WHY PROTEIN QUALITY MATTERS IN LIVESTOCK PRODUCTION

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1. Preface

In recent years CIEL has produced several reports related to Net Zero and Livestock which are available here. A common theme has been the value livestock add to our food system by supplying higher quality protein than other food sources. This report focuses on protein quality because it is fundamentally important to the use of feed resources for efficient livestock production as well as to human nutrition.

Not all proteins are equal. Protein from most plants are of a lower quality than from animals, but even the best plant proteins are not as high-quality as animal protein. Despite this, modern science has led to plant proteins being used very effectively in livestock nutrition using good diet formulation, quality ingredients and supplementation with synthetic amino acids. This report explains how that occurs.

Proteins are unique in that they contain a high proportion of nitrogen in their molecular structure compared to carbohydrates and lipids (fats and oils). When proteins are not used efficiently by livestock, nitrogen losses increase, leading to negative impacts for our climate, air and water through emissions of nitrous oxide (a potent greenhouse gas), ammonia (a pollutant and respiratory irritant) or nitrate leaching (which has adverse effects in waterways).

Protein quality directly impacts on this efficiency, with lower-quality protein diets leading to greater losses than high-quality protein diets.

Livestock fall into two main categories for protein nutrition: monogastrics and ruminants. Nature has adapted these two animal types for different feed types, and this has an impact on protein nutrition and nutritional efficiency. There is not much difference in protein composition of products from these two types of livestock, but there is a considerable difference in how they obtain the protein they need from the feeds that evolution adapted them to. We look at these differences in this report and consider the consequence of the roles they can play in our food system.

Protein quality is not just about the nutritional needs of livestock, it is also about the nutritional needs of humans, which evolution has also shaped over time from early hunter-gatherers to our modern agricultural society today.

As omnivores, our digestive systems are optimised for diets containing both plant and animal products, meaning that the quality of animal protein is a close match to our needs. Combined with livestock's ability to convert lower-quality feed into highly-nutritious, protein-based food, it is easy to see why farming evolved and why livestock play a key role in our food system. In fact, modelling of different food production systems shows that the most efficient systems always have livestock playing a key role in this 'up-cycling' of food by-products and plant material that humans gain little nutritive value from. The common thread in these ideas is protein quality. I hope you will gain a better understanding of this property of feeds and foods from our report. It is a critical component within the context of sustainable farming systems that requires a deeper understanding, particularly when exploring the potential role livestock should play in such systems.

CIEL has produced another relevant report focusing on the importance of nitrogen cycling which is available here. Given that proteins differ from carbohydrates and lipids due to their nitrogen content, that report is highly complementary to this protein report. We recommend you read that as well in order to gain a wider appreciation of nitrogen, protein and efficient production of highly nutritious food, in the context of net zero and livestock.

CIEL commissioned leading experts to produce this report in a style accessible to non-experts who have an interest in nutrition and food production. We welcome feedback and queries about concepts and ideas detailed in the report.

Dr Mark Young,
Innovation Specialist, CIEL

2. Executive Summary

The human population is rising which increases demand for high-quality protein. Increased affluence is also expanding demand for animal protein food products. This has placed demands on the production of meat, milk and eggs where previously diets have been based on plant proteins supplemented with a smaller amount of animal proteins.

Protein quality is primarily related to the concentrations of different amino acids the protein contains and how available they are to the animal. Amino acids are the building blocks of protein and the closer the concentrations of the different amino acids match animal requirements the higher the quality of protein produced. A shortage of one amino acid will result in reduced protein synthesis and the wastage of the surplus amino acids. Of the 20 amino acids needed to make animal protein, around 10 are essential because they cannot be synthesised by the animal and must be supplied in the diet.

For human nutrition, in terms of their amino acid content, milk and eggs are close to the ideal protein for humans and are considered of high-quality[1] in the diet. Meat also contains a good balance of amino acids compared to plant proteins, which are also more variable in quality. Demand for animal protein is increasing rapidly, especially for poultry meat, putting pressure on sources of feed ingredients such as soyabean meal, currently the main protein source in poultry feed[2,3]. There are large variations in the amount of protein eaten and in sources of dietary protein consumed by humans. Generally, humans need to consume both animal and plant-based proteins to ensure that the quality of the protein consumed meets their nutritional requirements.

To produce protein-based foods, animals must be fed a diet that meets their amino acid requirement for body maintenance processes and production of eggs, milk or muscle (protein) growth. Insufficient essential amino acids in the diet limits use of other amino acids for such processes. Excesses of other amino acids are used as an energy source which does not use nitrogen, leading to nitrogen being excreted. Nitrogen is excreted as urea, which is readily converted to ammonia (a pollutant and respiratory irritant), nitrous oxide (a potent greenhouse gas) or nitrate (plant growth promotant) that when lost through leaching adversely affects aquatic ecosystems. Optimising protein quality improves efficiency of protein use in the diet and helps to reduce harmful emissions.

For monogastric animals (including humans) the dietary protein must supply all the amino acids the animal requires. Ruminant protein nutrition is different because micro-organisms in the rumen enable the ruminant to synthesise some of the amino acids they require. To do this, the microbes need to be supplied with a readily-fermentable energy source and either low-quality protein or nitrogen in a form they can use to make amino acids. Most protein used by ruminants themselves is microbial protein. Microbes are present in the rumen, which is the first stomach. Therefore, microbes are exposed to ingested protein before the animal can absorb this protein from the diet further down the gastrointestinal tract. To supply more protein to high-producing ruminants (e.g. high-yielding dairy cows), diets need to be supplemented with high-quality, undegradable protein which bypasses rumen degradation.

Protein requirements change according to an animal's physiological state (egg production, pregnancy, lactation, age and health), increasing during pregnancy and early lactation, during the finishing stages of growth for meat production and during periods of illness. Diets can be fine-tuned to better meet requirements during these situations.

To maximise protein synthesis, nutritionists must make the best use of dietary plant proteins while minimising wastage of amino acids, as currently all proteins used in UK livestock feed are plant based. These are an excellent source of amino acids, but their concentrations do not match animal requirements. To meet animal requirements diets are formulated predominately using soya and smaller amounts of other plant proteins. Essential amino acids (synthesised by industrial processes) can be added to improve amino acid balance. This results in a reduction in the total amount of protein in the feed for the same level of performance i.e. total protein content of the diet can be reduced but still meet protein requirements of the animal. This includes humans consuming a vegetarian diet where care must be taken to ensure a good balance of amino acids is consumed for optimum health. For ruminants when demand for protein is high, protecting amino acids or feeding high-quality undegradable protein sources enables high-quality protein to bypass microbial fermentation and be absorbed by the animal.

Through accurate diet formulation and reducing the amount of feed protein in diets by supplementing with synthetic amino acid or protected amino acids, nutritionists can create feeds that meet requirements while decreasing demand for soyabean and helping to reduce the overall carbon footprint for a production system. Further to reducing soyabean meal in animal feed, we need to continue to look for alternatives to soyabean meal and consider how we might reintroduce animal proteins as an option for livestock diets, in particular monogastric animals.

3. Introduction to protein and amino acids

Rapid and extensive development has been achieved in protein nutrition with a great emphasis on ensuring appropriate dietary protein quality for livestock animals, and balancing cost effectiveness. This is because meat, milk and egg production costs are mainly associated with feed costs, with protein being one of the most expensive parts of animal diets.

Proteins are complex organic compounds and in common with carbohydrates and fats they contain carbon (C), hydrogen (H) and oxygen (O), but they also contain nitrogen (N) and some contain sulphur (S). Proteins are present in all living cells, each species has its own specific proteins and each organism has many different proteins in its cells and tissues.

Amino acids are the building blocks of protein and are released from proteins when the latter are broken by enzymes, acids or alkaline solutions. Over 200 amino acids have been isolated from biological materials though only 20 amino acids are commonly found as components of proteins. Most micro-organisms and plants can synthesise all 20 amino acids, but in mammals (including humans) around half of the amino acids, termed as 'essential amino acids', must be obtained from protein consumed in food or, in the case of ruminants, synthesised by micro-organisms in the rumen. These essential amino acids include histidine, lysine, leucine, isoleucine, methionine, phenylalanine, threonine, tryptophan and valine.

Monogastric animals need their diet to supply essential amino acids; for poultry this list is extended to include arginine because it cannot be synthesised by birds. On the other hand, amino acids that can be synthesised by animals are termed 'non-essential' amino acids and include glutamine, alanine, asparagine, hydroxyproline, glycine, serine and proline. **Table 1** shows the roles of some individual amino acids in livestock animals.

Function	Amino acids
Energy substrate for the small intestine	Gln, Glu, Asp
Regulation of cell turnover	Gln, Glu, Arg, Pro, Trp, Gly
Regulation of the microbes within the gut	Gln, Arg, Trp, Pro, Hyp
Maintenance of the gut lining integrity	Gln, Glu, Asp, Arg, Pro, Gly, Trp
Antiviral effects	Gln, Arg, Leu, Trp, Pro
Antioxidant effects	Gln, Glu, Asp, Arg, Pro, Gly
Anti-inflammatory effects	Gln, Glu, Asp, Trp, Gly, Cys, Hyp
Regulation of metabolism	Gln, Glu, Arg, Asp, Pro, Gly, Trp

Gln, glutamine; Glu, glutamic acid; Asp, aspartic acid; Arg, arginine; Pro, proline; Trp, tryptophan; Gly, glycine; Hyp, hydroxyproline; Leu, leucine; Cys, cysteine.

Table 1. Functions of amino acids in livestock animals[4]

Considering the amino acids supplied by cereals and with soyabean meal being the most used feed ingredients for broilers, there is an order within them regarding which are most limiting. When wheat and maize are the main cereal, which is typical in UK and US rations respectively, the first limiting amino acid is methionine, followed by lysine, threonine and valine in diets containing 20-30% crude protein (CP) and in which 75-85% of the total dietary amino acid are provided by soyabean[5]. For typical pig rations, lysine is often the first limiting factor. In high-producing lactating dairy cows, methionine and lysine have been identified as the two most limiting amino acids in maize/whole crop-based rations, and histidine is known as a limiting amino acid in grass-silage based rations[6]. This concept of first limiting amino acid can be depicted as a barrel with uneven staves[7] with the lowest stave indicative of the limit on how much protein can be synthesised **(Figure 1).**

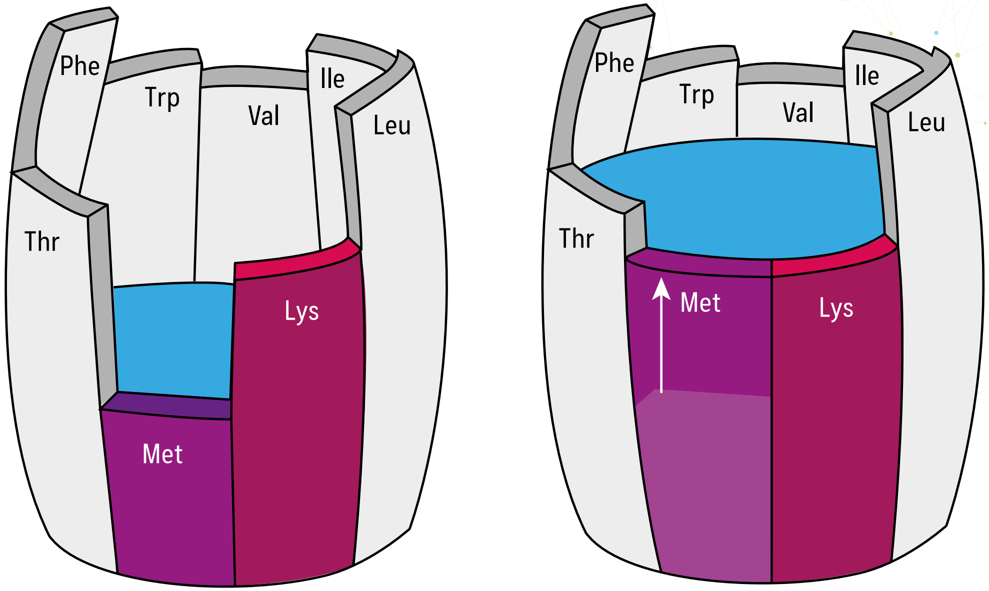


Figure 1. Liebig's barrel applied to plant-based poultry feed. The shortest stave of the barrel represents the first limiting amino acid (here methionine followed by lysine). The higher the lowest stave the more protein can be made

Rapid and extensive development has been achieved in protein nutrition with a great emphasis on ensuring appropriate dietary protein quality for livestock animals, while balancing cost effectiveness.

4. Amino acid supply from protein digestion

Monogastric animals obtain amino acids for their bodily functions through digestion of dietary protein. This starts in the stomach and continues in the small intestine, from where amino acids are absorbed into the bloodstream, to be transported to the liver. Protein that is not digested by the end of the small intestine no longer directly contributes to amino acid supply. Instead, it is either excreted with the faeces in the form of biomass or fermented by the hindgut microbiome, and resulting N-rich compounds, including ammonia, are absorbed, metabolised and excreted in the urine, in the form of urea in mammals, or uric acid in poultry **(Figure 2a)**.

Unlike monogastric species, ruminants can to a large extent rely on amino acids synthesised by rumen microorganisms. Each amino acid can be found in rumen microbial protein, which typically supplies more than 50% of the absorbed amino acids, with the rest coming from dietary protein that is not degraded in the rumen. This mixture of microbial and so-called by-pass dietary protein then undergoes digestion in much the same way as in monogastrics. However, some of the urea derived from large intestinal absorption of N-rich compounds is recycled into the rumen to contribute to microbial protein production **(Figure 2b)**. The foregut, microbial protein production, and nitrogen sparing through urea recycling make ruminant species uniquely able to use relatively poor-quality forage-based feed sources to produce high-quality proteins in the form of red meat and milk. Nevertheless, the total supply of amino acids is often limiting at times of elevated amino acid requirements, e.g. during rapid growth in young ruminants, late pregnancy and peak lactation. Therefore, to optimise production, supplementing with feedstuffs rich in by-pass protein is necessary to provide additional methionine, lysine and histidine. For example, (processed) soyabean and rapeseed meal or protected synthetic amino acid sources can make up for amino acid limitations from the combined microbial protein and background by-pass protein supply.

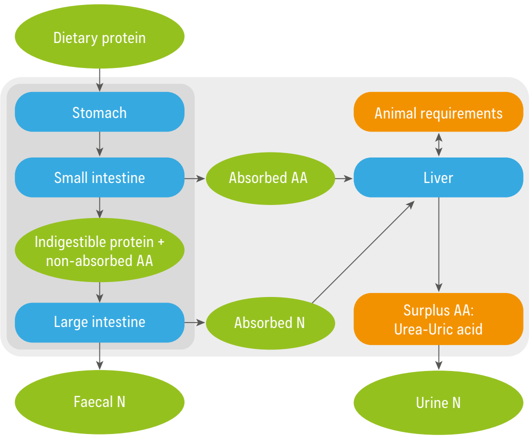


Figure 2a. Protein digestion for amino acid requirements in monogastrics

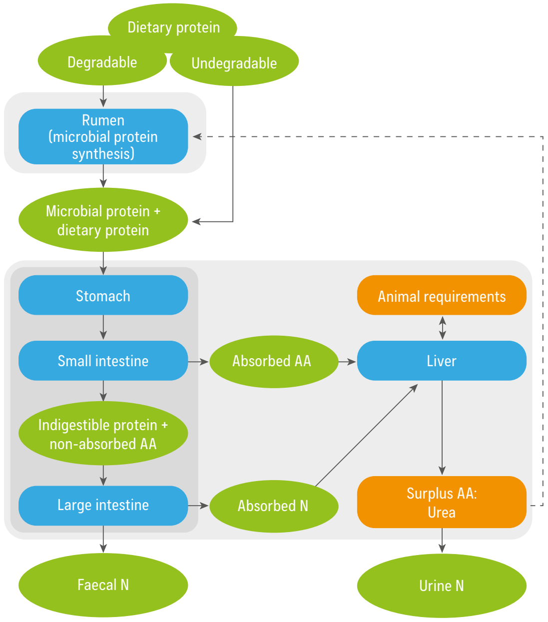


Figure 2b. Protein digestion for amino acid requirements in ruminants

5. Evaluating protein quality in monogastric diets

Traditionally, protein quality of feedstuffs and rations for monogastrics was evaluated through their crude protein (CP) levels. This is calculated by determining the N content of a feed and assumes that all protein contains 16% N. Over time, this evolved into the concentration and ratios of digestible essential amino acids. The concept around essential amino acid ratios is known as the ideal protein concept, which is based on supplying essential amino acids in the proportions required to meet the animal's requirements, thus avoiding both deficiencies and/or excesses[7]. In practice, when considering the ideal protein concept for monogastric animals, each of the dietary essential amino acids is considered relative to lysine requirements. Using lysine as a reference, the aimed levels for each of the other essential amino acids are then expressed as a ratio of lysine, which is set at 100% (see **Tables 2 and 3** for examples in broiler chickens and fattening pigs, respectively). Poultry and pig diets are primarily based on cereals which are low or deficient in many amino acids, including the essential amino acids methionine and lysine. Therefore, the most common way to achieve required protein quality is through adding protein-rich feedstuff together with synthetic amino acids to balance the content of the total ration to the ideal protein concept.

Amino acids	Starter (0-10d)	Grower (11-24d)	Finisher (25-39d)
Lysine	100	100	100
Methionine	40	41	42
Arginine	107	107	107
Valine	75	76	76
Threonine	67	67	67
Tryptophan	16	16	16
Isoleucine	67	68	69
Leucine	10	110	110

Table 2. Ideal amino acid profiles (lysine=100) for Ross 308 broiler chickens[8]

Amino acids	Starter (25-50kg)	Grower (50-80kg)	Finisher (80-120kg)
Lysine	100	100	100
Methionine+ cystine	60	61	62
Threonine	66	67	68
Tryptophan	20	20	20
Isoleucine	53	53	53
Valine	67	67	67
Leucine	100	100	100
Histidine	32	32	32
Phenylalanine+ tyrosine	95	95	95

Table 3. Ideal amino acid profiles (lysine=100) for starter, grower, and finisher pigs[9]

6. Evaluating protein quality in ruminant diets

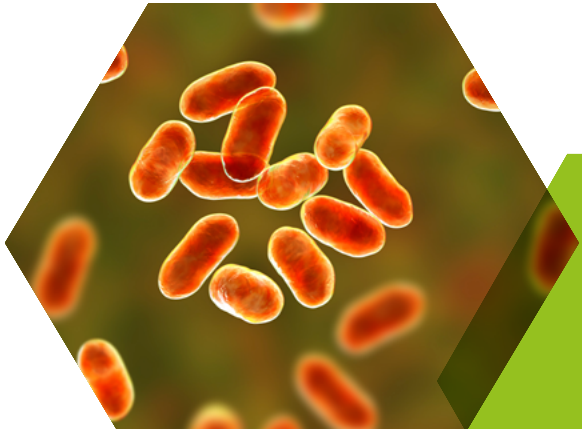
For ruminants, protein was traditionally evaluated in terms of CP but as this approach has limitations the UK has since adopted the metabolisable protein (MP) system[10]. The MP system describes the degree to which dietary protein is degraded in the rumen (known as rumen degradable protein (RDP)) and captured as microbial crude protein, and the amount of protein that leaves the rumen as undegraded protein (UDP), or the aforementioned by-pass protein, passing unaltered into the abomasum (stomach) and then small intestine (see **Figure 2b**). The microbial demand for protein is stated in terms of effective rumen degradable protein (ERDP) and feeds are evaluated in these terms. The MP system also takes into account the proportion of true protein in microbial crude protein (assumed to be 75%) and the digestibility of this true protein (assumed to be 85%), to obtain the amount of digestible microbial true protein (DMTP) in the form of microbial protein derived amino acids absorbed from the small intestine. The UDP fraction consists of potentially digestible and indigestible protein fractions and will vary considerably between feedstuffs, in much the same way as how protein digestibility between feedstuffs varies in monogastric animals. The digestible part of the UDP fraction, effectively the sum of amino acids derived from it, is known as digestible undegradable protein (DUP). The total MP supplied by a feed (g/kg DM) is then calculated as DMTP + DUP.

7. Ruminant protein synthesis

In addition to using protein from their rations (see **Figure 2b**), ruminants are unique in their ability to use non-protein nitrogenous (NPN) compounds such as urea. Urea entering the rumen is rapidly hydrolysed into ammonia by bacterial urease, and the rumen ammonia concentration is therefore going to rise considerably. For ammonia to be efficiently made into microbial protein, two conditions must be met: the initial ammonia concentration must be below the optimum (otherwise additional ammonia will be wasted) and there must be a source of readily-fermentable energy to capture ammonia N as microbial protein. This is why in practice urea is often mixed with feeds that are known to be low in RDP and high in readily fermentable carbohydrates e.g. cereals such as barley or molasses. However, urea is toxic if consumed in large doses, therefore it must be thoroughly mixed and the quantity in the diet controlled.

Ammonia is a key intermediate for microbial protein synthesis, derived directly from feed or through nitrogen cycling by the ruminant when urea is returned to the rumen either directly or in saliva. There can be a net gain in nitrogen, because recycled urea is converted to microbial protein in the rumen. This cycling and conversion to microbial protein, reduces the amount of protein excreted for poor protein quality diets and so improves nitrogen use efficiency (**Figure 2b**).

Ruminant microbes obtain N, in the form of amino acids, peptides and ammonia, by breakdown of the protein and non-protein N fractions of the food. The microbes then use ammonia to synthesise microbial proteins. Some of the microbial protein will be broken down in the rumen and its N recycled. When the microbes reach the abomasum and small intestine their cell proteins are digested, yielding amino acids that are absorbed as part of the total pool of MP. An important feature of microbial protein is that the microbes can synthesise all amino acids, including the essential amino acids regardless of the protein quality of the feed. With most diets the greater part of the protein reaching the small intestine will be microbial protein of reasonably constant composition. The rest will be undegraded food protein, which will vary in amino acid composition according to the type of feedstuffs in the ration.



Alongside the quality of protein offered, the rate of protein degradation in the ruminant can also differ as the animal moves through the physiological stages both related to age and stage of production, with physiological state altering rumen outflow rate and therefore protein breakdown. **Table 4** shows the rumen outflow rate in ruminants throughout the different physiological stages for dairy cattle.

Stage	Rumen outflow rate (% of total rumen contents leaving per hour)
Pre-ruminant (0-14days)	-
Growing/Finishing	5%
Dry	2%
Late pregnancy	5%
Lactation < 15kg Milk	5%
Lactation > 15kg Milk	8%

Table 4. Rumen outflow throughout different physiological stages of dairy cattle[10]

These different rumen outflow rates are expanded upon below and have direct implications for the time taken for a full rumen volume to have completely passed through.

- **Pre–ruminant:** In new-born ruminants the digestive system is more similar to a monogastric where the rumen is closed off by the oesophageal groove. Rumen development and therefore opening of the oesophageal groove is stimulated by coarse fibre, cereals and high energy and protein ration
- **r = 2% / h:** Animals fed a low level of feeding around maintenance. It takes 50 hours for 100% of rumen contents to pass through the rumen
- **r = 5% / h:** Calves, low-yielding dairy cows (<15 l milk/d), beef and sheep on increased levels of feeding up to 2x maintenance. It takes 20 hours for 100% of rumen contents to pass through the rumen
- **r = 8 %/ h:** High-yielding dairy cows (>15 l milk/d) and sheep in early lactation. It takes only 12.5 hours for 100% of rumen contents to pass through the rumen

As rumen outflow rate increases, the degradation of protein breakdown within the rumen decreases due to the reduced time for microbial digestion. This means that the proportion of DUP that reaches the small intestine is increased, altering the way protein is broken down in the ruminant during peak production. The fraction that remains in the rumen, ERDP, is described as the total amount of N that is retained and used by the rumen microbes. As rumen outflow increases, especially during peak production, the ERDP level decreases causing a reduction in microbial protein produced therefore making the ruminant more reliant on amino acids from DUP supplied in the diet. For example, **Table 5** shows that soyabean fed to a high-yielding dairy cow with a rumen outflow rate of 8%/h has an ERDP content of 287 g/kg DM and a DUP content of 194 g/kg DM. By comparison, if the same soyabean is fed to a dry dairy cow with a rumen outflow rate of 2%/h, the fraction of ERDP is increased to 433 g/kg DM and DUP decreases to 70 g/kg DM. This has implications for MP yield. Following on from the early description of the MP system, and assuming the sufficient fermentable energy is available for microbial protein synthesis, the MP yield of this soyabean for the high-yielding dairy cow would be 377 g/kg DM, or 9% greater than the 346 g/kg DM for the dry dairy cow.

	ERDP (g/kg DM)			DUP (g/kg DM)		
Rumen outflow	2%	5%	8%	2%	5%	8%
Feed						
Soyabean	433	342	287	70	147	194
Rapeseed meal	332	296	268	41	73	99
Distillers dark grains	204	154	133	52	96	115

Table 5. The effect of rumen outflow rate on ERDP and DUP supply of protein[11]

8. Role of synthetic amino acids in reducing dietary protein levels

The economic availability of an increasing number of synthetic amino acids and the ideal protein concept as used for monogastric species play a key role in reducing dietary CP content and thus reducing the global dependence on soyabean[3]. In addition, using reduced CP diets has the potential to decrease total N excretion and ammonia emissions, which are considered main environmental burdens arising from pig and poultry protein production. Up to 75% of CP intake is ultimately excreted as ammonia due to inefficient amino acid metabolism of high-protein diets[12]. Moreover, using reduced CP diets is associated with less undigested protein entering the large intestine. In addition to the earlier mentioned production of toxic N-rich compounds that need to be metabolised and excreted, this can also lead to pathogenic bacterial proliferation, putting gut health at risk as another contribution to impaired performance. **Figure 3** shows the importance of amino acid balance when applying the ideal protein concept in feed.

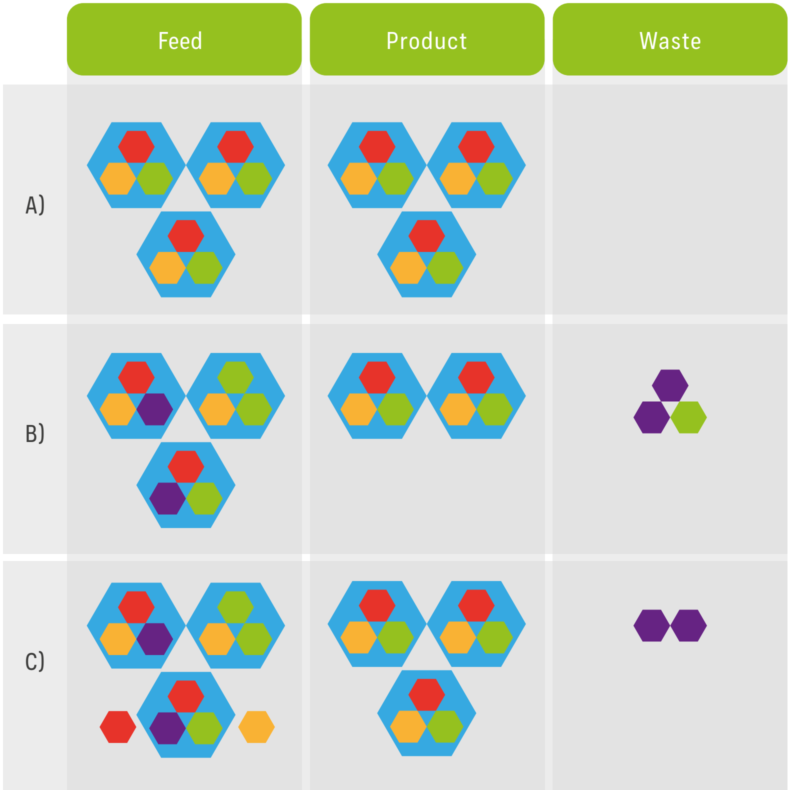


Figure 3. The importance of amino acid balance when applying the ideal protein concept in livestock animal feeds (different coloured hexagons refer to different amino acids)

a) amino acids on offer are 100% in balance with amino acids required, resulting in no waste (0% of amino acids supplied)

b) a lower-quality animal feed consists of amino acids in the diet that are unbalanced, resulting in less product and more waste (33% of amino acids supplied)

c) adding the two missing amino acids as synthetic amino acids to the feed makes the feed more balanced, with increased production and less waste (18% of amino acids supplied)

Note: this illustrates the ideal protein concept; in reality there will always be some wasted protein, e.g. from basal endogenous losses.

The principle of using synthetic amino acids to reduce dietary CP levels is presented in **Table 6**, which shows that when lysine, methionine and threonine are available, soyabean levels in a theoretical ration could be reduced from over 70% to 29% and the protein levels from 35.6% to 20% compared to unsupplemented diets[13].

Based on current research, there is no specific minimum level of dietary CP. Minimum level here refers to maintaining bird performance, as it depends on many factors that should be considered when exploring reduced CP diets (**Figure 4**). These include the weighing up of poultry litter quality (due to decreased N excretion) and improved efficiency of dietary CP utilisation against other factors such as costs of supplementing of synthetic amino acids, increased reliance on amino acid digestibility figures to be accurate, ensuring there is sufficient N for production of non-essential amino acids (even if all amino acids are accounted for, if ration CP is very low then effectively dietary non-essential amino acids may limit protein production) and ensuring that feed intake is not reduced e.g. by providing the correct electrolyte balance.

Ingredients %	Un-supplemented	+Met*	+Lys+ Met**	+Lys+ Met+ Thr***
Maize	14.01	57.21	59.47	62.42
Soyabean Meal	70.86	33.91	31.94	29.29
Composition (calculated), %****				
Protein	35.60	21.61	20.89	20.00
Lysine	2.13	1.15	1.10	1.10
Methionine	0.50	0.55	0.56	0.58
Methionine+ Cysteine	1.04	0.90	0.90	0.90
Threonine	1.37	0.80	0.80	0.80
Valine	1.63	0.98	0.95	0.90
Isoleucine	1.54	0.88	0.85	0.80

*, methionine supplemented; ** lysine and methionine supplemented; ***, lysine, methionine and threonine supplemented; ****, composition of feeds formulated to meet amino acid requirements using NRC (1994) nutrient requirements and ingredients composition tables

Table 6. Influence of synthetic amino acids on protein level of theoretical maize and soyabean meal-based rations for poultry[13]

In ruminant animals, there is also a considerable interest in lowering dietary CP levels and using more home-grown forages due to the high and volatile costs of purchased protein feeds, for example soyabean, as well as the environmental impact of N losses. A recent report from AFBI[14] refers to experiences in the Netherlands that suggest that reducing dietary CP offered to dairy cows by 1% has the potential to reduce ammonia emissions by 10%, and predicts that CP levels will drop to 16% or less by 2024 from a typical 17% level in 2020. However, lowering ration CP can adversely affect milk yield, dry matter intake and milk composition, therefore to alleviate some of these effects, particularly milk performance, researchers have studied the supplementation with rumen-protected amino acids, with emphasis on methionine, lysine and histidine. These are amino acid products developed to supply amino acids to the small intestine without being degraded by the rumen microbes. Their economic viability, together with the development of precision feeding, is driving forward dairy industry adoption of reduced CP rations.

Considerable progress has been made in recent years to establish better models to estimate absorbed amino acids from total mixed rations, allowing progress in balancing diets for amino acids and establishing the optimal concentration in MP of the most limiting amino acids. Formulating diets for optimal amino acids composition of MP allows for reducing ration CP levels without sacrificing milk production performance.

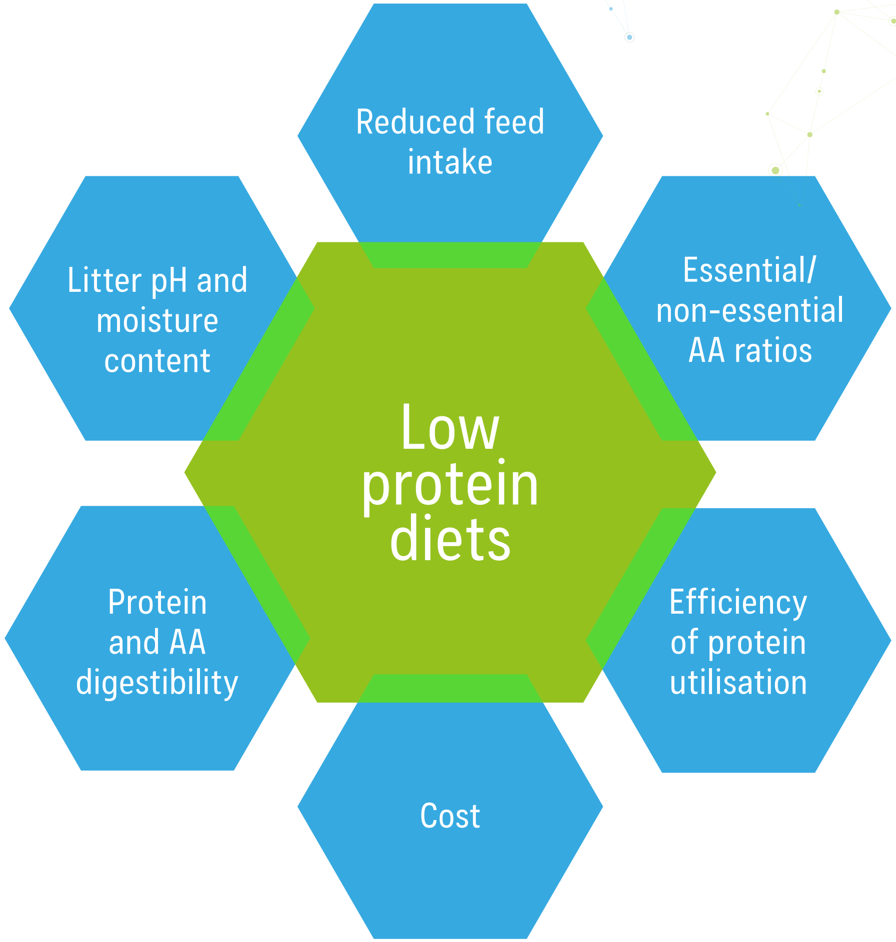


Figure 4. Factors that should be considered while feeding birds low protein diets

9. Protein sources for livestock

Livestock production in the UK uses predominantly plant-based feedstuffs. In response to the Bovine Spongiform Encephalopathy (BSE) crisis, the use of protein sources of animal origin (meat meal, bone meal and fishmeal, etc.) is severely restricted for monogastric livestock and banned in ruminant livestock, according to the EC regulation No. 169/2009. However, in the form of processed animal proteins, such products are being considered again as protein feedstuff, initially for monogastrics. As and when this materialises, it will provide the industry with more high-quality protein (and mineral) sources, which are a closer match to the amino acid profile of proteins in meat, milk and eggs.

Plant sources that are high in protein include soyabean, rapeseed meal, linseed meal, distillers' grains, legumes and forage legumes. Soyabean remains the most important and preferred high-quality plant protein source for animal feed manufacture. Soyabean, which is the co-product of soya oil extraction, has a high CP content of 44-50% and a more balanced amino acid composition compared to that of other protein-rich plant-based sources **(Table 7)**. Consequently, large inclusion levels (30-40%) are common for high performing monogastric diets and for ruminants due to its ability to supply significant amounts of DUP. However, this is falling out of favour with farmers, consumers and processors.

The environmental concerns of how imported soyabean is produced and the desire to reduce the carbon footprint of livestock means that more farmers are looking at alternatives such as rapeseed meal which has been heated or chemically processed to improve the DUP content. Studies have shown that lactating dairy cows and ewes fed these alternatives can have similar or improved milk production compared to a soya-based diet.

Item	CP (%)	Lys (%)	Met (%)	Trp (%)	Thr (%)	Arg (%)	His (%)	Ile (%)	Leu (%)	Phe+Tyr (%)	Val (%)
Barley*	11.0	0.40	0.18	0.14	0.37	0.53	0.24	0.38	0.75	0.86	0.53
Wheat*	10.7	0.31	0.17	0.14	0.31	0.52	0.25	0.35	0.71	0.74	0.45
Soyabean*	44.0	2.69	0.60	0.60	1.72	3.19	1.17	1.98	3.34	3.78	2.09
Rapeseed meal*	33.5	1.72	0.65	0.45	1.42	1.94	0.89	1.30	2.28	2.26	1.68
Grass nuts*	16.0	0.62	0.24	0.22	0.66	0.67	0.30	0.61	1.10	1.12	0.83
Microbial protein**	62.5	7.9	2.6	-	5.8	5.1	2.0	5.7	8.1	10.0	6.2
Eggs**	35.5	6.7	3.4	1.9	4.7	6.1	2.2	5.4	8.6	-	6.4
Chicken breast***	22.1	7.7	3.7	0.8	5.8	4.8	3.1	4.9	7.9	7.4	5.1
Beef****	20.6	8.2	2.2	1.3	4.2	6.4	2.8	5.0	8.5	4.1	5.6
Lamb****	20.0	7.5	2.4	1.2	4.8	6.8	2.9	4.7	7.2	3.8	5.1
Pork****	20.3	7.9	2.6	1.5	5.2	6.6	3.1	4.8	7.6	4.3	5.2
Milk (dried)*	25.0	1.95	0.65	0.33	1.10	0.90	0.70	1.33	2.40	2.38	1.55

*CP and amino acids as % as fed[15]; **CP in %DM and amino acids as % of 100g amino acids[11]; ***CP in fresh and amino acids as % in total amino acids[16]; ****CP in % across a number of animal products and amino acids as % of 100g amino acids[17]

Table 7. A brief comparison of protein quality for common feedstuffs against animal proteins[11,15,16,17]

Lys - Lysine, Met - Methionine, Trp - Tryptophan, Thr - Threonine, Arg - Arginine,
His - Histidine, Iso - Isoleucine, Leu - leucine, Phe - phenylalanine, Tyr - Tyrosine, Val - Valine

The ruminant diet is different from the monogastric one due to the unique ruminant digestive system, which involves microbial fermentation of feed before its exposure to the ruminants own digestive enzymes. Forage, typically grass, often makes up the largest proportion of the ration of the grazing ruminant or it may be consumed as silage or hay when pasture is limited or unavailable due to housing over the winter or times of reduced pasture growth. Around 70% of a typical British beef cattle herd's diet is grass, with the remainder made up of co-products such as grains from crops not suitable for human consumption.

To meet high demand for dietary CP, for example in late pregnancy (sheep), early lactation or in high-yielding animals (dairy) or the final period of growth (beef cattle), plant protein supplementation is commonly used in ruminant feeds. For example, oilseed cakes and meals are the residues remaining after the removal of oil from oilseeds. The residues are rich in protein (200-500g/kg) and most are valuable foods for ruminants. **Table 8** shows some of the most common raw materials used in animal feed and their protein content and total amount used in UK animal feed production 2021/22. High protein (Hipro) soyabean was the most used protein feed in 2021/22 in feed production (1,359 Kt), followed by rapeseed meal (684 Kt).

Livestock system	Protein feed	Crude protein %	Total usage in UK (thousand-ton Kt)
Ruminants, monogastrics	Hipro soyabean	52	1,359
Ruminants, monogastrics	Rapeseed meal	40	684.2
Ruminants	Distillery by-products	32-34	262.8
Ruminants	Sunflower meal	28	295.2
Ruminants, monogastrics	Field beans	29	122.6
Ruminants, monogastrics	Field peas	26	27.1
Ruminants	Maize gluten	22	54.6

Table 8. UK protein source usage for ruminants and monogastrics

10. Microbial protein as a high-quality protein source for humans, non-ruminants and aquaculture

As a result of the world population increasing towards 10 billion, a 70% increase in food calories will be required between 2006 and 2050[18].
In addition, there is great environmental pressure from soyabean production due to land and water use in tropical areas of the world. Therefore, good quality feed alternatives are urgently needed to strengthen future food security while minimising impacts on global sustainability[19]. While ruminant microbial protein is a key feature in ruminant livestock production, the production of non-ruminant, microbial protein is considered to be a key opportunity for the supply of high-quality protein for both the global human population and as an alternative source of high-quality protein to replace soyabean and fish meal in livestock nutrition and aquaculture. Moreover, such microbial protein has been reported to meet FAO/WHO nutrition requirements for good protein quality in human diets.

11. The impact of protein and energy balance on animal performance and emissions

Ruminants impact the environment through the process of digestion and metabolism. Methane (CH_4) is produced by gut microbe fermentation, and decomposition of carbon compounds in faeces stored as manure. Ammonia (NH_3) and nitrous oxide (N_2O) are produced from the decomposition of undigested and waste products of N compounds in faeces and urine.

It has long been believed that CH_4 represents a 2-12% loss of feed gross energy through fermentation by ruminants[20]. There are several methods that have been explored to find a way of potentially reducing the production of CH_4 from rumen fermentation. One key way is increasing animal productivity (feed conversion efficiency) which can reduce CH_4 both directly and indirectly per kg of product. Directly, through increasing the energy density of the diet to achieve greater animal performance, usually by increasing the quantity of non-fibrous feeds, such as concentrates, for example a commercial compound feed/nut and lowering the inclusion of fibrous foods. Indirectly, as fewer animals are required to produce the same output of meat or milk products and thus total requirements for maintenance (basic requirements not directly associated with production functions) are smaller, therefore reducing methane intensity.

Nitrogen is the most abundant element in our atmosphere and is crucial to life. Through a continual cycle of processes, N moves through both living and non-living 'pools', i.e. the atmosphere, soil, water, plants, animals and bacteria. Livestock obtain N as amino acids and protein from their feed directly, or through microbial activity, and convert this into milk, meat or eggs. Nitrogen that is not used or recycled will be excreted in animals' faeces and urine. Plants can take up this N, however they are not able to capture all of this. A component of N within the soil is lost through volatilisation, e.g. the conversion of ammonia from urine patches into ammonia gas, and denitrification, e.g. the conversion of nitrate (NO_3) to nitrous oxide (N_2O). Although these are natural processes, the conversions are considered losses as the nutrients are no longer available to the plant.

There will always be N losses due to the inherent inefficiencies of biological systems involved within the N cycle. However, we can minimise N losses from animals by ensuring feeds are balanced for the nutrients they require, protein in particular (see **Figure 3**). Good management of manure and slurry waste should be followed.

To achieve maximum efficiency and production of microbial protein for ruminants, the synchronisation between energy and degradable protein in the rumen is a vital factor in optimising microbial protein synthesis. When the correct balance between energy and degradable protein is achieved, rumen fermentation, digestibility of nutrients and the microorganism populations from the rumen, as well as microbial protein production, nitrogen retention, the animal's productivity response and N-use efficiency are optimised. Any residual N loss is then considered the outcome of biological inefficiencies, which are not sensitive to (nutritional) management strategies.

12. Amino acid requirements of livestock according to physiological and production status

In general, rations for poultry have the highest percentages of crude protein (16-23% CP), followed by those for pigs (16-20% CP). The lowest percentage are found in cattle, with dairy (15-17% CP) being slightly greater than beef (14-16% CP)[21].

The amino acid requirement can be defined as the amount of amino acids needed to achieve specific production objectives such as maximising weight gain or lean tissue gain and improving feed conversion. Amino acid requirements might vary according to production methods, health status, genetics and age. During the production cycle, livestock require specific nutrients for whole body growth and development of specific organs. To illustrate this, we will focus on three livestock animal species; laying hens (layers), pigs and dairy cattle, to illustrate the impact of physiological and production status on amino acid requirements.

12.1 Protein requirements of poultry (laying hens)

During the rearing period of the pullets (young hens), different staged diets (starter and grower) are required to develop different parts of the body. Pullets are fed a pullet ration ad libitum for growth and development of reproductive tract during weeks 14 and 15. Pre-layer diets are then fed until egg production has reached 2% of expected production in the flock. **Table 9** shows the nutrient requirements for pullets and laying hens, expressed as CP and amino acid percentage in the rations offered. Layers' diets include greater amino acid content, compared to pullet diets which is needed for production and body weight gain. However, the amino acid requirement doesn't change throughout the laying period and any deficiency of one or more essential amino acids reduces performance (total egg weight production), of which two-thirds comes from reduction in laying rate and one-third from decreases in egg weight. Therefore, it is not possible to reduce egg weight towards the end of lay by decreasing dietary amino acids concentration without a reduction in laying rate.

	Starter	Grower	Pullet	Pre-lay	Early lay*	Mid-lay*	Late lay*
Period (weeks)	0-3	3-8	9-17	18-19	19-50	50-70	>70
CP (%)	19.5	18	15.3	17.5	15.4	15.0	14.2
Amino acids (%)							
Methionine	0.52	0.46	0.31	0.42	0.40	0.39	0.38
Lysine	1.18	1.01	0.66	0.84	0.80	0.78	0.76
Threonine	0.78	0.70	0.46	0.59	0.56	0.55	0.53
Tryptophan	0.23	0.21	0.16	0.18	0.18	0.17	0.17

*Based on Lohmann Brown-classics daily feed intake of 120 g/day

Table 9. Protein and amino acid requirements for pullets and laying hens[22]

Over the past 30 years, the daily amino acid requirement has altered due to changes in the genetic make-up of the birds following extensive breeding for improved production. Production has improved by more than 40% while feed consumption has decreased by 10%. In addition, there is an increasing trend towards formulating poultry diets on ideal amino acid profile basis with lower CP levels in the rations and supplementing with synthetic amino acids which are commercially available[21]. **Table 10** represents the estimated requirements for amino acids based on ideal amino acid profile for laying hens to reach maximum production.

	Dietary content in feed (%)	Ratio to lysine
Lysine	0.67	100
Methionine	0.33	50
Threonine	0.47	70
Tryptophan	0.15	22
Valine	0.58	88
Isoleucine	0.53	80

Table 10. Estimated requirements for standardised ideal digestible amino acids for laying hens at mid lay[22]

12.2 Protein requirements of pigs

The amino acid requirement differs according to the physiological state of the animal and production method used. In the case of growing versus pregnant versus lactating pigs, especially in high-producing lactating sows, amino acid requirements have increased substantially to support the milk production demand of large litters. The amino acids for milk production represent most of the requirements, as lactating sows use as much as 70% of dietary protein for milk protein synthesis[23]. It appears that milk production varies little with dietary energy provision because sows can mobilise body reserves[24]. However, strategic amino acid supplementation when employing the ideal protein concept for sows can improve milk protein output and reduce muscle protein mobilisation.

Recent studies highlight that a dietary intake of balanced protein is both important to sow and litter performance during lactation[23]. Dietary intake of ideal protein provides amino acids though that should be combined with sufficient total N necessary to synthesise non-amino acids. Growing pigs, gestating sows and high-producing sows benefit from such balanced protein intake as seen from improved feed conversion, greater litter growth rate and reducing bodyweight loss during lactation. This variation between physiological status is illustrated in **Table 11**, which shows the lysine requirements across growing, gestating and lactating pigs, in terms of the amount of digestible lysine (dLys) needed per day actual g/d and as a % in typical ration (assuming pigs satisfy energy requirements through feed intake) and associated total lysine levels.

	Rearing			Reproducing	
	Grower	Finisher 1	Finisher 2	Gestating*	Lactating**
Weight (kg)	30-60	60-90	90-120	225	225
dLys (g/d)	17.9	21.8	22.7	12.7	69.5
dLys (%)	9.8	8.9	8.2	4.2	7.7
Total lysine (%)	11.7	10.6	9.8	5.0	9.2

*Assumed 50 kg maternal weight gain; **Assumed 13 kg milk/day

Table 11. Lysine requirements for pigs in different physiological states[9]

12.3 Protein requirements of ruminants

Dairy cows

The protein requirements of the dairy cow depend on her size, bodyweight change, milk production and stage of pregnancy. For a lactating dairy cow, milk production will be the biggest influence on protein requirements.

In the UK, protein requirements for dairy cows are calculated using the MP system from the Feed into Milk system (FiM, 2004). The MP demand is calculated by FiM as the sum of that required for maintenance (MPm), foetal growth (MPc), milk production (MPl) and body weight change, with additional MP for gain (MPg) but reduced MP at times of weight loss (MPloss).

In most dairy diets there is an excess of ERDP and microbial protein synthesis is limited by the supply of fermentable energy to the rumen microbes. FiM calculates this from the degradability constants of DM in soluble and very small particles, concentrates and forage together with the fractional outflow rate of liquid, forage and concentrate components. This is then converted into the potential yield of microbial protein dependant on whether protein or energy is limiting. This is then, in turn, added to the DUP content to provide the total MP supply of the diet.

In high-yielding cows the MP requirement is considerably more than microbial protein synthesis can provide. Therefore, the first step in diet formulation is to optimise rumen fermentation so that microbial growth is maximised by providing sufficient ERDP and energy in the diet. The total MP requirement of the cow is then met by supplementing DUP, because microbial protein supply and background DUP alone is insufficient. Excess protein in the diet is excreted, therefore the aim is to formulate a diet that will meet but not exceed requirements in order to maximise overall nitrogen use efficiency.

Table 12 illustrates how MP requirements increase with increasing milk yield, for example a cow yielding 45 litres/day has an MP requirement of 2727g/day, compared to a cow yielding 15 litres/day which only has an MP requirement of 1341g/day. **Table 13** shows the MP requirements of a dry cow at different stages of pregnancy; compared to a lactating cow, the MP requirements are much lower at 549g/day at six weeks pre-calving, which increases to 585g/day at three weeks pre-calving. Therefore, the diet should be adjusted to meet MP requirements depending on the animal's stage of production to prevent over or under supply to the animal.

Milk yield (litres/day)	15	25	35	45
Liveweight change (kg/day)	+ 0.6	+0.2	-0.3	-0.6
MP requirement (g/d)	1341	1758	2205	2727

Table 12. MP requirements of a 650kg dairy cow producing milk of 3.8% fat and 3.4% protein[11]

Weeks pre-calving	6	3
MP requirement (g/day)	549	585

Table 13. MP requirements of a 650kg dry cow[11]

Rearing heifers

Protein requirements of rearing heifers are calculated from the AFRC (1993)[10] MP system. Optimal protein nutrition is required for heifers to achieve their target liveweight, particularly for those calving at two years of age. It is recommended that heifers reach 65% of their mature weight at first oestrus, therefore if the average cow weight is 650kg, heifers must weigh 420kg before the breeding season.

Between weaning and breeding, heifers need to steadily grow by around 0.7kg/day. **Table 14** shows the MP requirements of growing heifers according to their liveweight and targeted liveweight gain. For example, a 100kg heifer growing 0.75kg/day requires 286g of MP/day, compared to a 500kg heifer growing at 0.75kg/day which requires 426g of MP/day. Therefore, as a heifer grows the diet must be correctly formulated to account for her increase in liveweight.

The requirements will also be greater if the target liveweight gain is increased. For example, in **Table 14** a 300kg heifer growing 0.75kg/day will require 355g of MP/day, but if the target liveweight gain is increased to 1.00kg/day her protein requirements increase to 409g/day as she is growing more lean tissue, therefore protein supply from the diet must be adjusted to match MP requirements.

Liveweight gain (kg/day)	MP requirement (g/day) according to heifer liveweight		
	100kg	300kg	500kg
0.75	286	355	426
1.00	348	409	477

Table 14. MP requirements (g/day) according to heifer liveweight and target liveweight gain[10]

13. The effect of amino acid imbalance on animal performance and N losses

It should be recognised that amino acid requirements are dynamic because they can vary according to different factors including genetics, age, physiological state and level of production. Reproduction affects animals' amino acid requirements and consequently when in female mammals there is an increased amino acid requirement for ovulation, implantation process, foetal development and milk production.
The health status and immunity responses of the animals to disease exposure also affect amino acid requirements and consequently when applying the ideal protein concept. Additional requirements for amino acids must be considered to maximise growth performance and productivity, promoting optimum health and minimising nitrogen excretion.

Not all absorbed amino acids are used by animals. Those unused, together with amino acids that come from cell regeneration, are catabolised producing urea as an end product which passes into the blood stream and from there to the kidneys to be excreted in urine (**Figure 2a and 2b**). The urea cycle requires energy for urea production and therefore feeding excess dietary protein induces high urea levels which diverts energy away from productive processes.

Oversupplying dietary protein can thus lead to nitrogen pollution, which is a serious environmental issue of global concern having detrimental effects on the environment and particularly, due to elevated levels of ammonia, on health of livestock and farmworkers.

In the case of ruminants, if too much protein is provided or there is an imbalance of the fermentable energy to degradable protein available, there will be wastage. Ruminants are poor nitrogen converters with only 5-30% of ingested nitrogen taken up by the animal and the remaining 70-95% excreted via faeces and urine. The efficiency of nitrogen captured by microorganisms in the rumen depends on the speed and extent of protein breakdown, as well as synchronisation of a fermentable energy source (usually in the form of cereals or high energy grass) to fuel the production of microbial protein at the correct time post-feeding. Offering the correct ratio of fermentable energy and RDP over the day but not synchronised within smaller time frames reduces the overall yield of microbial protein.

When this balance isn't achieved it results in too rapid and extensive a breakdown of protein and the rumen microbes are unable to capture resulting ammonia. This results in an excess of ammonia which is absorbed and largely excreted as urea, although some will be recycled via the rumen wall or in saliva.

As mentioned before, excreting excess nitrogen as urea, comes at an energy cost to the animal, reducing feed efficiency.

The environmental impact of these significant concentrations of nitrogen depends on the fate of the manure, which is dependent upon the manure management system. Most nitrogen compounds mineralise rapidly during the first phase of manure management. In urine, typically 70% of the nitrogen is present as urea, and hydrolysis to NH_3 is very rapid in urine patches.

There are significant nitrogen losses through volatilisation during storage and treatment of manure. The magnitude of N_2O emissions depends on environmental conditions, with greater emissions in wetter and warmer conditions.

On the other hand, if too little protein is supplied performance targets will not be achieved. More specifically for ruminants, sub-optimal protein in the diet will impair growth of the rumen microbe population, reducing fermentative functions and ruminal synthesis of both microbial protein and volatile fatty acids, the energy source ruminants heavily rely on. This is extremely important for ruminants as microbial protein is the main protein source and the microbe population drives the digestion of fibre in forage. Inadequate levels will negatively impact rumen function, and subsequent productivity of the animal e.g. a drop in milk yield in dairy cows or reduced liveweight gain in cattle and sheep.

Not only is the overall protein content of the diet important but also the type of protein (ERDP vs DUP). ERDP is used by rumen microbes for microbial protein synthesis, whereas DUP bypasses the rumen and is absorbed in the small intestine. Meeting requirements and the balance of these two types of protein is critical, for example supplying protein in the form of DUP will not make up for a shortfall in ERDP and so suppress microbial growth.

14. CIEL commentary

Dr Fiona Short, CIEL

With an ever-increasing human population to feed and demand for protein rising, efficient use of agricultural resources is critical. An understanding of the roles livestock play in our food system is important and that is intimately tied up with protein nutrition and the concept of protein quality. These concepts also impact farm profitability and the environmental footprint of agriculture.

Animals, including humans, obtain energy from carbohydrates, lipids and protein, and have specific requirements for amino acids to make their own protein. The amino acid content of the feed protein compared to the balance an animal requires denotes the 'protein quality'. Protein is more expensive than energy across feed ingredients and so protein nutrition is critically important to profitability as well as productivity of livestock systems.

Animal products such as milk and eggs are ideal proteins for human nutrition because they contain significant quantities of amino acids in the proportions required. Protein from meat also has higher protein quality compared to plant protein which varies because of species and variety. Meat, eggs and milk also provide a variety of other important nutrients, in addition to high-quality protein.

For livestock, as in all biology, there are natural inefficiencies in the feeding and use of protein that cannot be overcome. However, protein will be most efficiently used by animals when energy and protein, with the correct blend of essential and non-essential amino acids, meet the requirements of the animal. This also minimises nitrogen excretion from breakdown of amino acids in the gut which lead to production of ammonia (a respiratory irritant for animals and humans), nitrous oxide (a potent greenhouse gas), and nitrate losses to the environment.

With low-protein quality diets more total protein is required to meet the needs of the animal. However, this is less profitable, less efficient and has a higher environmental footprint because metabolism of excess amino acids increases nitrogen losses which impacts on the environment. The goal should be to minimise the quantity of protein fed, while still supplying quantities and proportions of amino acids needed by the animal.

Monogastric livestock can produce substantial amounts of protein extremely efficiently from cereals and protein crops, supplemented with essential amino acids and other nutrients, resulting in high-quality protein foods.

Artificially produced amino acids and accurate diet formulation are key to maximising production and minimising emissions from poultry and pigs.

Ruminant livestock have a unique relationship with microbes which affects their protein nutrition. Rumen microbes use the feed before the ruminant itself does and can modify the quality and quantity of nutrients that the host animal itself then digests and absorbs. This allows low-quality feed to be 'up-cycled' but also high-quality feed can be 'down-cycled'. Ruminants are ideally suited to make use of low-quality roughage to produce high-quality protein foods. High-quality proteins will be 'down-cycled' unless protected from digestion by rumen microbes.

While it is more difficult to precisely control protein nutrition in ruminants than in pigs or poultry, ruminants have adapted so they can use feedstocks that other animals and humans cannot. Thus, ruminants play a key role in human food production by converting fibre-rich plants (indigestible in monogastrics, including humans) and plant protein into highly nutritious foods.

We face challenges in delivering more sustainable food systems for the future especially regarding protein supply. For livestock production, these include:

- Producing sufficient environmentally friendly protein-rich raw materials for livestock feed while minimising the food versus feed competition for land
- Improving protein quality in the raw materials used for livestock feed
- Continuing investigations into alternative novel protein sources and appropriate regulation to allow use of animal protein by-products in livestock nutrition
- Accurate assessment of animal requirements and feeding as they mature, particularly in group fed animals
- Optimising microbial populations in the gut of all livestock to maximise efficiency of digestion and absorption, including the rumen
- Models for describing nitrogen flows in food production that adequately values the up-cycling that occurs as nitrogen is captured from the environment and upgraded through plant and microbial protein to animal protein
- How best to use nitrogen and other nutrients from animal manure to increase circularity of productive farm enterprises and systems

Livestock play a key role in supplying human diets with high-quality protein. They are the reason we can provide nutritionally adequate diets, in terms of protein, to much of the world. Modern farming methods use a knowledge of protein nutrition to help create livestock feeds which maximise efficiency and profitability and provide high-quality pig and poultry products from small concentrations of plant and cereal protein and the upcycling of lower quality forage to produce milk and meat. The same concepts are important for managing the environmental footprint of livestock systems and understanding the roles livestock play in a sustainable food system.

Livestock are complementary to food production from plants by:

- Adding nutritional value to low-quality feedstock
- Making use of by-products from the feed and food supply chains
- Returning nutrients to land as manure to enhance soil health and sequester carbon

Links to other CIEL reports

Ideas presented in this report are intricately linked to those in another report CIEL produced in 2023, *Why nitrogen matters in livestock production*, due to the fundamental role nitrogen has in the derivation and breakdown of protein. Both reports are complementary to the series of reports related to **Net Zero and Livestock** that CIEL has produced in 2020, 2022 and 2023. Nitrogen and protein deliver value in agriculture through their roles in providing highly nutritious food but are also implicated in the harmful environmental impacts that occur when production systems are less efficient than they could be. Alternative protein sources are discussed in the report *Bridging the Gap* which can be found here.

Dr Fiona Short

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Authors

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16. Glossary

Agricultural and Food Research Council's Technical Committee (AFRC)	The UK nutritional model for dairy, rearing heifers, beef cattle and sheep
Amino Acid	Building blocks of protein
Crude Protein (CP)	Provides a measure of the protein content of feed. This measurement assumes all nitrogen present in feed is present as protein and that all feed protein contains 16% nitrogen
Ideal protein concept	Supplying amino acids in the proportions required to achieve the correct balance between essential and non-essential amino acids, thus avoiding both deficiencies and excesses
Catabolism	Process of breaking down complex molecules to simpler ones
Digestible undegradable protein (DUP)	The portion of UDP that is digestible and is absorbed in the small intestine
Dry matter (DM)	The portion of feedstuff that remains after the removal of water
Effective rumen degradable protein (ERDP)	This is a measure of the amount of RDP that is available for microbial digestion and growth and captured as microbial crude protein
Essential amino acids	Amino acids that cannot be synthesised in monogastric body and must be supplemented in the diet
Feed into milk (FIM)	The UK nutritional model for dairy cows
Fermentable carbohydrates	Dietary carbohydrates that are degraded by microbes, e.g. in the first stomach of cows and sheep (rumen)
Rumen microbes/microorganisms	A diverse microbial population within the rumen consisting of bacteria, archaea, protozoa and fungi
Microbial protein	Protein synthesised by the microbes obtained from the breakdown of the nitrogen fraction of the feed ingested
Metabolisable protein (MP)	The UK system used in ruminant nutrition to describe the degree to which protein is degraded (broken down) in the rumen and transformed to microbial protein, and the amount of protein that is undegraded and leaves the rumen passing to the small intestine
Non-protein nitrogen (NPN)	Refers to feeds such as urea that are not protein but can be converted to proteins by rumen microbes
Rumen degradable protein (RDP)	Protein which is easily degraded in the rumen making nitrogen available for the rumen microbes
True protein	Protein containing amino acids
Undegradable dietary protein (UDP)	Protein that is not digested by the rumen microbes and essentially bypasses the rumen to the small intestine
Volatilisation	The conversion of a liquid into a vapour which escapes into the atmosphere

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CIEL
Innovation Centre
York Science Park
YO10 5DG

Email: enquiries@cielivestock.co.uk
Telephone: +44 (0)1904 217 493

www.cielivestock.co.uk

@CIELivestock1

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