements and forages used in studies. Whilst the addition of RUP to the ruminant diet can improve the flow of amino acids, it does not change the AAs themselves. An alternative solution is to tailor the content of individual amino acids offered in the diet.

Targeted feeding of AAs

Twenty different amino acids exist, of which, 10 of these are 'essential' – meaning that the animal cannot produce them herself so they must be provided in the diet. These amino acids are combined to make chains which are then termed 'proteins'.

Certain amino acids are less abundant than others and research has established that methionine and lysine are the two most limiting amino acids in dairy cows, as they are low in most feeds when compared to levels in the rumen bacteria and milk. The third most limiting AA varies from study to study but is generally considered to be histidine, particularly in grass silage diets. In cows producing high levels of milk, it is theorised that leucine and valine may also be limiting due to use by intestinal tissue as an energy resource.

Recent research suggests that transition cows may benefit the most from balancing AA. Supplementing diets with lysine and methionine increased DMI, milk yield, and milk protein concentrations as well as regulating liver function, inflammation, and oxidative stress. Additionally, balancing AAs can increase profitability by lowering feed costs and increasing the production of milk whilst reducing waste, helping to ease environmental pollution. Research has indicated that with stable forage, high milk yields (>41 kg milk) are possible with 14-15% protein in the ration when AAs are balanced. When forage is of variable quality, the protein content of the ration may need to be increased to ensure a sufficient supply of metabolisable protein, thus highlighting the importance of consistently good forage.

Rumen-protected AAs

The use of Rumen Protected Amino acids (RPA) is based on the same principle as feeding specific amino acids, described above. But in this case, the amino acids are delivered in a case or coating of polymer that can resist digestion in the rumen. This means that the RPA can pass through unharmed into the other chambers of the cow's stomach where the coating is broken down, meaning that they are available for absorption in the intestine. This ensures a supply of scarce or essential AAs directly to the intestines for use in milk protein synthesis.

As mentioned previously, methionine and lysine are the most limiting AAs in the dairy cow diet. Research has suggested that the ideal ratio between lysine and methionine should be 3:1 to maximise milk protein synthesis. Studies have found a link between methionine

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supplementation and improved fertility and one such experiment found a 13.5% reduction in pregnancy loss when rumen-protected methionine was supplemented, in addition to significantly larger embryo sizes.

One of the biggest challenges when balancing rations is the limited intake of the cow and managing the ration space accordingly. It is important that there is some room for flexibility in order to cater for the changing requirements of the dairy cow. RPAs create that space by reducing unused protein, leaving room for other important nutrients such as fibre. Perhaps the most optimal use of RPAs is to substitute or partially replace the essential amino acids currently provided by other feed ingredients. Although, the most common approach is to add on top of the current feed to improve the lysine: methionine ratio and increase the total concentration in the ration. However, there are several drawbacks to this approach, for example, input cost will increase and therefore an improvement in performance is needed to achieve a profit.

Protein in forages

Early on, scientists recognised that there were problems with utilisation of forage CP, especially in hay-crop silages, as a result of plant proteases breaking down protein in the silo. Formic acid application immediately decreases pH and reduces free AA release. Although less common now, treating forages with formic acid at ensiling was widely applied in Europe as a means of preserving more protein in direct-cut silages.

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In terms of high protein forages, red clover is a prime example, containing up to [8% more protein than grass silage](). Red clover also produces polyphenol oxidase (PPO), an enzyme which helps to reduce protein breakdown in silo and in the rumen resulting in higher levels of protein in the diet as well as higher levels of protein escaping ruminal degradation. Furthermore, PPO also helps protect health beneficial polyunsaturated fatty acids in the silage, which may help boost their presence in milk. Studies have found that feeding red clover silage was found to improve nitrogen efficiency without impacting milk yield and protein yield in lactating cows. The benefits of feeding red clover are clear, but this plant also confers advantages to the land as it is able to fix nitrogen which reduces the need for nitrogen fertilisers.

Low protein diets

At first glance, a low protein diet may appear completely counterintuitive, however, research has found that dietary crude protein levels for lactating dairy cows can be reduced down to 14% with little to no loss in milk yield or quality. Feeding diets with lowered protein content reduces nitrogen input, improves nitrogen utilisation efficiency, and reduces nitrogen losses from manure. Dairy cows can actually be extremely efficient in recycling urea when fed a deficient or marginal level of protein. However, this is based upon the assumption that the cow is receiving adequate dietary energy and that amino acids are balanced. When diets are fed that are extremely low in protein (12%) we begin to see negative effects such as depressed nutrient digestibility, decreased DMI, reduced milk yield and a drop in microbial protein synthesis. Low protein diets remain experimental and are not widely used in the dairy industry, however, paired with rumen-protected AAs or feeding of targeted AAs this strategy could present a feasible method of reducing waste nitrogen whilst maintaining maximum production efficiency in dairy cows.

Summary

The nutrition of dairy cows is a complex matter, due to the microbial population of the rumen and the nutritional requirements of high-yielding cows. The problems of overfeeding and underfeeding protein are clear and result in negative biological, economic and environmental effects. Balancing of amino acids (particularly of limiting AAs like methionine) offers a solution which reduces waste and environmental pollution whilst ensuring that the animal receives adequate nutrition. Trials using rumen-protected amino acids have shown some success, but such supplementation remains relatively expensive, especially on a large scale. A combination of a low protein diet with targeted feeding of lacking amino acids could offer a solution to reducing environmental pollution from waste nitrogen whilst providing the necessary nutrition for high-yielding dairy cows.

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Note to editors:

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