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Protein systems for ruminants

TORBEN HVELPLUND
National Institute of Animal Science, Department of Research in Cattle and Sheep, Research Centre Foulum, DK-8830 Tjele, Denmark
and
JØRGEN MADSEN
The Royal Veterinary and Agricultural University, Department of Animal Science and Health, Rolighedsvej 23, DK-1958 Frederiksberg C, Denmark

SUMMARY

Based on an increased knowledge gained concerning the nitrogen metabolism in the ruminants during recent years and the shortcomings of the present systems based on digestible, true or crude protein several new protein evaluation systems have been proposed. Although the basic framework of all the proposed new systems are similar, the units and factors used to calculate the protein values differs. The AAT-PBV protein evaluation system proposed in the Nordic countries is described and the different factors which are of importance for the protein value of a feed is discussed in relation to factors used in other systems. The Nordic system deviates from other systems in especially three respects: (1) The system has a value which express the protein supply of the microorganisms relative to their need. (2) The amino acid proportion in undegraded protein is 0.85 for concentrates and 0.65 for roughages where nearly all other systems use a factor of 1.0. (3) The microbial protein synthesis in the rumen is related to the amount of totally digested carbohydrates. In production experiments with dairy cows in early lactation the new protein evaluation system has proven its superiority over the present system based on digestible crude protein. For growing animals with a low AAT requirement per energy unit, use of the new system has not improved the prediction of animal performance above the system based on digestible crude protein. The present recommendations are discussed in relation to the French PDI system where the protein values on the feed can be compared, by using a conversion factor, to the values in the AAT-PBV system.

Key words: amino acids, degradation, microbial protein, protein evaluation, ruminants, systems.

YFIRLIT

Próteinmatskerfi fyrir jórturdýr

Vegna aukinnar þekkingar á efnaskiptum köfnunarefnis hjá jórturdýrum á undanförnum árum og takmarkana þeirra próteinkerfa sem verið hafa í notkun og byggjast á meltanlegu próteini, raunverulegu próteini eða hrápróteini, hafa nokkur ný próteinmatskerfi verið þróuð. Þó að grundvöllur þessara nýju kerfa sé svipaður eru einingar og stuðlar, sem notaðir eru við útreikninga þeirra, mismunandi. AAT-PBV próteinkerfinu, sem þróað var á Norðurlöndunum, er lýst og þeir þættir, sem eru mikilvægir fyrir próteingildi fóðurs, ræddir og bornir saman við sömu þætti í öðrum próteinkerfum. Norræna próteinkerfið er aðallega frábrugðið öðrum kerfum að þrennu leyti: (1) Það hefur stuðla fyrir próteinframboð til vambarörveranna í hlutfalli við þarfir þeirra. (2) Hlutfall amínósýra í óniðurbrotnu próteini er 0,85 í kjarnfóðri og 0,65 í gróffóðri en 1,0 í nánast öllum öðrum kerfum. (3) Framleiðsla örverupróteins í vömbinni er tengd magni meltra kolvetna. Þetta nýja kerfi hefur í framleiðslutilraunum með mjólkurkýr sýnt yfirburði sína yfir eldra kerfi sem nú er í notkun og byggist á meltanlegu hrápróteini. Nýja kerfið hefur aftur á móti ekki aukið öryggið, miðað við eldra kerfi byggt á meltanlegu próteini, við mat á framleiðslu hjá gripum í vexti með lágar þarfir fyrir AAT á orkueiningu. Tillögurnar eru ræddar með hliðsjón af franska PDI kerfinu þar sem hægt er að bera saman próteingildi fóðursins með breytingarstuðlum við gildi í AAT-PBV kerfinu.

INTRODUCTION

Feed evaluation is of importance for several reasons. First of all it is necessary to know the values of the feeds to: (1) be able to make an optimal allocation of the feeds to the animals and (2) be able to choose the most profitable feeds to buy, or to grow in the fields.

Several measures for feed values exist. It can either be the content of a single chemical component in the feed, the amount of the component digested, absorbed, metabolized or being deposited in the final product. Moreover the feed value can be predicted on the basis of different analytical measures as e.g. used in the traditional calculation of energy values of feeds.

Basically, the protein requirement of the animal is a requirement for each of the individual amino acids which can not be synthesized in the body plus a nitrogen requirement to synthesize non-essential amino acids. In addition, amino acids can be required for gluconeogenesis. These requirements must be satisfied by the amino acids absorbed from the small intestine to the blood.

The rumen microorganisms have a “protein” requirement, mainly in the form of ammonia, but in some situations they may lack specific amino acids or peptides from degraded true protein (Thomsen, 1985) or branched chain fatty acids which are end products of protein degradation in the rumen.

For many years the protein value of the feeds has been expressed as digestible, true or crude protein, but these measures do not express the amount of absorbed amino acids to any reasonable extent.

On the basis of the better understanding of the nitrogen metabolism in the ruminants and the shortcomings of the present protein evaluation system several new protein evaluation systems have been proposed.

Although the basic framework of all the proposed new protein evaluation systems for ruminants are similar, the units used and factors used to calculate the protein values differ. Comparisons of the proposed systems are made by e.g. Madsen (1979, 1980, 1985), Waldo and Glenn (1984), Alderman (1987), Jarrige (1987) and Ørskov and Miller (1988).

A description of the stage of development of the new systems in the different countries in 1987, has been made for Germany by Rohr (1987), France by Verité (1987), Italy by Susmel and Piva (1987), Nordic countries by Madsen (1987), Switzerland by Bickel and Landis (1987), United Kingdom by Webster (1987), United States by Owens (1987) and Australia by Corbett *et al.* (1987).

At present the knowledge concerning the requirements of individual amino acids for ruminants is poor, and therefore the different proposed new protein evaluation systems do not take individual amino acids into considerations. The microbial need for other protein related substances is also poorly understood and not taken into consideration in any of the proposed new systems.

The system proposed to be used in the Nordic countries (NKJ, 1985) uses the units AAT (amino acids absorbed in the small intestine) and PBV (protein balance in the rumen). The basic concepts of the AAT-PBV system which was first defined by Madsen (1982) and Hvelplund (1982) deviates from the other proposed systems in several respects of which especially three has to be mentioned:

1. The AAT-PBV system has a value which express the protein supply of the microorganisms relative to the need of the microorganisms. This value is called the protein balance in the rumen (PBV).

2. The undegraded feed protein from concentrates is assumed to contain 85% amino acids and the undegraded feed protein from roughages 65% amino acids, whereas other systems except the German use 100% amino acids in undegraded feed protein.
3. The microbial protein synthesis is related to the amount of totally digested carbohydrates, and the size of the synthesis used in the system is higher than in the other systems.

CALCULATION OF AAT AND PBV

A direct measurement of the AAT and PBV value of all available feeds using fistulated animals is not realistic, and therefore formulas were developed by which the AAT and PBV were expressed by factors which are either constants, or variables which can be related to analysis on the feeds:

AAT g/kg DM = g crude protein / kg DM
× (1 – degradability in the rumen)
× proportion of amino acids in undegraded feed protein
× digestibility in the small intestine of undegraded amino acids
+ g microbial protein produced / kg DM
× proportion of amino acids in microbial protein
× digestibility in the small intestine of microbial amino acids

PBV g/kg DM = g crude protein / kg DM
× degradability in the rumen
– microbial protein produced / kg DM

THE AMOUNT OF MICROBIAL PROTEIN SYNTHESIZED AND ITS PREDICTION

Measurements of microbial protein synthesis in the forestomachs of ruminants are performed with animals fistulated in the duodenum. To be able to utilize information about the microbial protein synthesis in practical feeding situations, it is necessary to relate the microbial protein synthesis in the rumen to feed characteristics which can easily be analyzed.

The limiting factor for microbial growth in the rumen is normally considered to be energy and our approach has been to relate the microbial yield to the amount of total digested carbohydrates. The reason for this is that carbohydrates are mainly digested in the rumen and thus contribute with energy for microbial growth. Energy released from the protein degraded in the rumen is limited and fatty acids are not digested in the rumen and make no contribution with energy for microbial growth.

Although the variability of the estimated microbial synthesis is reduced by expressing the efficiency in relation to digested carbohydrates rather than digested organic matter which is used in other systems, there are still a great variation in the estimates of microbial synthesis in the rumen as shown in Table 1.

Although some of the differences may be ascribed to technical problems there seems to be differences according to diet fed. The reason for this variation can be ascribed to a number of factors. Besides energy, specific nutrients from the feed can be a limiting factor for microbial growth in the rumen. An adequate supply of nitrogen either from degradable protein or from recycled nitrogen is essential for optimal microbial growth and although ammonia-nitrogen can serve as the principal nitrogen source for microbial protein synthesis this synthesis may well be influenced by the “quality” of the degraded protein (Thomsen, 1985; McAllan *et al.*, 1988; Ciszuk and Lindberg, 1988).

THE DEGRADATION OF FEED PROTEIN IN THE RUMEN AND ITS PREDICTION

The feed crude protein serves as a protein source in two distinct ways:

1. As a source of amino acids for the ruminant body through the feed amino acids that reaches the small intestine undegraded and is absorbed.
2. As a nitrogen source for microbial growth

Table 1. Microbial N production on basis of organic matter apparently digested in the rumen (DOMR) or on basis of totally digested carbohydrates (DCHO) in different diets for cattle.
1. tafla. Framleiðsla örveruköfnunarefnis sem er byggð á séðum meltanleika lífræns efnis í vömbinni (DOMR) eða á heildarmeltanleika kolvetnis (DCHO) í mismunandi nautgripafóðri.

Diet	Microbial nitrogen g/kg DOMR	g/kg DCHO	Reference
Hay with concentrates	29		ARC, 1984
Concentrates	14		ARC, 1984
Grass silage	27		ARC, 1984
Grass silage with concentrate	36		ARC, 1984
Maize silage with concentrate	45		ARC, 1984
Maize silage, alfalfa hay with concentrate	72		Santos *et al.*, 1984
Concentrate with straw	49	29	Hvelplund & Madsen, 1985
Concentrate with different roughages or roughages alone	74	46	Hvelplund & Madsen, 1985
Grass silage with concentrate		34	Møller, 1985
Grass silage with concentrate		30	Harstad & Vik-Mo, 1985

in the rumen through the feed protein degraded in the rumen.

Many different factors influence the actual degradation of a feed protein in the rumen. Among those the most obvious is the passage rate, and also the effect of different rumen environments on the degradation of feed protein have been demonstrated. The most significant effects are obtained where high amounts of starchy feeds has been fed. Vik-Mo and Lindberg (1985) reduced the protein degradation of eight out of ten tested feeds from 3 up to 29 units when a ration of grass silage and barley at a ratio of 47:53 was fed instead of a ration of grass silage, barley and soybean meal at a ratio of 46:26:28, and Lees and Miller (1988) found a reduction from 3 to 9 units by feeding hay and concentrate at a ratio 60:40 instead of 100% grass cubes.

In a feed evaluation situation it is impossible to cope with the effect of different feeding situations on passage rate and rumen environment, unless a dynamic model for feed planning is used instead of an additive factorial approach. It is normally accepted that feed values refer to well balanced diets fed at a specified level of feeding. What is needed in this situation is a figure for the degradation of the feed protein, and a standard procedure to measure the degradation.

The feeding situation chosen to be the basis for measuring protein degradability and the fractional outflow rate used to calculate the nylon bag degradability has been different in different experiments which make it difficult to compare values. Madsen and Hvelplund (1985) used a hay fed cow and an outflow rate of 8%, whereas Lindberg (1986) used 50% hay and 50% concentrate and published the degradabilities using 3.5 or 7% outflow per hour. An attempt to standardize the method was made by NKJ (1985) and now an European standard is agreed upon (Oldham, 1987).

Measuring protein degradability in feeds with a low protein content and especially of roughages with a high content of crude fibre implies certain problems, as the residues in the nylon bags after fermentation are contaminated with microbial protein which is difficult to wash out of the bags with the normal washing procedure (Kennedy *et al.*, 1984; Chapman and Norton, 1984; Varvikko and Lindberg, 1985). To solve the problem with contamination, Hvelplund and Møller (1987) used a stomacher.

Another problem in determining protein degradability with the nylon bag method is, that small particles can pass out of the bag without being degraded. This problem arises especially when estimates are performed with finely ground and pelleted feed mixtures. A possible method to overcome this source of error is to correct the degradation measurement by the difference between buffer soluble protein and protein which can be washed out of the bag in the washing procedure at incubation time zero.

Good alternatives to the nylon bag method is needed. When the origin of the feed is known the buffer solubility can give some information about the degradability of the protein (Madsen and Hvelplund, 1985), but it is of little value for mixtures of unknown botanical composition. Methods of general application has to be developed.

The degradability of protein in different feeds estimated with the nylon bag technique, which is considered to be equivalent to the degradability in the rumen of the animals, are shown for some feeds in Table 2.

THE AMINO ACID CONTENT OF MICROBIAL PROTEIN AND UNDEGRADED FEED PROTEIN

Based on 49 bacterial samples isolated on a variety of different diets Hvelplund (1986) found a significant relation between proportion of amino acid nitrogen in total bacterial nitrogen and the content of sugar + starch in the diet. The variation found in this experiment was between 0.62 and 0.72 for the proportion of amino acid nitrogen in total bacterial nitrogen and thus much lower than the average value of 0.83 reported by Storm (1982) based on a literature survey. The reason for this discrepancy is at present not clear.

A value for the proportion of amino acid nitrogen in undegraded feed protein of 0.85 as used in the Nordic system for different protein rich feeds seems justified based on available data from nylon bag residues and confirmed by the amino acid content in duodenal digesta collected from cows fed diets with a high proportion of concentrates in the diet, as shown in Figure 1 (Hvelplund and Madsen, 1985).

The proportion of amino acid nitrogen in undegraded feed protein from different roughages of 0.65 as used in the Nordic system is probably on oversimplification of the actual situation; the value will probably vary among different roughages according to their amino acid nitrogen content in the original feed. The lower value for roughages compared to concentrates seems also justified based on data available, from nylon bag incubations and from duodenal content collected from cannulated cows fed a high proportion of

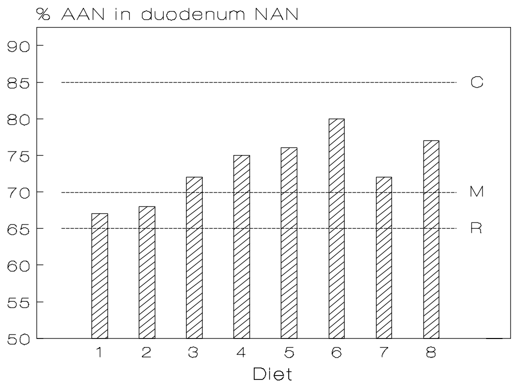

Figure 1. The percentage of amino acid nitrogen (AAN) in non ammonia nitrogen (NAN) of duodenal content from dairy cows fed different diets in relation to the content in microbial protein (M) and undegraded dietary protein from concentrates (C) and roughages (R), respectively. Diet 1 and 2 are roughages alone. Diet 3 to 6 are different concentrates with variable degradability.

1. mynd. Hundraðshluti amínósýru köfnunarefnis (AAN) í ammoníaklausu köfnunarefni (NAN) mjógirnis hjá mjólkurkúm sem fá mismunandi fóður í hlutfalli við magn örverupróteins og próteins frá kjarnfóðri (C) og gróffóðri (R), sem ekki er rofið í vömb. Fóður 1 og 2 er eingöngu gróffóður. Fóður 3 til 6 er kjarnfóður með mismunandi vambarrof.

Table 2. Comparison of estimates of degradability.
2. tafla. Samanburður á áætluðu vambarrofi.

Feed	Mean and range of nylon bag degradability[a] %	*In vivo* or nylon bag degradability %
Concentrates		
Barley	70 (60–74)	66[b] 67[c] 62[c] 80[i]
Beetpulp-molasses	65 (63–67)	
Blood meal	40	18[k]
Brewers dried grain	49	39[f] 52[f] 46[g] 74[i]
Coconut meal	37 (29–44)	43[c]
Cottonseed meal	56 (39–73)	66[b] 39[d] 76[d]
Dried beetpulp	38	59[b] 45[h]
Fishmeal	43 (22–53)	56[b] 16–71[c] 21–52[h] 43–44[i]
Grasspellets	54 (50–57)	27–91[c]
Guarmeal	66	56[h]
Horsebeans	86	58[c] 84–93[i]
Linseed	82	46[h]
Linseed meal	60	71[b] 56[d]
Maise	31 (26–33)	35[b] 39–49[c]
Meat and bone meal	66 (52–79)	30[d] 41[h] 51[k]
Oats	84	80[b]
Palmcakes	34 (25–43)	
Peas	77 (73–80)	74[h]
Rapeseed meal	68 (63–77)	80[b] 60[c]
Rye	81	
Soyabeans	74 (66–81)	
Soyabean meal	60 (51–65)	72[b] 39–54[c] 82[d] 85[d] 63–78[e] 76[f] 50[h] 65–75[i] 71[k]
Sunflower meal	73 (66–78)	77[c] 70[h] 65[i]
Wheat	82 (80–84)	71[b]
Wheat brand	63 (61–64)	76[b]
Roughages		
Barley whole crop silage	73	
Beets	80 (76–82)	
Beettop silage	74 (73–74)	
Clovergrass hay	38	
Clovergrass silage	72 (66–79)	
Grass	60 (47–70)	50–70[c] 74[j]
Grass silage	71 (60–79)	78[c]
Maise silage	62	70[i]
Red clover	70 (67–73)	
Red clover silage	62	

a) Madsen & Hvelplund, 1985. b) Boever *et al.*, 1984. Nylon bag. Mean of 5 and 10% dilution rate. c) ARC, 1980. *In vivo*. Different authors. d) Zinn *et al.*, 1981. *In vivo*. e) Stern & Satter, 1980. Nylon bag. Different calculations. f) Merchen *et al.*, 1979. *In vivo*. g) Firkins *et al.*, 1984. *In vivo*. h) Ørskov, 1982. Nylon bag. 8% dilution rate. i) Miller, 1982. Nylon bag. 5% dilution rate. j) Kaufmann & Lüpping, 1982. *In vivo*. k) Loerch *et al.*, 1983. *In vivo*.

Table 3. Degradability of nitrogen (N) in the rumen and digestibility of nitrogen (N) and amino acid nitrogen (ANN) in the small intestine of sheep (Hvelplund, 1985).
3. tafla. Rof köfnunarefnis í vömb og meltanleiki köfnunarefnis og amínósýru köfnunarefnis í mjógirni sauðfjár.

Protein	Degradability N	Digestibility N	Digestibility AAN
Undegraded soyabean meal	0.75	0.81	0.87
Undegraded cottonseed cakes	0.59	0.70	0.75
Undegraded rapeseed meal	0.77	0.63	0.77
Undegraded sunflower cakes	0.87	0.67	0.74
Undegraded fishmeal	0.44	0.86	0.87
Undegraded coconut cakes	0.33	0.85	0.87
0.5% HCHO treated soyabean meal		0.65	0.67

roughage in their diets which also is illustrated in Figure 1 (Hvelplund and Madsen, 1985). The value of 1.0 as adopted in most of the new protein evaluation systems (ARC, 1984; NRC, 1985; Verité *et al.*, 1987) is too high and leads to an overestimation of the contribution of amino acid nitrogen from undegraded feed protein.

Based on the comparisons shown in Figure 1 and from published values as well, it is concluded that a factor of 0.7 for amino acid nitrogen content in microbial protein and 0.85 and 0.65 for amino acid nitrogen content in undegraded protein from concentrate and roughage respectively seems justified.

THE DIGESTIBILITY OF AMINO ACIDS IN THE SMALL INTESTINE

Measuring disappearance of nitrogen or amino acid nitrogen between the duodenum and ileum provides an estimate of the apparent absorption and has been performed on a variety of different diets with both sheep and cattle (Armstrong *et al.*, 1977; Tamminga, 1980; Hvelplund, 1984) and summarized in the NRC (1985) review.

The NRC (1985) review collected available data based on regression analysis and although minor differences were revealed, a mean value of 0.80 for the true absorption of amino acids entering the duodenum was found. Such a common figure for the digestibility of both microbial protein and dietary protein that has escaped degradation in the rumen implies that these two fractions has the same true digestibility and further that no differences exist within different sources of dietary protein.

Estimates of the true digestibility in the small intestine of amino acids in bacterial protein has been obtained by Tas *et al.* (1981), Storm *et al.* (1983) and Hvelplund (1985), the values obtained in these studies varied between 0.85 and 0.87 which indicates that the true digestibility of amino acids in bacterial protein can be considered as a constant and a value of 0.85 is used in the AAT-PBV system.

Hvelplund (1985) measured the increments in amino acids passing the terminal ileum when different proteins, which had previously been exposed to some degradation in the rumen, were infused into the abomasum of sheep. This experiment showed that the amino acids in different undegraded proteins were digested to a variable degree in the small intestine as shown in Table 3, and there is therefore a considerable need to assess the digestibility of undegraded dietary protein for all types of feeds. *In vivo* experiments and especially infusion techniques for estimation of post ruminal digestion of undegraded dietary protein can only be applied to a limited extend as they are both costly and time consuming. Therefore, different alternative methods has been tested.

Acid detergent insoluble nitrogen (ADIN) has been proposed as an estimate for the indigestible fraction of the undegraded protein (Wilson and Strachan, 1980; Loerch *et al.*, 1983). However, it has shortcomings especially with protected proteins, like formaldehyde treated proteins, where an overprotection cannot be disclosed with the ADIN method (T. Hvelplund, unpublished).

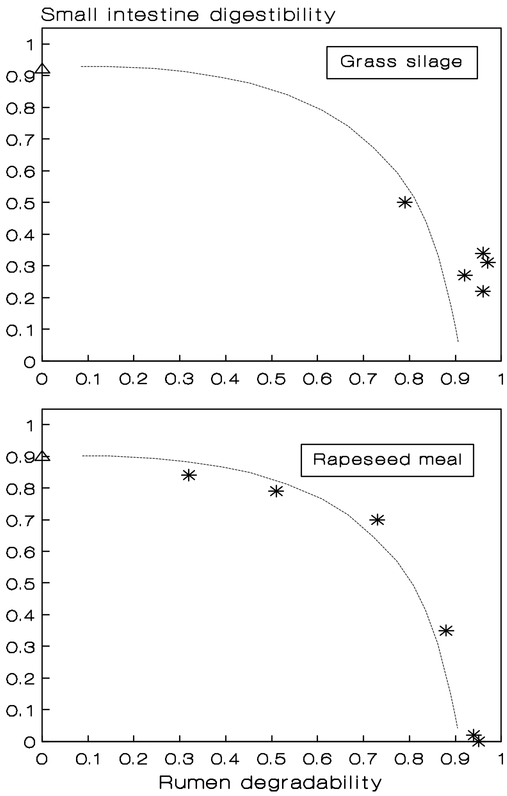

Figure 2. The relation between intestinal digestibility and rumen degradability on two different feeds. △— = True digestibility of original feed protein used to estimate the digestibility from the equation: TD = (UDN – TU) / UDN (explained in text). * = True digestibility estimated on samples of undegraded dietary protein.

*2. mynd. Samband meltanleika í þörmum og vambarrofs í tvenns konar fóðri. Ù— = Heildarmeltanleiki fóðurpróteins notaður til að áætla meltanleika út frá líkingunni: TD = (UDN – TU) / UDN (sjá texta). * = Heildarmeltanleiki ákvarðaður á sýnum í órofnu fóðurpróteini.*

The value used for the true digestibility of amino acids in undegraded proteins, except for the French system (INRA, 1978), is kept as a constant and values between 0.8 and 0.9 is used in the different new protein evaluation systems. In the French system (INRA, 1978), the true digestibility is a variable and varies between 0.6 and 0.95 according to the class of feed. Following the concept that the protein in a feedstuff contains a totally undegradable fraction which is equal to the indigestible fraction in the feed means that the true digestibility could be calculated at any extend of degradation according to the following equation:

$$TD = (UDN - TU) / UDN$$

where TD = true digestibility in the small intestine, UDN = fraction of undegraded dietary nitrogen, TU = fraction of true indigestible nitrogen in the feed.

Proof for the validity of this equation is obtained using the mobile nylon bag technique for estimation of the digestibility of protein feeds held in the rumen for different hours of incubation. In practice this means, that not only are there differences in the true digestibilities of the undegraded protein between classes of feeds but the same feed would also have different digestibilities at different degradabilities as shown in Figure 2. The consequence of this is that the fixed factor for intestinal digestibility of 0.82 used at present will be changed to a variable factor calculated according to the equation given above.

AAT-PBV VALUES OF FEEDS

Calculation of the AAT and PBV values on a feedstuff is shown below where soybean meal is chosen as an example. Values used for the calculations are:

- Crude protein in dry matter 51.6%
- Nylon bag degradability of the protein 64%

Table 4. Protein values of some feeds.
4. tafla. Próteingildi nokkurra fóðurtegunda.

Name	Crude protein	Digestible NFE + crude fibre	AAT	PBV	Degradability in nylon bag %
	g/kg dry matter				
Barley grain	134	739	107	–38	70
Maize grain	102	780	132	–108	31
Soyabean meal	515	343	180	248	60
Coconut meal	236	471	154	3	37
Rape seed meal	395	314	123	210	68
Fodder beets	74	803	93	–84	80
Grass silage	153	520	79	16	71
Grass silage	180	502	80	40	74
Whole crop					
Barley silage	91	615	78	–43	74
Barley straw	40	458	49	–62	50

- Proportion of undegraded amino acids in undegraded protein 85%
- Digestibility of undegraded amino acids 82%
- Digested carbohydrates (NFE + crude fibre) 350 g
- Proportion of amino acids in microbial protein 70%
- Digestibility of microbial amino acids 85%

AAT =

$$516 \times (1 - 0.64) \times 0.85 \times 0.82 + 0.02 \times 6.25 \times 350 \times 0.85 = 166.7 \text{ g per kg dry matter}$$

PBV =

$$516 \times 0.64 - 0.02 \times 6.25/0.7 \times 350 = 267.7 \text{ g per kg dry matter}$$

A feedstuffs table including the AAT and PBV values of the feeds used in Denmark has been established, and the values for some feeds are shown in Table 4 (Hvelplund and Madsen, 1990).

PERSPECTIVES AND PRESENT STATUS FOR AAT-PBV RECOMMENDATIONS FOR CATTLE

Basically the recommendations for AAT and PBV in different situations have to be based on production experiments, where marginal outputs are related to the input of AAT and PBV. Such experiments are expensive and time consuming, and many experiments are required. Therefore, a first and valuable approach is to use the information which can be gained by looking at the net requirements of amino acids for different productions and for maintenance.

Recommendations for AAT

The question arises as to how requirements should best be expressed. Several possibilities exist:

1. g/kg feed dry matter
2. g/Scandinavian feed unit
3. g/Scandinavian feed unit for production and maintenance separately
4. g/day
5. g/kg 4% milk, kg weight gain and for maintenance
6. g/g protein in milk, in weight gain and need for maintenance

The last mentioned possibility seems to be the most logical way of expressing the AAT requirement. Expressed in this way the ratio between the net and the gross requirement is equal to the utilization of the protein for the production in question.

The net requirements of protein for dif-

Table 5. The net requirements of protein for different productions and maintenance.
5. tafla. Þarfir fyrir prótein til mismunandi framleiðslu og viðhalds.

Type of production	Net requirement g protein per kg	
4% milk		
RDM	33.8	LK, 1989
SDM	32.4	LK, 1989
Jersey	29.4	LK, 1989
Pure muscles	200	ARC, 1980
Weight gain		
Bulls, 200 kg	140	ARC, 1980
Bulls, 400 kg	126	ARC, 1980
Bulls, 600 kg	125	ARC, 1980
Dairy cows	75	ARC, 1980
Weight loss		
Dairy cows	56	ARC, 1980

ferent productions and maintenance is shown in Table 5.

Net maintenance requirement of tissue protein:

g/day =

weight in $kg^{0.75} \times 2.2$ ARC, 1984

The utilization of the protein will vary according to the type of production and feeding regime, and it should be stressed that the maximum utilization is almost certainly not the most profitable, as the production at that point will be limited by shortage of amino acids.

These considerations illustrate the difficulties which can arise in comparison of experiments, even when the same and most obvious expression of the protein requirements is used. The situation becomes even more complex when the AAT requirement is expressed per kg of 4% milk produced or per unit of feed consumed.

To simplify the complexity of establishing recommendations for AAT to dairy cows it is possible to look at the first part and the latter part of the lactation separately, as they represent different feeding principles, due to the different physiological state of the cow:

1. The feeding system recommended in Denmark, is to allocate a constant amount of concentrates to all cows in the first 4 to 6 month of the lactation, and to feed roughage *ad libitum* (Østergaard, 1979) or to feed a complete diet to the cows in this period.
2. When the first period with constant feeding has finished, the cows are fed according to requirements for the milk produced and the desirable weight gain.

What has to be established in relation to AAT requirements to dairy cows is, the response to increased AAT supply in the beginning of the lactation.

In the later part of the lactation the rumen microbes synthesize protein in excess of the requirement of the cows. Consequently there is no need to find the exact amount of amino acids required when the cows are gaining weight.

Recommendations for PBV

Some possible ways of expressing the optimum level of PBV or the minimum level, which is equal to the maximal level of recycling of crude protein, may be:

1. As a percentage of the crude protein intake
2. g / day
3. g / Scandinavian feed unit

The maximum recycling is not likely to support optimum production, as the microbial fermentation and thereby the digestibility of the feed may be suboptimal.

Production experiments with dairy cows

The following preliminary AAT and PBV requirements for dairy cows (Madsen, 1985), were partly based on recalculations of earlier production experiments using mean values for AAT and PBV content of the individual feeds:

AAT

Maintenance	$3.3 \times weight^{0.75}$ g
Milk	45 g per kg 4% milk

PBV
Maintenance min. –400 g per day
Maintenance and milk
min. –200 g per day

Production experiments were planned in accordance with present knowledge gained from our studies concerning nitrogen metabolism in ruminants, in order to test the AAT-PBV system and to establish requirements for dairy cows as well as young stock. All experiments have not yet been published in detail, but parts have been described by Kristensen *et al.* (1985); Hvelplund *et al.* (1987); Kristensen *et al.* (1988) and Andersen and Foldager (1988).

The main conclusions from the conducted production experiments with dairy cows in early lactation (15–20 weeks), fed a constant ration independently of yield as given by Kristensen *et al.* (1988), are:

1. The application of the AAT-PBV system offers the possibility of improving the protein allocation to dairy cows.
2. It seems to be appropriate to express the AAT requirement per unit of total net energy supplied.
3. The requirement in the beginning of the lactation is 95 g AAT per total Scandinavian feed unit (TSFU) supplied.
4. Low values of PBV, down to –300 g per day, has reduced the production, and PBV values around 0 are recommended.

The results of the experiments as presented by Kristensen *et al.* (1988) show a good relation between the content of AAT per total Scandinavian feed unit intake (AAT/TSFU) and the response in milk production (Figure 3). In all six experiments, the milk production has increased up to 95 g AAT/TSFU. The response between 95 and 100 g AAT/TSFU has been variable, and there has been no response at higher AAT supplies.

It is astonishing that the expression AAT/TSFU was found to be the best expression for the relation between AAT intake and milk production. It was expected that the total supply of AAT expressed in g per day would lead to a better prediction of the milk production (Hvelplund *et al.*, 1987), since a lower energy supply cause mobilization of fat and to a lesser extent protein from the body, thereby increasing the need for supplementary AAT from the feed. In extreme situations this must certainly be the case, as also illustrated by Ørskov *et al.* (1977) using intergastric infusion technique, and by Krohn and Andersen (1978) who found a higher optimal protein concentration in the diet when feeding less energy.

Comparisons of requirements between systems are difficult because of the different values of the feeds, but a comparison to the French PDI system (INRA, 1978) seems obvious because of the comparable units and because many production experiments have been conducted.

Verité and Geay (1987) summarize the French production experiments and recommend a requirement of 50 g PDI per kg 4% milk except in the first 2 to 3 months of lactation where the mobilization can meet the protein requirement for approximately 200 kg 4% milk which means that the requirement in this period is only 45 g PDI per

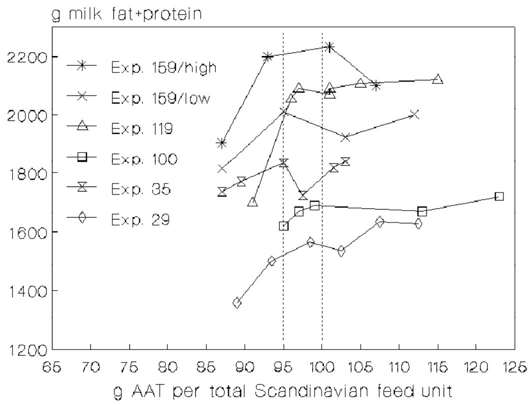

Figure 3. The relation between AAT supply and production of milk fat + milk protein in six experiments with dairy cows (Kristensen *et al.*, 1988).
3. mynd. Samband AAT magns og framleiðslu mjólkurfitu + mjólkurpróteina í sex tilraunum með mjólkurkýr.

kg 4% milk. According to Verité *et al.* (1987) these results indicate that the utilization of PDI for production is 64%. The requirement for maintenance is given as 3.25 g PDI per kg metabolizable body weight (Verité *et al.*, 1987), which is the same figure as given by Madsen (1985) for AAT.

In the early lactation a negative effect on the production has been observed when the PBV is below –300 g PBV per day (Hvelplund *et al.* 1987). In late lactation normal rations fed in this period will give PBV values as low as this or below. As demonstrated by Verité and Geay (1987) there may be a relation between the amount of amino acids absorbed relative to requirement and the amount of nitrogen that can be recycled to the rumen. Verité and Geay (1987) showed that if the amount of absorbed amino acids was in excess of the amount required then the recycling could be higher than when the amount of absorbed amino acids was lower than the requirement for amino acids. In our terminology these results can be interpreted to: The PBV can be lower when the AAT supply is above requirement. The reason for this is that the nitrogen from the surplus of absorbed amino acids can be recycled to the rumen. At the end of the lactation, the AAT supply is well beyond the requirement, and plenty of nitrogen is available for recycling. The recommendation given by Verité and Geay (1987) when recalculated to our system is approximately –10 g PBV/SFU in the beginning of the lactation, and –15 g PBV/SFU in mid lactation. Verité *et al.* (1987) tolerate down to –40 g PBV/SFU for dry cows.

Production experiments with young cattle

For growing cattle the main conclusions from the Danish production experiments are given by Andersen and Foldager (1988). According to these authors the following can be concluded at present:

1. Compared to dairy cows in early lactation the AAT requirement per SFU of growing cattle of the dual purpose breeds is relatively low, and in most situations the synthesis of microbial protein covers more than the requirement of AAT. This means that the PBV value becomes more important than the AAT value for most growing animals. It is likely that the AAT requirement of young bulls with a high growth potential is higher than the amount normally synthesized by the microbes, but it has not been possible to establish the precise size of the AAT requirement for these animals.
2. The ability to recycle nitrogen from a surplus of AAT is of great importance. When growing animals are supplied with excess AAT compared with the amount required they can recycle more nitrogen. Expressing the requirement in only PBV is of less value than to use simply the content of digestible crude protein, as a relatively great proportion of the protein not degraded in the rumen but absorbed as amino acids can be recycled and thus substitute a lack of PBV. At present, where the precise relation between AAT and PBV requirements has not yet been established, the system is not considered to be an advantage for use in feed planning for young stock under practical feeding conditions.

The experiments conducted by Andersen and Foldager (1988) showed, that the PBV in the rations for growing young bulls heavier than 200 kg fed concentrated rations according to the Danish standards for energy and protein, will have a PBV/SFU value of approximately –40 g. The heifers fed according to Danish standards will reach a PBV/SFU value as low as –70 g. This very low value is considered to be too low and the protein recommendations for older heifers will be revised on basis of this (Andersen and Foldager, 1988).

Recalculating values from the French system (Verité *et al.* 1987) to PBV values show that fast growing animals can only tolerate down to –20 g PBV/SFU. Olsson and Lindberg

(1985) imply a PBV of not lower than 0 when they interpret the results from growth experiments and calculate the AAT. Olsson (1987) suggests from his experiments, that PBV values of less than –2 or higher than 2 g per MJ metabolizable energy (ME) limit performance. These values are equivalent to approximately –20 to 20 g PBV per SFU. Olsson (1987) also established requirements for AAT for growing animals and concluded, that at least 7.7 g AAT per MJ ME is necessary to reach maximum utilization of ME in animals of live weight between 100 and 200 kg and that 6.7 g AAT per MJ ME is sufficient for animals weighing more than 200 kg. Verité *et al.* (1987) specify the amino acid requirement for growing animals as 250 to 350 g PDI per kg weight gain plus the requirement for maintenance. This interval in PDI requirement is a result of both different content of protein in the gain and decreasing utilization of absorbed amino acids with age.

It is obvious from the previous discussion that the results concerning the AAT-PBV requirements for young growing animals are not in good agreement among the different authors. The AAT requirement could not be established in the Danish experiments (Andersen and Foldager, 1988), and the requirement for AAT is given per MJ by Olsson (1987) and the PDI requirement per day by Verité *et al.* (1987), respectively. The calculated PBV in rations using the present requirements for digestible crude protein in Denmark will in some cases be as low as –70 g per SFU, whereas Verité *et al.* (1987) recommend that PBV should not be below –20 g per SFU, and Olsson (1987) assume that PBV must not be negative. The reasons for these differences may be numerous. One obvious reason could be that sufficient attention has not yet been given to the necessity of evaluating the requirement for AAT and PBV simultaneously, which is of importance as the level of one of the parameters may influence the level required for the other and of major importance for these animals where the extent of recycling is of significance. Also for other categories of animals, it is of importance to evaluate the AAT and PBV requirements together. When requirements for dairy cows in late lactation, for suckling cows and other ruminants with a low protein requirement compared to their energy requirement are going to be established in the future this joint evaluation of AAT and PBV may show up to be of major importance.

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