(b) for the rumen as a whole, and (c) for the host animal. The second is to devise cultural methods for isolating the many micro-organisms that can be seen in the rumen but have hitherto tantalizingly evaded the bacteriologist.

REFERENCES

Bailey, R. W. (1959). *Biochem. J.* **71**, 23.
Baker, F., Nasr, H., Morrice, F. & Bruce, J. (1950). *J. Path. Bact.* **62**, 617.
Bryant, M. P. & Small, N. (1956). *J. Bact.* **72**, 16.
Bryant, M. P., Small, N., Bouma, C. & Chu, H. (1958). *J. Bact.* **76**, 15.
Bryant, M. P., Small, N., Bouma, C. & Robinson, I. M. (1958). *J. Bact.* **76**, 529.
Burroughs, W., Frank, N. A., Gerlaugh, P. & Bethke, R. M. (1950). *J. Nutr.* **40**, 9.
Carroll, E. J. & Hungate, R. E. (1955). *Arch. Biochem. Biophys.* **56**, 525.
Doetsch, R. N., Howard, B. H., Mann, S. O. & Oxford, A. E. (1957). *J. gen. Microbiol.* **16**, 156.
Doetsch, R. N. & Robinson, R. Q. (1953). *J. Dairy Sci.* **36**, 115.
Doetsch, R. N., Robinson, R. Q., Brown, R. E. & Shaw, J. C. (1953). *J. Dairy Sci.* **36**, 825.
Gray, F. V., Pilgrim, A. F., Rodda, H. J. & Weller, R. A. (1952). *J. exp. Biol.* **29**, 57.
Gray, F. V. & Weller, R. A. (1958). *Aust. J. agric. Res.* **9**, 797.
Halliwell, G. (1957). *J. gen. Microbiol.* **17**, 166.
Heald, P. J. (1951). *Brit. J. Nutr.* **5**, 84.
Hobson, P. N. & MacPherson, M. (1952). *Biochem. J.* **52**, 671.
Hobson, P. N. & MacPherson, M. J. (1954). *Biochem. J.* **57**, 145.
Hobson, P. N. & Mann, S. O. (1957). *J. gen. Microbiol.* **16**, 463.
Hueter, F. G., Gibbons, R. J., Shaw, J. C. & Doetsch, R. N. (1958). *J. Dairy Sci.* **41**, 651.
Hueter, F. G., Shaw, J. C. & Doetsch, R. N. (1956). *J. Dairy Sci.* **39**, 1430.
Hungate, R. E. (1950). *Bact. Rev.* **14**, 1.
Hungate, R. E. (1957). *Canad. J. Microbiol.* **3**, 289.
Johns, A. T. (1951). *J. gen. Microbiol.* **5**, 326.
Ladd, J. N. (1959). *Biochem. J.* **71**, 16.
MacPherson, M. (1953). *J. Path. Bact.* **66**, 95.
Marston, H. R. (1948). *Biochem. J.* **42**, 564.
Moir, R. J. & Masson, M. J. (1952). *J. Path. Bact.* **64**, 343.
Oxford, A. E. (1958). *J. gen. Microbiol.* **19**, 617.
Pazur, J. H., Shuey, E. W. & Georgi, C. E. (1958). *Arch. Biochem. Biophys.* **77**, 387.
Sijpesteijn, A. K. & Elsden, S. R. (1952). *Biochem. J.* **52**, 41.
Warner, A. C. I. (1956). *J. gen. Microbiol.* **14**, 733.
Weller, R. A. & Gray, F. V. (1954). *J. exp. Biol.* **31**, 40.

Protein utilization by the dairy cow

By M. J. HEAD*, *National Institute for Research in Dairying, Shinfield, Reading*

The content of true protein, or the amino-acid composition of the protein, in a nitrogenous feed is less important to a dairy cow than to a single-stomached animal. Johnson, Hamilton, Mitchell & Robinson (1942) have, in fact, suggested that the biological value for ruminants of all nitrogenous feeds is about 60, but Williams & Moir (1951) have since found that this generalization is not correct. The suggestion was based on the knowledge that food protein is fermented by the rumen micro-organisms and that the bodies of these organisms provide the host with much of its protein for subsequent enzymic digestion, which microbial protein has a relatively high value and constant composition.

* Present address: Spillers Limited, Nutrition Research Laboratories, Middle Aston, Oxon.

The ammonia produced from the fermentation in the rumen of the nitrogenous feed is either absorbed through the rumen epithelium into the blood stream or used by other micro-organisms for growth, only a small fraction passing on to the abomasum and small intestine. That absorbed can be considered as wasted to the animal because the liver rapidly converts it into urea, which is excreted by the kidneys, although McDonald (1948) showed that there was a recycling of ammonia absorbed from the rumen through the urea of blood and saliva. Obviously the ease of attack by micro-organisms is influenced by the accessibility of the protein and its solubility in rumen liquor. The feed can be readily attacked if it has no extensive cellulosic envelopment and the protein is readily soluble; ammonia is then produced more rapidly than other organisms can utilize it and is consequently mainly absorbed through the rumen wall and wasted.

This factor of actual loss of nitrogen from the rumen and subsequently from the animal has not been sufficiently considered in the evaluation of protein feeds for ruminants and particularly for the dairy cow. The classical assessment of the biological value of nitrogen-containing feeds is complicated for the ruminant by the ruminal reaction superimposed on the utilization by the body of that nitrogen absorbed as amino acids resulting from the enzymic digestion of proteins in the abomasum and small intestine. In fact, the major influence on the biological value of a protein for a ruminant may be the degree to which it is attacked in the rumen, because the digestible nitrogen reaching the abomasum is often largely in the bodies of micro-organisms that have a relatively constant composition and biological value.

The proportion of various proteins that are converted into ammonia in the rumen is variable for many reasons. McDonald & Hall (1957) have shown that about 90% of the easily soluble protein, casein, is digested in the rumen in a relatively short time, so that a large part of a supplement of casein would be lost to the animal because of the absorption of ammonia through the rumen wall. The biological value of casein, though high for a single-stomached animal because of its high digestibility and favourable amino-acid composition, is thus low for a ruminant. Head (1953) compared the nitrogen retention by sheep receiving casein or fish meal as the protein source in a ration of hay and starch, and found that raising the nitrogen intake by raising the casein level of the ration increased the nitrogen balance only very little in comparison with the increase after a similar rise in the level of the fish-meal supplement. This casein effect was not due to a decrease in digestibility, but to increased excretion of nitrogen in the urine as a result of rapid and excessive deamination within the rumen. Similarly, it can be shown that large quantities of the soluble groundnut-cake protein in a cow's ration can result in low nitrogen retention compared with that from a lower intake of nitrogen from other sources. The study of this problem was taken a stage further by Chalmers & Synge (1954) when they showed that lambs grew better on fish meal than on casein, contrary to what would have been expected from the data available from experiments on single-stomached animals; they have related this finding to the different amounts of ammonia produced in the rumen on the two rations. Similarly, it has been shown that if casein is denatured with formaldehyde so that its solubility is reduced, its nutritive value for

the ruminant is increased as a result of the curtailment of ammonia production in the rumen (Chalmers, Cuthbertson & Synge, 1954).

However, in judging the significance of these results for application to agricultural practice, it must be realized that casein is a protein rarely if ever found in rations for dairy cattle, the species of ruminant consuming most of the protein concentrates available. Casein is also the most soluble of the commercially available proteins and fish meal the most expensive, and for these reasons they may be considered atypical proteins from a practical point of view. If the various oil-cake residues commonly used as protein supplements in dairy rations are compared on the basis of production of ammonia in the rumen (Table 1), it is found that, although there are differences between such proteins, they do not result on the whole in ammonia concentrations in the rumen as high as found on grass.

Table 1. *Ammonia concentration (mg N/100 ml) in the rumen liquor and urea concentration (mg N/100 ml) in the blood serum of a dairy cow receiving various protein foods included on an equal nitrogen basis in a standard dairy ration*

	Ammonia concentration		Urea
Protein food	Summation*	Peak†	concentration
Sunflower meal	105·0	26·3	20·1
White fish meal	103·2	31·6	18·9
Linseed cake	99·2	32·1	18·0
Dried skim milk	92·6	29·9	25·5‡
Dried groundnut cake	79·7	27·8	18·2
Dried cottonseed cake	68·1	23·9	13·0
Soya-bean meal	65·8	14·5	12·3
Coconut meal	64·4	21·8	10·4
Palm-kernel meal	47·7	11·7	10·2
Bean meal	39·2	21·6	10·1
Spring grass (grazing)	209·4	52·7	35·0

* Sum of the values obtained 2, 4, 6, 8 and 10 h after feeding.
† Highest of the values obtained.
‡ This value is high in comparison with values obtained with other protein foods, whereas the corresponding value for ammonia concentration in the rumen liquor is not. The ammonia peak therefore probably occurred before the first sampling at 2 h.

It has been suggested that as the ammonia absorbed from the rumen is quickly converted into urea, it should be possible to use the serum-urea concentration as an index of the value of the protein to the ruminant (Lewis, 1957). The results in Table 1 show that when proteins are compared so as to supply equal quantities of nitrogen in an otherwise similar ration, the concentration of urea in the serum varies with the concentration of ammonia in the rumen liquor. It is not so, however, when proteins are evaluated in different basic rations, and particularly in the comparison of winter rations and grass. The relative ammonia production in the rumen from the various proteins incorporated in a standard ration may be judged satisfactorily by the proportion of their total nitrogen soluble in a molar sodium-chloride solution under a standard set of conditions (Fontaine, Samuels & Irvine, 1944).

The biological value of a protein for a ruminant, as measured by classical methods, is much less dependent on the animal's requirement for nitrogen than it is for the single-stomached animal. A large proportion of the urinary nitrogen of a ruminant often originates from nitrogen absorbed from the rumen, which amount is independent of the animal's requirement. That is, if a dry cow and a milking cow are fed on similar rations, the rumen fermentations in each are similar and, in consequence, the loss of nitrogen as ammonia is similar. However, the milking cow will utilize the nitrogen digested in and absorbed from the abomasum and small intestine more efficiently than the dry cow because of the additional requirement of the lactating udder. Thus the classical variation in biological value due to body requirement is lessened or possibly overriden by the effect due to the solubility of the protein in the rumen.

The value of a protein to a dairy cow is dependent on the other foods given at the same time, rather because of the nature of the rumen fermentation than, for example, because of the protein-sparing action of carbohydrates shown in classical metabolism studies. As mentioned earlier, the ammonia produced in the rumen by the action of the proteolytic bacteria is either synthesized by micro-organisms into the proteins of their own structures, or absorbed through the epithelium into the blood stream. It can only be used for synthesis if the micro-organisms also have an energy source and, of course, all the minerals, vitamins, and other nutrients that the rumen liquor seldom lacks, but with a ration such as hay alone the amount of soluble available energy is small and little synthesis is likely to occur, so that most of the ammonia produced is absorbed into the blood stream and lost to the animal. The situation is seldom so bad in the normal feeding of dairy cows, because some starchy foods are usually given and, of course, influence the type of rumen fermentation. The influence of these starchy foods is on the level of ammonia that accumulates in the rumen (McDonald, 1952; Annison, Chalmers, Marshall & Synge, 1954; Head & Rook, 1957). It has been shown on several occasions that when starch is given as a supplement to a ration on which high values for rumen ammonia are found a depression in these values occurs, and the consequent depression in urinary nitrogen has also been shown (Head, unpublished). The possible influence on the nitrogen economy of the cow of the loss of ammonia from the rumen is thus indicated. It is important then to consider the other foods of the ration when the biological value of a protein is being considered, as well as the animal's particular metabolic requirements.

The other important factors in the consideration of protein utilization by the dairy cow are that (1) most of the protein digested by the enzymes of the host has a high true biological value and (2) the greater the ammonia loss from the food protein in the rumen, the greater the significance to be attached to the amino-acid composition of the digestible portion of the protein leaving the rumen unchanged. The biological value of the protein of the organisms leaving the rumen has been shown to be between 80 and 90 for the rat (McNaught, Smith, Henry & Kon, 1950) and there is no reason to believe the values to be any different for the cow. If, therefore, say 75% of the food nitrogen of a biological value of 50 is converted into 50% of the food nitrogen of a biological value of 75 and the remaining nitrogen is

lost from the rumen as ammonia, the nitrogen economy of the animal does not suffer from that ammonia loss. If, however, insufficient nitrogen of unsuitable biological value is available to the animal as a result of this process, the portion of the feed escaping digestion by the micro-organisms in the rumen assumes greater importance. This residual food nitrogen reaching the abomasum and intestines is not necessarily that most difficult to digest, because the amount of food eaten by a high-yielding cow may not allow the feed residues to remain in the rumen as long as they might otherwise do. The better the amino-acid composition of the residual feed passing from the rumen, the better the biological value of the total feed.

The most desirable type of feed protein for a ruminant is, therefore, one of reasonably low solubility in the rumen yet of high biological value for the single-stomached animal.

These arguments must be taken a stage further for application to agricultural practice because, although this thesis has been supported by experimental evidence, there are two further points which need consideration: (1) is the cow normally rationed sufficiently tightly for protein for any of these theoretical improvements to become evident, and (2) may it not be more economical to give a theoretically wasteful protein source if it still supplies cheaper units of biological value?

REFERENCES

Annison, E. F., Chalmers, M. I., Marshall, S. B. M. & Synge, R. L. M. (1954). *J. agric. Sci.* **44**, 270.
Chalmers, M. I. & Synge, R. L. M. (1954). *J. agric. Sci.* **44**, 263.
Chalmers, M. I., Cuthbertson, D. P. & Synge, R. L. M. (1954) *J. agric. Sci.* **44**, 254.
Fontaine, T. D., Samuels, C. & Irving, G. W. Jr. (1944). *Industr. Engng Chem.* (*Industr.*) **36**, 625.
Head, M. J. (1953). *J. agric. Sci.* **43**, 281.
Head, M. J. & Rook, J. A. F. (1957). *Proc. Nutr. Soc.* **16**, 25.
Johnson, B. C., Hamilton, T. S., Mitchell, H. H. & Robinson, W. B. (1942). *J. Anim. Sci.* **1**, 236.
Lewis, D. (1957). *J. agric. Sci.* **48**, 438.
McDonald, I. W. (1948). *Biochem. J.* **42**, 584.
McDonald, I. W. (1952). *Biochem. J.* **51**, 86.
McDonald, I. W. & Hall, R. J. (1957). *Biochem. J.* **67**, 400.
McNaught, M. L., Smith, J. A. B., Henry, K. M. & Kon, S. K. (1950). *Biochem. J.* **46**, 32.
Williams, V. J. & Moir, R. J. (1951). *Aust. J. sci. Res.* Ser. B, **4**, 377.

Lipids in relation to rumen function

By G. A. GARTON, *Rowett Research Institute, Bucksburn, Aberdeen*

The term lipids can be taken to include, *inter alia*, all fatty acids both in the free state and in their esterified forms. However, for the purpose of this Symposium, the formation of the water-soluble, steam-volatile fatty acids that result from the bacterial breakdown of carbohydrates and amino acids in the rumen will not be discussed. Nevertheless, it should be mentioned that the acetate absorbed from the rumen probably plays an important part in the synthesis of higher fatty acids which contribute to the formation of depot and milk glycerides. Further, the occurrence in ruminant body and milk lipids of small amounts of branched-chain, higher fatty acids and of n-fatty acids containing an odd number of carbon atoms is probably the