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– EVALUATION OF THE DCP AND THE NORDIC AAT-PBV PROTEIN EVALUATION SYSTEMS

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DISSERTATION

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ABSTRACT

Effects of level and origin of protein supplements on feed intake, live weight gain and efficiency of feed utilization of intensively reared bulls were studied in five experiments, (A) to (E). Experimental periods comprised live weights (LW) from 80 to 500 kg and treatment averages for daily live weight gain (LWG) ranged from 1.00 to 1.40 kg. Concentrates were fed ad lib. in all experiments, except in (B) and (E) where feed intake was restricted for half or for all of the animals, respectively. In concentrates, based on oats and barley, soyabean meal (A, B), peas, rapeseed meal or soyabean meal (C), soyabean meal and fish meal (D) or coconut cake, fish meal and urea (E) were used to alter the protein content.

The effects of protein supply were evaluated in terms of the Nordic AAT-PBV system. In the data compiled for all experiments the calculated amount of amino acid crude protein absorbed in the small intestine (AAT) per MJ ME intake varied between 6.7 to 7.7 g in the LW range 100 to 200 kg. The efficiency of ME utilization was improved in all experiments when the AAT content per MJ ME increased. A diminishing return in efficiency of ME utilization was observed in (A) at the highest AAT content per MJ ME (7.5 g). This was interpreted as an effect of a simultaneously high value for the protein balance in the rumen (PBV) (3.1 g per MJ ME) rather than of the AAT supply per se. Also low PBV values (less than -2 g per MJ ME) seemed to reduce efficiency of ME utilization. For LW above 200 kg, efficiency of ME utilization was not affected when the AAT content per MJ ME increased from 6.7 to 7.4 g. For rations with PBV values less than -2 g and higher than 2 g per MJ ME the AAT and PBV contents together provide a better explanation of the differences in performance than the digestible crude protein content of the ration.

Replacing soyabean meal (9 % of the concentrate) with conventional high glucosinolate rapeseed meal (12 %) did not affect LWG or efficiency of feed utilization, but a 50 % increase in the weight of the thyroid glands was observed. When soyabean meal was replaced by peas (25 % of the concentrate) an increased thyroid weight was also found, although the enlargement was less (25 %).

Except for a high fat deposition at slaughter when large amounts of peas were included in the concentrate, no effects of protein supply on fat deposition or carcass composition were found.

CONTENTS Page

LIST OF PUBLICATIONS INCLUDED IN THE THESIS

The present thesis is based on the five publications listed below.

(A) Olsson, I. 1987. Performance of bulls fed concentrates with different crude protein content and calculated amino acid absorption in the intestine. 1. Effect on bull calves of supplementing oats and barley with different amounts of soyabean meal. To be published.

(B) Olsson, I. 1987. Performance of bulls fed concentrates with different crude protein content and calculated amino acid absorption in the intestine. 2. Effect of supplementing oats and barley with soyabean meal in concentrates fed ad lib. or in restricted amounts. To be published.

(C) Olsson, I. 1987. Performance of bulls fed concentrates with different crude protein content and calculated amino acid absorption in the intestine. 3. Effect of supplementing oats and barley with soyabean meal, rapeseed meal or peas. To be published.

(D) Olsson, I. & Lindberg, J.E. 1987. Performance of bulls fed concentrates with different crude protein content and calculated amino acid absorption in the intestine. 4. Effect of supplementing oats and barley with soyabean meal or fish meal. To be published.

(E) Olsson, I. & Lindberg, J.E. 1985. Performance of bull calves fed rations with different calculated amino acid flow to the duodenum. Acta Agric. Scand. Suppl. 25, 184-193.

Each paper is provided with an abstract where the conditions and results of each experiment are summarized. References to these papers is made with the capital letters (A) to (E) used above.

INTRODUCTION

Generally a major part of the protein fed to the ruminant is degraded to peptides, amino acids and ammonia in the rumen while the undegraded portion of the feed proteins becomes directly available to the animal in the small intestine. The degraded nitrogenous compounds are utilized for synthesis of protein by the rumen microbes which, when leaving the reticulo-rumen, will became available to the host. The rate of microbial synthesis is determined not only by the nitrogen available, but also by the amount of energy available to the microbes. In growing cattle microbial protein usually constitutes the major part of the amino acid flow to the duodenum.

It has long been recognized that crude protein (CP) and apparently digestible crude protein (DCP) poorly describes the dynamics of the protein metabolism in ruminants (e.g. Klooster et al. 1977; Poppe & Gabel, 1977). Measuring the difference between CP intake and CP found in feces does not take into account the extensive degradation of nitrogenous compounds in the rumen and the simultaneous incorporation of degraded protein and NPN into microbial protein. The difficulties to establish requirements for different classes of growing cattle in terms of digestible crude protein are also reflected in the large variations between countries in the recommended allowances (Geay, 1980).

Based on the rapidly increasing knowledge of nitrogen metabolism in ruminants, several new systems for protein evaluation have been proposed which estimate the amounts of amino acid nitrogen available to the animal in the small intestine and take into account the nitrogen requirements of rumen microbes (e.g. Burroughs et al., 1974; Chalupa, 1975; INRA, 1978; ARC, 1980 and 1984). Of these systems the INRA and ARC approaches seem most complete. They not only provide methods to calculate the amino acid nitrogen supply to the small intestine, but also include estimates of animal requirements in terms of the respective systems for a wide range of production conditions applicable to breeds and production systems used in Sweden. Later, a proposal for a new system, called the Nordic AAT-PBV system, was elaborated by a joint Nordic committee (Madsen, 1985; NKJ, 1985).

The main advantages of the new systems would be a possibility to utilize the protein in different feedstuffs more efficiently, since the needs of nitrogen for rumen microbes and the supply of amino acids to the animal is taken into account contemporarily. The systems thus predict whether a deficit in the protein supply should be covered by increased amounts of undegradable feed protein (amino acids) or by supplying readily degradable protein or simply a nitrogen source (e.g. urea). Waldo & Glenn (1984), Chalupa (1984) and Sniffen (1986) have discussed differences and similarities of some of the new protein evaluation systems. Although the basic assumptions of the INRA, the ARC and the Nordic AAT-PBV systems are essentially the same, considerable differences exist between the coefficients adopted to calculate the amounts of amino acids absorbed in the small intestine (Madsen, 1985). Due to the different assumptions made when predicting the amino acid supply to the small intestine and the amino acid requirements of the animals for maintenance and growth, however, it has been shown that quite different needs for protein supplementation of the rations are predicted by the ARC and INRA systems for the same breed, sex, growth rate and size of animals (Rohr et al., 1983).

The protein requirements of growing cattle in Sweden are still expressed in terms of DCP (Norrman, 1977), later summarized in English (Olsson, 1980). There is, however, great interest among advisors and farmers to make use of the recent knowledge of protein metabolism in ruminants and to include that knowledge in the protein evaluation of feeds for ruminants.

As stated by the NKJ committee (NKJ, 1985) when proposing the AAT-PBV system, the requirements of the animals in terms of the new system have to be established in production experiments before the system can be brought into practice. In the present thesis, data from Swedish feeding trials with rapidly growing bulls fed concentrates with different protein content and different protein sources are presented. The data were brought together with the main purpose of creating a basis for the evaluation of the needs for amino acid crude protein absorbed in the small intestine (AAT) and the effects of different values for the protein balance in the rumen (PBV) at different live weights for this category of cattle within the framework of the AAT-PBV system.

GENERAL CONDITIONS FOR THE EXPERIMENTS

The experiments presented in papers (A) to (E) all concerned growing bulls within the live weight (LW) range 80 to 600 kg. In the first two experiments presented, (A) and (B), the effects on the performance of growing bulls fed concentrates with different levels of soyabean meal were studied. In subsequent papers, soyabean meal was compared with other protein supplements, rapeseed meal and peas (C) or fish meal (D). The experiments presented in papers (A) to (C) were initially planned and conducted to study the effect of DCP supply on performance. These experiments took place in 1973 to 1976 in light of the rapidly increasing prices of imported protein supplements in relation to costs of grain in the early 70's. They were performed in order to investigate the possibilities to limit the use of imported protein supplements, like soyabean meal, by a reduction of the allowances for DCP in the rations for growing cattle, or by an increased use of protein feeds, rapeseed meal and peas, that could be produced in Sweden. In contrast, experiments (D) and (E), conducted in 1980 and 1983, were planned to study the effects on performance when rumen degradability of protein in the ration and the nitrogen supply to rumen microbes (E) was altered, although the framework of the AAT-PBV system was not yet established.

In order to obtain comparable information on performance and levels of protein supply, large efforts were made to standardize the prerequisite conditions when analysing the data from the experiments presented in the five publications. The absorption of amino acid CP in the small intestine (AAT) and the protein balance in the rumen (PBV) were calculated according to the Nordic AAT-PBV protein evaluation system (Madsen, 1985). For calculations of AAT and PBV supply, either tabulated values (A) for effective protein degradability (EPD) according to Lindberg (1986) or EPD estimated from in sacco degradability of concentrate components (B) to (E) as outlined by Lindberg (1985) were used. When calculating EPD, a rumen outflow rate of 0.05 per hour, as proposed by NKJ (1985), was used in all investigations except in (E) where the outflow rate was determined in the experiment. The EPD values determined on concentrate components were generally comparable to those presented by Lindberg (1986). The content of digestible carbohydrates (DCH) used in the calculations of AAT in publications (A) to (D), was estimated as the sum of digestible nitrogen free extracts and digestible crude fibre using tabulated values for the digestibilities (Eriksson et al., 1972; Eriksson et al., 1976). In paper (E) DCH was calculated as the difference between digestible organic matter (DOM) and the sum of DCP and digestible ether extracts.

In papers (A) to (D) metabolizable energy (ME) intakes were calculated according to Axelsson (1941) from the nutrient content and tabulated digestibilities of the concentrate components and hay. In publication (E), however, ME intake was calculated from the DOM intake determined in the experiment. These ME estimates were slightly lower than ME intakes calculated according to Axelsson (1941). In order to make the data of paper (E) fully comparable to those of publications (A) to (D), ME intakes and efficiencies of ME utilization calculated according to Axelsson (1941) are provided in Table 1 together with daily dry matter (DM) intake and efficiency of DM utilization. These ME values have been used in all comparisons between experiments. Due to the high rates of protein deposition in young cattle (Robelin & Daenicke, 1980) in relation to the supply of microbial protein (Ørskov, 1982), the most pronounced effects of an altered protein supply should be expected at low LW. The experimental period in all experiments was therefore subdivided into shorter periods comprising similar LW intervals in the different experiments.

Table 1. Daily intake of dry matter (DM) and calculated metabolizable energy ($ME_{calc.}$ according to Axelsson, 1941) intake, and live weight gain (LWG) per kg DM and MJ $ME_{calc.}$ in experiment (E). Treatment and period notations according to (E). Least squares means (LSM) and standard error (SE)

	HPU		LPU		LP	
	LSM	SE	LSM	SE	LSM	SE
DM, kg/d:						
Period 1	3.36	0.05	3.30	0.05	3.40	0.05
Period 2	4.74	0.03	4.73	0.03	4.63	0.03
$ME_{calc.}$, MJ/d:						
Period 1	41.8	0.7	40.5	0.6	41.9	0.6
Period 2	59.2	0.4	58.4	0.3	57.1	0.3
LWG, g/kg DM intake:						
Period 1	362	7	328	6	319	6
Period 2	278	7	273	7	259	6
LWG, g/MJ $ME_{calc.}$ intake:						
Period 1	29.1	0.6	26.7	0.5	25.9	0.5
Period 2	22.3	0.6	22.1	0.5	21.0	0.5

GENERAL DISCUSSION

Protein requirements for growth

Protein, or more specifically amino acid, requirements of growing cattle are conventionally divided into requirements for maintenance and growth. The maintenance requirements are derived from the inevitable losses of nitrogen as endogenous urinary nitrogen, fecal endogenous nitrogen, hair and scurf. The net requirements of amino acids for growth derive from the amino acids deposited in the new tissues. The requirements of absorbable amino acids for tissue formation depend on the efficiency by which the absorbed amino acids are utilized. The amount of protein deposited per kg live weight gain (LWG) depends on the breed, sex, weight (or age) and growth rate of the animal. For the same breed and sex, protein deposition in growing cattle is mainly determined by LW and LWG, as summarized from available slaughter data by Robelin & Daenicke (1980). At the same LW daily protein deposition increases with increasing daily LWG, although the proportion of protein deposition in LWG decreases. At the same LWG, daily protein deposition and the proportion of protein in LWG decreases with increasing LW. Since also body fat deposition is inversely related to protein deposition, the highest AAT requirements in relation to ME intake would be expected at lower LW.

Effect of protein supply on body fat deposition

In addition to the commercial carcass grading, further measurements of fat deposition was made at slaughter in all experiments. In experiments (B), (D) and (E) also one side of the carcass was dissected into lean meat, fatty tissue, bones and tendons. As the data from these dissections only concern the carcass at the end of the experiment they are of limited value for estimates of body protein deposition in different LW intervals.

The bulls in experiments (B) and (C) were slaughtered at the same degree of fat deposition, as judged from palpation over the ribs, at the head of the tail and at the base of the groin, and any differences in the rate of fat deposition should thus be reflected in LW at slaughter and rearing time. Although attempts were made to slaughter all bulls at the same degree of fatness, a higher deposition of subcutaneous fat (p=0.06) and fat in abdominal cavities ($p<0.001$) was obtained in bulls fed large amounts of peas (C) despite a shorter rearing period. An increased deposition of fat at a given LW is generally expected when the feeding intensity increases (Robelin & Daenicke, 1980; Andersen et al., 1983). At least part of the higher fat deposition at slaughter in the bulls fed peas could thus be attributed to the higher voluntary daily ME intake and LWG.

Apart from the significantly lower dressing-out percentage in the LP and PEA treatments in comparison with the SBM and RSM treatments of (C), for which no clear explanation was found, no further effects on the carcass grading, carcass composition or fat deposition of slaughter could be attributed to the protein content of the diet or the kinds of protein supplements used in the present experiments.

Specific effects of peas and rapeseed meal

The high feed intake achieved when concentrates were supplemented with 25 % peas in comparison with 9 % soyabean meal or 12 % rapeseed meal (C) suggests a high palatability of the peas. Comparative data for growing cattle have not been published, but peas usually seem to have been readily consumed when fed to dairy cows (Pelletier & Bouchard, 1978; Öster & Thomke, 1978; Syrjäla-Qvist et al., 1981).

The similar daily intakes when concentrates were supplemented with either high glucosinolate rapeseed meal or soyabean meal or were unsupplemented (C), indicate that the voluntary feed intake was not depressed by the rapeseed meal used in this experiment. Similar results for animals weighing more than 150 kg were obtained for heifers by Ingalls & Seale (1971) and for bulls by Iwarsson et al. (1973), but negative effects of rapeseed meal on feed intake and LWG of older bulls have also been reported (Geay & Beranger, 1975). When concentrates supplemented with conventional high glucosinolate rapeseed meal have been fed to calves with LW below 100 kg, feed intakes and LWG have frequently been reduced (Stake et al., 1973; Schingoethe et al., 1974; Olsson, 1978; Papas et al., 1979; Fiems et al., 1985), while up to 20 % of rapeseed meal has been included in the concentrate without deleterious effects in Canadian experiments (Sharma & Ingalls, 1973; Stone & Wood, 1973). When rapeseed meal from newer varieties of low glucosinolate rapeseed has been used, feed intakes and LWG have usually been comparable to soyabean meal, also for young calves (Papas et al., 1979; Wheeler et al., 1980; Andersen & Sørensen, 1985; Fiems et al., 1985).

The weight of the thyroid glands was significantly increased when both rapeseed meal and peas were fed (C). In comparison with the thyroid weights of bulls fed an unsupplemented concentrate or a concentrate including 9 % soyabean meal, the inclusion of 12 % high glucosinolate rapeseed meal increased thyroid weights by about 50 % while the increase when 25 % peas were included was about 25 %. An increased thyroid weight when feeding conventional high glucosinolate rapeseed meal to growing bulls, fed similar diets as in (C), was observed by Iwarsson et al. (1973), Iwarsson & Ekman (1974) and Geay & Beranger (1975). Iwarsson et al. (1973) and Iwarsson & Ekman (1974) interpreted the increased thyroid weight in their studies as a compensatory growth in response to glucosinolates or glucosinolate split products of the rapeseed meal. The antinutritional component or components of the peas responsible for the increased thyroid weight in (C) was not recognized in the present data. The possibility of more pronounced effects of a prolonged feeding period, an increased daily intake or the use of rapeseed meal or peas in rations for younger calves must not be disregarded. Concerning rapeseed meal, however, the use of low-glucosinolate varieties seems to overcome most of these problems (Andersen & Sørensen, 1985).

Performance in response to AAT and PBV supply

Compilation of present experiments

The older data adapted for this evaluation of the AAT-PBV system would naturally not provide the ideal data sets for such evaluations, mainly because the experimental designs do not consider the possible effects of AAT and PBV separately. Another major difficulty for the interpretation of feeding trials where animals have been fed ad lib., is to separate the direct effects of protein supply on growth rate and efficiency of feed utilization from the indirect effects arising from differences in voluntary feed intake. This could be overcome by restricting the feed intake as in (B) and (D), but for application in practice also information on the effects on voluntary feed intake is of interest. Efficiency of feed utilization would be less at an imbalanced nutrient supply. LWG in relation to feed intake (efficiency of feed utilization) rather than daily LWG might thus be useful for comparing treatment effects when minor differences in voluntary feed intake occur. When compiling the performance data of the present experiments, main attention was thus paid to the efficiency of feed (ME) utilization.

In papers (A) to (D), concentrations of DCP, AAT and PBV in the total ration were primarily related to DM instead of ME intake. This was done firstly because the DM intake was determined in the experiments while ME intake was calculated and secondly because digestible carbohydrates comprise a major component in the estimates of both ME and AAT. All rations were based on oats and barley and although the replacement of grain by soyabean meal or peas involved a slight increase in the calculated energy density, the differences in the calculated ME contents per kg DM between the rations were small and would not be expected to account for any large differences in efficiency of ME utilization (ARC, 1980). For practical applications, and for comparison with rations including higher proportions of roughage, however, it is also useful to relate intake of AAT and PBV and the efficiency of feed utilization to ME intake.

The effects of AAT and PBV content per MJ ME on the efficiency of ME utilization in the LW ranges 100 to 200 kg (papers A, B, C and E) and 200 to 300 kg (papers B, C, D and E) are summarized for all experiments in Figs. 1 and 2. Due to the different conditions of the individual experiments, however, the desired LW limits could not always be strictly maintained as indicated in the figure text. The figures correspond to those given for daily LWG and efficiency of DM utilization in relation to AAT and PBV content per kg DM intake in the individual publications.

A generally positive relationship between the efficiency of ME utilization and the AAT content per MJ ME was noted in all experiments (A, B, C and E) for the LW range 100 to 200 kg as shown in Fig. 1a. However, a diminishing return in efficiency of ME utilization was apparent after the AAT content per MJ ME had passed an optimum level in the experiments presented in paper (A). The diminishing return may be interpreted as an effect of the interrelationships between protein and energy supply (Balch, 1967). However, the results provided in (E) and by Andersen et al. (1986) suggest that calves in this LW range may respond to a further increase in AAT per MJ ME at a lower PBV value. One obvious difficulty in the interpretation of the data, especially (A) and (B), thus arises from the simultaneous change in AAT and

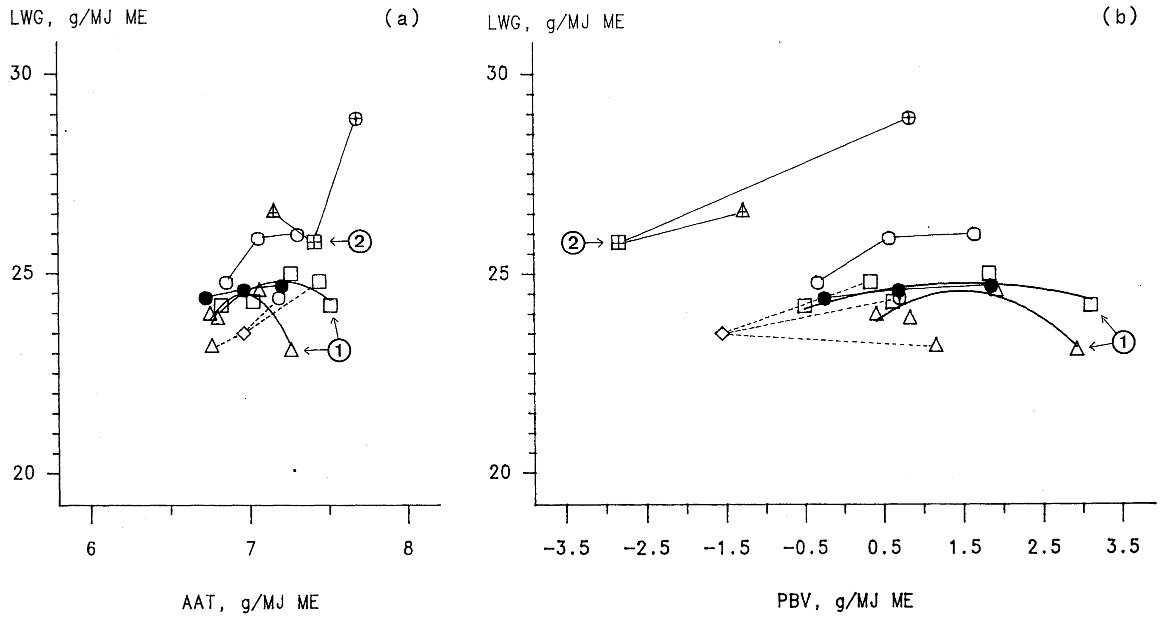

Fig. 1. Relationships between LWG per MJ ME and AAT (a) or PBV (b) content per MJ ME intake in the LW range 100 to 200 kg. Compiled from publications:

(A) Exp. 1: □ ; exp. 2: △ . Graphs (according to model 3 in the publication) shown for LW at start (LWST) = 82 kg. (80-180 kg LW).

(B) HI (ad lib. feeding): ●——● (100-260 kg LW);
LI (restricted feed intake): ○——○ (100-230 kg LW).

(C) LP, SBM, RSM and PEA respectively: ◇---□---○---△ (130-200 kg LW).

(E) HPU, LPU and LP respectively: ⊕——▲——⊞ (90-180 kg LW).

PBV with the increasing level of protein supplementation. Certain deviations from the general patterns may provide some clues to distinguish between the effects of AAT and PBV contents in the ration. For the two experiments presented in paper (A), significant curvilinear regressions of the efficiency of DM utilization on the AAT and PBV contents per kg DM intake were found, and the corresponding regressions of LWG per MJ ME intake on the AAT and PBV content per MJ ME are shown in Fig. 1. The maximum efficiency of ME utilization was obtained at slightly different AAT contents in the two experiments. However, with respect to the PBV content the decrease in efficiency of ME utilization seemed to coincide in the two experiments and occurred when PBV exceeded 2 g per MJ ME intake (① in Figs. 1 a and b). In contrast, the slightly lower efficiency obtained on the low protein (LP) concentrate (② in Figs. 1 a and b) in comparison with

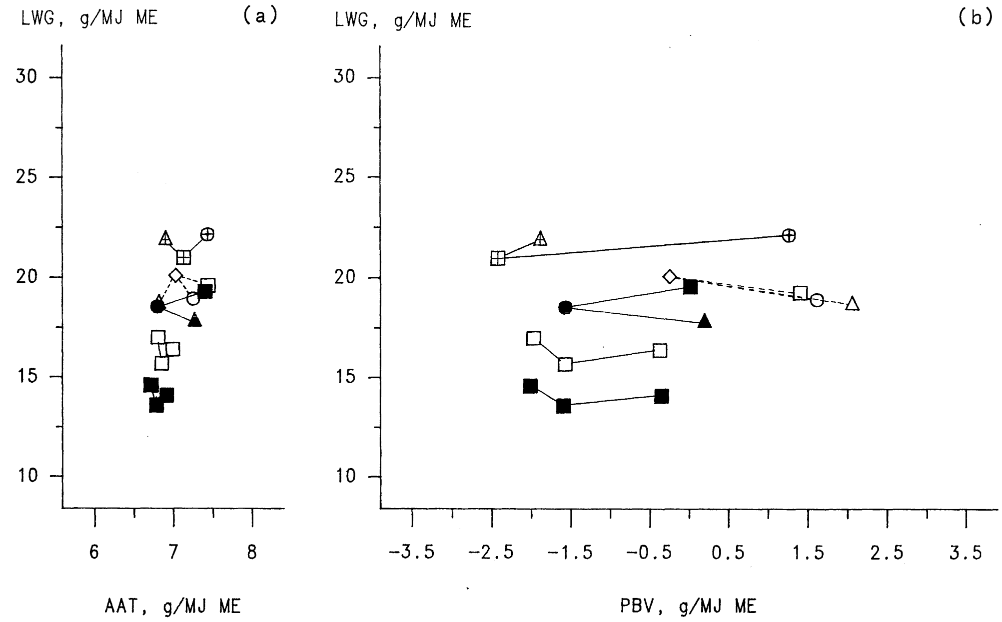

Fig. 2. Relationships between LWG per MJ ME and AAT (a) or PBV (b) content per MJ ME intake in the LW range 200 to 300 kg. Compiled from publications:

(B) HI (ad lib. feeding): ■——■ (260-450 kg LW);
LI (restricted feed intake): □——□ (230-400 kg LW).
(C) LP, SBM, RSM and PEA respectively: ◇---□---○---△ (200-280 kg LW).
(D) FS, HS and LS respectively: ■——▲——● (180-290 kg LW).
(E) HPU, LPU and LP respectively: ⊕——Δ——⊞ (180-290 kg LW).

the urea-supplemented (LPU) concentrate in (E), despite a slightly higher AAT content per MJ ME, could be interpreted as an effect of the low PBV content of that ration. If not covered by a sufficient recirculation of nitrogen to the rumen, a deficit in rumen degradable protein may reduce microbial protein synthesis (Harrison & McAllan, 1980) and less AAT than anticipated would be available to the ruminant. For all rations with PBV content per MJ ME intake between -2 to 2 g, efficiency of ME utilization within the present experiments was positively related to the AAT content per MJ ME intake. This was further illustrated in (C) by the apparently linear relationship between efficiency of ME utilization and AAT content, despite the considerable differences in PBV between the treatments fed the low protein (LP) (-1.6 g per MJ ME) and the soyabean meal (SBM) (0.3 g), rapeseed meal (RSM) (0.7 g) or pea (PEA) (1.2 g) supplemented concentrates. Especially the similar performance at a similar AAT supply in the LP and PEA treatments, despite the marked difference in PBV, is worth mentioning.

For LW exceeding about 200 kg no consistent response in efficiency of ME utilization to alterations in AAT content was found in investigations (B), (C), (D) and (E) as shown in Fig. 2a. The small effect of the AAT supply on the performance of bulls of this size could be explained by the reduced amino acid need for protein deposition with increasing LW in relation to the microbial amino acid supply to the small intestine (Ørskov, 1982). When half of the CP from soyabean meal was replaced by fish meal in the LW range 180 to 290 kg (D), however, a marked ($p=0.07$) increase in efficiency of ME utilization was found despite the AAT contents per MJ ME were only slightly different. One possible explanation for this difference would be an improved amino acid composition of AAT due to a higher content of, e.g., methionine in the less degradable fish meal, as further discussed in (D). Since the differences in DCP content of the concentrates during this part of experiment (B) were obtained mainly by the use of low and high protein batches of oats and barley, the calculated differences in AAT content between the rations in (B) were small and thus unlikely to be responsible for large differences in performance. The comparatively low efficiency of ME utilization in (B) was due to the higher average LW in the relevant part of this experiment in comparison with the other experiments.

As discussed for the AAT content per MJ ME intake, the effects of PBV content per MJ ME intake were less pronounced in the LW range 200 to 300 kg (Fig. 2 b). However, also the range in PBV values per MJ ME intake were less and mainly within the limits of -2 to 2 g PBV per MJ ME intake. The increased CP content of the grain used in the relevant period (9-16 weeks) of experiment (C) and the subsequently increased PBV values in all treatments might have contributed to the reduced efficiency of ME utilization observed in the supplemented rations (SBM, RSM and PEA) in relation to the unsupplemented (LP) and in comparison with the previous (start-8 w) and subsequent periods of (C). In the PEA treatment, in which the highest PBV value of ME intake was noted, the high concentrate intake recorded both before and after this period was reduced to a level similar to that in the other treatments.

If the lower passage rate, 0.035 per hour, found in (E) for bulls of this size, is applied also in (B), (C) and (D), instead of the 0.05 else used, the EPD of these rations would increase. A slightly lower AAT supply and a higher PBV value than presented would then be obtained. However, the slightly restricted feed intake in (E) may have reduced the outflow rate (Evans, 1981; Owens & Goetsch, 1986).

Effects of low PBV values - nitrogen recycling

Since the efficiency of feed utilization seems to be fairly well related to the AAT content per MJ ME for PBV values between - 2.0 to 2 g per MJ ME in the LW range 100 to 200 kg, it may be of interest to further discuss the possible reasons for the deviating results at lower or higher PBV. The reduced efficiency of ME utilization indicated when the PBV content per MJ ME was less than -2.0 g may reflect an impaired microbial protein synthesis. A deficit in nitrogen supply would cause a reduction in microbial protein synthesis if the supply of rumen degradable protein and the contribution from urea nitrogen recycled to the rumen becomes insufficient (Satter & Slyter, 1974; Pisulewski et al; 1981; Harrison & McAllan, 1980). The amount of plasma urea recycled to the rumen via saliva and rumen wall is dependent on, e.g., type and protein content of the ration and concentration of rumen ammonia (Leng & Nolan, 1984; Oldham, 1984; Kennedy & Milligan, 1980). Recycling of urea is increased at low nitrogen intakes and when the supply of fermentable carbohydrates to the rumen is increased. Quantitative estimates of the amounts of urea nitrogen recycled to the rumen in cattle are, however, scarcely mentioned in the literature. On a hay-based diet, 11 g urea nitrogen per day were recycled in steers (Kennedy, 1980; Kennedy & Milligan, 1980). This amount was increased to 22 g per day when diet was supplemented with sucrose. Based on the work by Kennedy & Milligan (1978), Sniffen (1986) suggested an equation for prediction of the amount of urea recycled to the rumen from the protein content of the diet. The 17 g urea nitrogen per day thus predicted from this equation for the LP treatment of (E) in the LW range 100 to 200 kg is comparable to the daily deficit of PBV (-120 g) in that treatment. In spite of the high degree of uncertainty of these estimates they may support the conclusion also drawn from the experimental results of (E), that a lower PBV value than -2 g per MJ ME intake could interfere with performance, possibly by a reduced microbial protein production. However, also other endogenous nitrogen sources than urea like sloughed mucosal cells and salivary proteins, would contribute considerably to the nitrogen recycled to the rumen (Leng & Nolan, 1984).

In the PDI system (INRA, 1978) a maximum deficit of 12 g PDI per FU (corresponding to about -1.0 g PBV per MJ ME) is accepted in rations for intensively reared bulls to allow for recycling of endogenous urea. According to Danish experiences, -15 to -20 g PBV per FU (corresponding to about -1.5 g PBV per MJ ME) could be accepted (H.R. Andersen & J. Foldager; personal communication). Until more experience has been obtained, lower PBV contents per MJ ME than -1 to -2 g in rations for growing cattle should be avoided.

Effects of high PBV values

A positive PBV value indicates a higher calculated intake of degradable CP in the feed than required for microbial protein synthesis in the rumen in relation to the available amount of digestible carbohydrates. The CP degraded to ammonia but not utilized for protein synthesis by rumen microbes could not be utilized by the host but must be eliminated from the body. A large part of the surplus nitrogen would be excreted as urea in the urine. Energy balance studies on sheep (Martin & Blaxter, 1965) showed a net energy cost for urea synthesis and excretion of 21.8 kJ per g urea nitrogen. The ME expenditures for excretion of 2 g surplus PBV per MJ ME by the calves in (A) correspond to about 1.5 % of the ME required for growth above maintenance as calculated from Swedish feeding standards (Norrman, 1977). Thus, at least part of the reduced rate of gain and efficiency of ME utilization observed at the high PBV values in (A) could be directly accounted for by the additional ME expenditures for urinary urea excretion.

AAT and PBV allowances in comparison with other estimates

For rations fairly balanced with respect to PBV it is thus concluded that no clear indications of a diminishing return in efficiency of ME utilization in the LW range 100 to 200 kg within a range in AAT content from 6.7 to 7.7 g per MJ ME was found. It therefore seems likely that at least 7.7 g AAT per MJ ME was required for maximum efficiency of ME utilization at daily LWG between 1.00 and 1.35. Since the efficiency of ME utilization was unaffected by AAT contents per MJ ME between 6.7 and 7.4 g at LW beyond 200 kg the lower supply would be sufficient for this size of animal and at growth rates between 1.00 and 1.40 kg per day.

If applying the 7.7 and 6.7 g AAT per MJ ME intake in the 100 to 200 and 200 to 300 kg LW intervals respectively to the daily ME intakes achieved in the present experiments, a reasonably good agreement with the daily requirements of absorbed amino acids given by ARC (1980 and 1984) for bulls of "large breeds" (Friesian cattle) was found. The requirements for absorbed amino acids predicted by INRA (1978) for "bulls of dairy breeds" were considerably higher (30 %) than those experienced in the present investigations or predicted by ARC (1984). However, tabulated values for the PDI (PDIE) content of barley and oats (INRA, 1978) are about 30 % higher than the corresponding AAT estimates, and the relative PDI contents of protein supplements, e.g, soyabean meal and rapeseed meal are even higher. The higher requirements predicted by INRA (1978) would thus be accompanied by a higher predicted supply of absorbable amino acids to the small intestine. It must be emphasized, however, that the comparisons made with the ARC and INRA recommendations only concern the needs predicted at the LW and LWG achieved in the present experiments. The limited range in daily LWG in the present experiments and the lack of response in performance to an increased AAT supply above the lowest level provided for LW beyond 200 kg, render it difficult to scrutinize the development of the needs for absorbed amino acid as dependent on LW and LWG in relation to the recommendations.

So far very little data on the performance of growing cattle have been published in which the protein supply is expressed in terms of the AAT-PBV system. However, Danish Black Pied Milk Breed (SDM) bulls fed rations where 50 % of the daily intake of feed units (FU) was supplied as whole crop barley silage (Andersen et al., 1986), also showed a positive response in efficiency of feed utilization to an increase in the AAT content of the ration. Concentrates were based on barley and supplemented with either urea, soyabean meal or fish meal. Daily LWG was 1.2-1.3 kg. In the LW range 125 to 250 kg, efficiency of feed (ME) utilization increased when the AAT content per MJ ME intake increased from about 7.5 g to 8.8 g at PBV values per MJ ME intake between -1.4 to 1.5 g (assuming about 12.0 MJ ME per FU in the total ration). When the AAT content per MJ ME increased to more than 10 g by further addition of fish meal, a slight decrease in efficiency of feed utilization was obtained. Although feed intake was slightly reduced, efficiency of feed utilization in relation to treatments with similar AAT supply was not markedly affected by the high PBV value per MJ ME intake achieved in one of the rations (7 g) given high urea supplementation. No effects on daily LWG or efficiency of feed utilization were found for LW beyond 250 kg.

Comparison between DCP and the AAT-PBV system

When protein levels were altered by an increased inclusion of soyabean meal (A) and (B), the response in performance was equally well described by the

DCP as by the AAT contents of the ration, although the relative differences in protein supply between treatments were much higher when expressed as DCP than as AAT. When increasing amounts of soya bean meal were substituted for grain in, e.g. (A), the DCP content of the ration was increased by 55 % while the corresponding increase in AAT was only 12 %. As for AAT, a curvilinear response in daily LWG and efficiency of ME utilization to the DCP content per MJ ME was found in (A) and the optimum DCP content per MJ ME was 10 g. Quite similar results with respect to the performance in relation to the DCP content of the ration were obtained also in Danish experiments (Andersen et al., 1973). If, as previously discussed, the performance of the calves in (A) given the highest protein supply was limited by a high PBV, the optimum protein supply found for both DCP and AAT would underestimate the protein requirements of the calves. In contrast to DCP, the AAT-PBV system provides a possibility to predict and consider effects of a deficient or exessive supply of rumen degradable nitrogen. The shortcomings of DCP in predicting the performance were also illustrated in (C) where the AAT content of the rations differed depending on the kinds of protein supplements used although the DCP content of all supplemented concentrates was similar. The efficiency of ME utilization in the initial period (130 to 200 kg LW) was then related to the different AAT contents per MJ ME intake rather than the DCP contents.

Final comments

The AAT-PBV system provide a method to calculate the amount of amino acids absorbed in the small intestine and the supply of degradable nitrogen to rumen microbes. The animal requirements for absorbed amino acids in terms of the new system, has to be established from production experiments. From the present data it was concluded that at least 7.7 g AAT per MJ ME, corresponding to the highest AAT supply achieved in these experiments, was required for maximum efficiency of feed utilization for this type of ration in the LW range 100 to 200 kg. For animals above 200 kg, 6.7 g AAT per MJ ME, corresponding to an unsupplemented concentrate ration based on oats and barley with normal protein content, was sufficient. It was also suggested that PBV values lower than -2 and higher than 2 g per MJ ME limited the performance. The lack of a diminishing return in efficiency of feed utilization to an increased AAT supply if PBV values higher than 2 g per MJ ME were disregarded suggests, however, that an even higher content of AAT per MJ ME is required for maximum efficiency of feed utilization in the LW range 100 to 200 kg. Further investigations in which high PBV values are avoided would be required to establish this relationship for calves below 200 kg LW. With respect to the increasing interest to utilize peas as a protein source for ruminants in Sweden, the low efficiency of ME utilization below 200 kg LW and the high fat deposition at slaughter experienced when large amounts of peas were included in the ration require further attention.

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