FEEDING STANDARDS AND FEEDING SYSTEMS FOR RUMINANTS

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SUMMARY

The development of feeding standards is outlined. The standards are bases for feeding systems which should allow effective and profitable nutritional management of animals appropriate to the prevailing nutritional, economic and sociological environment.. It is insufficient to equate a given animal production with a standard feed requirement; the converse, that nutrient intakes determine production, is implicit in feeding systems. Some aspects of and problems in defining animal responses to their feed supply are discussed, with reference- to practical nutritional management.

INTRODUCTION

> From Christmas to May
> Weak cattle decay
> Thomas Tusser (1573)
> *Five Hundred Pointes of Good Husbandrie'

Cattle and sheep in Tudor England, as elsewhere in those times, existed through the winter in a state of semi-starvation. They were seldom fattened; meat came primarily from broken-mouthed sheep, which were valued for' their wool, from cows past milk production, and from oxen too weak or old for use as draught animals. The opportunity for change was provided by, successively, the introduction of new crops such as turnips and clover, the development by Jethro Tull of the seed-drill and his "Horse-Hoeing Husbandry*, and vigorous adoption of these new techniques by 'Turnip' Townshend, Coke of Norfolk, and others. Crop and livestock production were superbly integrated in farming systems typified by the Norfolk four-course rotation, with the result that animals could improve in condition and even fatten during the winter, and not just survive. Moreover, with continuity of feed supplies reasonably assured there could now be the continuity in the selection and breeding of livestock necessary for their improvement. Though a variety of animal diseases was endemic, progress in the feeding of animals and in their breeding, notably by Bakewell and his followers, was reflected in the average weights of animals at Smithfield market (Ernle 1936). In 1710 these were 370 lb. for cattle, 28 lb. for sheep and 18 lb. for lambs; they had increased to respectively 800, 80 and 50 lb. in 1795, the year after Lavoisier's death in revolutionary France. Lavoisier and his contemporaries (e.g. Priestleg, Davy) and successors during the next 50 years (e.g. Liebig, Lawes, Gilbert) established basic principles in the nutrition of both crops and livestock.

With the rise of agricultural chemistry, the relative merits of feeds could be defined more objectively than as 'hay equivalents', which have been attributed to Thaer but not wholly correctly (Tyler 1975). From the results of the first real digestibility trials with animals made in the mid 19th century by Henneberg and Stohmann at Weende near Göttingen, Wolff at Hohenheim developed feeding standards in terms of

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digestible nutrients. By the early years of this century, Kellner and Armsby had established net energy values for the digestible nutrients. Protein feeding standards were established in terms of digestible true or crude protein, or the compromise 'protein equivalent', and in Denmark were linked to energy standards by Møllgaard, but mineral needs were related only in rather general terms to the amount and composition of the ash present in the animal's body and products.

CONCEPTS AND MISCONCEPTIONS

Subsequent gains in knowledge have increased the accuracy of feeding standards but have not changed their basic purpose, namely to promote the productivity of livestock by efficient use of feeds. Jackson (1981) states their purpose in more restrictive terms: "to ration the feed of animals to meet their nutrient requirements". Surprisingly, he defines those requirements as "the amounts of nutrients needed by animals. to perform at stated levels which are usually close to their maximum biological capacity", and even more surprisingly states that "students the world over are taught that 'feeding up to standards* is an essential feature of modem, scientific systems of livestock husbandry". Political arrangements in some parts of the world may encourage, by a scheme of guaranteed prices, the production of milk, meat etc. without limit. Even in those areas, feeding standards should be applied in systems that are dynamic and not static in concept. They should not be applied simply by feeding animals according to their observed production nor, for example, on the basis that a dairy cow requires, and therefore must be'fed, X MJ of metabolisable energy (ME) in order to produce Y litres of milk. Level of feed intake determines level of production, and studies of input - output relationships in dairy cows made more than 40 years ago in the USA (Jensen et al. 1942) and Britain (Yates et al. 1942) demonstrated that optimal levels varied with economic circumstances. They-also vary with sociological and other conditions (Jackson 1981). Feeding standards are not in themselves feeding systems. They are bases for systems which should allow effective nutritional management of animals appropriate to and varying with the prevailing economic circumstances and other conditions.

SOME ELEMENTS OF FEEDING SYSTEMS

Feed Intake

It is necessary to establish how much an animal could eat of the feeds available, or can graze from pastures, if calculations on what it should eat to achieve the desired production are to result in practicable and economic nutritional management. Freer and Christian (1983) give details of a procedure they have developed for predicting the feed intake of grazing sheep and cattle which can also be applied in stall-feeding. In summary, the potential intake (P) of any particular class of animal is defined as the amount of feed that would be eaten when abundant feed is offered and a diet with a digestibility of at least 0.8 can be selected. P is related to the animal's current weight expressed as a fraction of its normal mature weight, with adjustment for effects of lactation and for lambs or calves not yet weaned. Actual intake is the proportion of P that the animal can be expected to achieve as determined by chemical and physical features of the feed. Owing to lack of information on how chemical components of feeds are related to the rates of digestion in and passage from the rumen, which are probably primary constraints on intake, the quality of a feed is described by its digestibility. It should be noted that with herbage diets offered long, or chopped, or grazed, intake is related directly to digestibility over its whole range (Freer 1981) though this may not be so for mixed diets of concentrates and roughage (Conrad *et al*. 1964). With grazing animals, the various physical features of a pasture that affect the animal's ability to harvest the herbage within the time it can spend on grazing are described by the amount of herbage dry matter available (DM, kg/ha); intake decreases as availability falls below a certain value (about 1500 kg/ha for many types of pastures) as described by an exponential relationship. The heterogeneous collection of plant components of varying nutritional value on a pasture, the way in which it is grazed by an animal would not be defined adequately by single values for the availability and digestibility of the total herbage. Instead, the total is viewed as comprising a number of classes, usually five, each of defined amount (kg/ha) and digestibility, with the animal grazing firstly from the most digestible class and then from successively lower classes until it has satisfied its potential intake to the extent that availabilities and digestibilities allow. Summation of the quantities grazed from each class yields a predicted intake of digestible feed which can readily be expressed as ME.

Supplements can increase pasture intake if they rectify a nutrient deficiency in the herbage, but otherwise they cause a reduction. Definition of this substitution effect is also important with housed animals when, as commonly occurs, they have *ad libitum* access to the roughage component of their ration and concentrates are individually rationed. Freer and Christian. (1983) allow for a reduction in pasture intake on the assumption that a supplement will be eaten before herbage of the same or lower digestibility. The predicted substitution rates, that is the reduction in herbage DM intake (g) for each g of supplement DM eaten, are in agreement with observation; for example with a supplement more digestible than the pasture the substitution rate approaches 1.0, though it decreases as the difference in digestibility between supplement and pasture increases, and decreases with decreasing herbage availability.

Energy and Protein Value of Feeds

The generally preferred standard measure of the energy value of feeds is their ME content at the maintenance level of feeding, expressed as MJ/kg DM (M/D) or as a fraction of gross energy ($q_m = ME_m/GE$). Prediction from a correlated and fairly readily determined variable, such as digestibility *in vitro*, is perhaps the least problem in its use. A practical problem, which would also apply to other measures such as digestible energy, is sampling a barn full of hay or the pasture grazed by animals. Data banks in the International Network of Feed Information Centres should increasingly provide information on the composition of feeds of particular types from particular geographic areas; information on grazed herbage is steadily increasing, even for arid and moist tropical areas (e.g. Lorimer 1981; Walker et al. 1983). Manufacturers of compounded feeds should ultimately be required to state ME content and will increasingly find it in their own interests to volunteer this information. A further problem is definition of the decrease from the standard ME value with levels of feeding (L) above maintenance (L=1). Compared with concentrates or ground forages, the decrease appears to be less with forages in long or chopped form (Reid et al. 1980) and for these feeds there is no firm basis for making corrections for L which, in any event, may not greatly exceed a value of 2. MAFF (1975) makes no correction for any diet, but it may be desirable to guard against overestimation of ME intake, and of predicted animal performance, particularly with dairy cows which can have an intake of concentrates plus roughage exceeding L = 3, and possibly with cattle in feed-lots. The proposal to discount M/D by 1.8% for each unit increase in L (Van Es 1975) appears to be the best compromise among various methods of correction reviewed by ARC (1980).

While the net availability of ME for maintenance (km) and lactation (k_l) varies with feed quality, the values can be predicted within fairly narrow limits. Net availability for growth and fattening (k_g) varies much more widely, and the relationship with M/D differs between types of feed (ARC 1980). Within one type of feed, increases in energy costs associated with digestion and metabolism in the gut, especially the rumen, may be an important cause of the reduction in kg with decreasing feed digestibility (Webster 1980). It can hardly account for the major difference in net energy value between spring and later growths of pasture herbage of similar digestibility (Corbett et al. 1966; Blaxter et al. 1971). Armstrong (1982) discussed possible reasons for variation in k_g, including variation in the ratio of gluconeogenic substances, including amino acids, to non-gluconeogenic produced in digestion and absorbed. Some support for this possibility is provided by the finding of Corbett and Pickering (1983) that microbial protein synthesis (non-ammonia N x 6.25) in grazing sheep was about 12 g/MJ of ME intake from the spring growth of pastures but considerably less, about 9 g/MJ, when the same pastures were grazed later in the year. There was a corresponding difference in total crude protein (microbial, undegraded dietary, and endogenous) apparently digested in the intestines, respectively 10.6 and 8.8 g/MJ of ME.

More knowledge of the arrays of metabolites resulting from the digestion of feeds and delivered to the tissues of the animal is required for clearer understanding and definition of the net energy values of feeds. Modern protein feeding systems do aim to predict the supply, and requirement, of amino acid N at tissue level, but though the conceptual bases of the systems are sound there is a number of problems that at present hamper their application in practice. Problems in the application of the ARC (1980) scheme that are discussed by Cottrill (1982), Filmer (1982), and Webster et al. (1982) include uncertainties in the extent of variation in the efficiency of utilisation of absorbed amino acid N in the body, the extent of absorption from the small intestine of dietary protein that has not been degraded in the rumen and, of central importance, the extent to which a dietary protein will be degraded in the rumen. Black et al. (1982) describe a computer model that integrates in an interactive manner the many variables that affect the N value of feeds for ruminants and their use of their protein supply. There is as yet insufficient information on the properties of feeds and other variables to allow general use of the model.

For dried and fresh forages there are some simple empirical approaches to the definition of the amounts of protein these feeds supply to the animal, which appear to be valid. Knowledge of the extent of protein degradation in the rumen is required first to assess whether there could be N limitation of microbial protein synthesis at the given energy intake. Hogan (1982) suggests, however, that N limitation is not likely to occur with dried and fresh forages until the ratio of digestible organic matter (DOM) to crude protein (CP = N x 6.25) approaches and exceeds 10:1. There have been reports of milk production responses to supplementary protein with cows grazing good quality pasture, with DOM:CP ratios much narrower than 10:1 (Stobbs et al. 1977; Rogers et al. 1980), but these reponses are probably not due to any enhancement of microbial synthesis. When responses to supplementary protein by growing cattle on poor quality pasture have been reported, the DOM:CP ratio in the herbage has generally exceeded 10:1 and there has been evidence that the supplement caused an increase in the amount of feed 'grazed (e.g. Hennessy 1983).

For dried forages with ratios less than 10:1, Hogan and Weston (1981) reported that the CP (non-ammonia N x 6.25) entering the intestine of sheep 'could be expressed as (0.36 CP intake + 160 g/kg DOMI + 6). The first term in this equation implies a ruminal degradation of about two-thirds of the CP intake. Corbett and Pickering (1983) found with sheep grazing a variety of pastures with DOM:CP ratios not exceeding 4.5:1, that 0.87 ± 0.02 of CP intake was degraded. With substitution of the corresponding coefficient 0.13 in place of 0.36, the equation of Hogan and Weston (1981) predicted values for CP supplies to the intestine which were in good agreement with those measured in a large number of experiments with grazing sheep (Corbett et al. 1982a). Measurements of microbial protein synthesis gave an average value of 161 g CP/kg DOMI, essentially the same as the coefficient of 160 in the prediction equation though, as noted above, there was some variation with season (185 g/kg DOMI in spring decreasing to 140 g/kg DOMI). In agreement with some other studies on fresh herbage (e.g. Walker et al. 1975), microbial synthesis was greater than the value adopted by the ARC (1980). This value was 188 g/kg OM apparently digested in the rumen (OMADR), equivalent to 122 g/kg DOMI on their assumption that OMADR was a constant 0.65 of DOM intake. It was not a constant in the grazing sheep, but varied with digestibility (D) of the pasture OM as described by the equation: OMADR = 0.9(±0.02)D.

The third term in the equation of Hogan and Weston (1981) assumes a contribution of 6 g/d of endogenous CP, or about 1 g N/d. The suggestion of MacRae and Reeds (1980) that the contribution may be as great as 6 g N/d is misleading because it refers to all endogenous secretions anterior to the duodenum and not to the quantity that actually flows from the abomasum. The ARC (1980) definition of protein degradability does not allow for endogenous N. The degradation of 0.87±0.02 of CP in the pastures grazed by sheep (Corbett and Pickering 1983) was calculated with the assumption of 2 g/d endogenous N; when 1 g N/d was assumed the mean degradation was 0.83±0.03. It can be expected that the discrepancy would be greater for pasture intakes with lower N content than those studied which, on average, contained about 33 g N/kg DM. It can also be expected that protein degradability would decrease with increasing maturity of herbage owing to increasing association of N with cell wall constituents, which may also reduce availability to the animal of the undegraded N that enters its intestine (Hogan and Lindsay 1980). Subtraction of the N in the acid detergent fibre of forages from their total N content may usefully indicate the amount of the forage CP that is degradable, and reduce uncertainty about the availability to the animal of the undegraded fraction (Wilson and Strachan 1980; Webster et al. 1982; Krishnamoorthy et al. 1982).

Studies have to be made with cattle as well as sheep grazing a wider range of pastures than has been used so far in order to establish more firmly the method of Hogan and Weston (1981) for predicting the protein value of pastures.

Animal Responses

Energy retention by an animal continues to increase with increasing feed intake to the limit set by its appetite. The relationship is curvilinear, and this is regarded by the ARC (1980) as being due to a decrease in the efficiency of utilisation of increments of feed given above a constant maintenance. There is, however, much evidence that a primary cause of the curvilinearity is a progressive increase in the basal component of the total heat production, the notional maintenance requirement (Graham 1982). This response to increasing feed intake, which occurs rather slowly, is probably a major reason why the observed energetic efficiency (k_g) of animals observed in long, term feeding trials is generally less than would be predicted from the results of short term calorimetric experiments (e.g. Garrett 1980). Conversely, when animals have been undernourished their maintenance requirement decreases (e.g. Graham and Searle 1979). This probably accounts to some extent for the compensatory gain that occurs when they are again given an adequate diet (Butler-Hogg and Tulloh 1982); the reduction in maintenance requirement continues for some time during realimentation, and during this period the fraction of the feed intake available for body gain, and the gain, are greater than standard calculations would indicate.

It is important to recognise that there is variation in maintenance requirement when animals are being fed for survival in drought; even small reductions in the amounts of feed provided can accumulate into large financial savings. The possible extent of such savings is indicated by feeding trials with cattle (Morris 1968) and sheep (CSIRO 1958) which showed that when not cold-stressed they could survive for long periods on amounts of feed that provided 10 to 20 per cent less ME than would be calculated from the results of standard measurements of fasting metabolism (e.g. ARC 1980). There is need to determine the maintenance energy expenditure of animals in a variety of practical conditions of management for comparison with standard values. This can be done with the carbon dioxide entry rate technique which has been used to define the energy requirements of grazing sheep (Corbett et al. 1980, 1982). Maintenance requirements of those sheep appeared to vary with feed intake, but were greater than those of comparable housed animals to an extent that could be accounted for by the increased physical activities at pasture and the known energy costs of those activities. In general, the maintenance requirements of animals not cold-stressed are increased by about 20% when they graze small areas of good quality pasture, and by up to about 60% in extensive grazing conditions.

APPLICATION OF FEEDING SYSTEMS

Cumulative and residual effects from periods of over- and under-feeding are especially important in lactating animals where antecedent, as well as current, nutrition affects the immediate response in milk production to a change in feed intake, the partitioning of nutrients between milk and body reserves, and the subsequent course of lactation (Broster and Thomas 1981). With current feeding systems, however, nutritional management is essentially on a day-to-day basis within a long-term pattern of feeding determined to a considerable extent by practical experience of what 'works'. The systems are described in what can properly be called manuals; they contain a variety of approximations, such as fixed values for km and k_l (MAFF 1975) and km = k_l (Van Es 1978) specifically to simplify their use for initial formulation of rations and for sequential revisions in the light of actual animal performance. This use of systems gives satisfactory results, and errors introduced by the approximations can be corrected, when all or the major part of the feed intake is well controlled and when the animal production can be measured easily and accurately. These conditions occur in intensive dairy production. The energy feeding system of MAFF (1975), for example, gives good results provided that account is taken of changes in cow body weight as well as in the much more readily determined milk production (Broster and Thomas 1981).

Current feeding systems for beef production are less satisfactory. Andersen and Foldager (1980) reported the liveweight gains that were predicted with the systems used in several countries, and though the types and amounts of feeds comprising a variety of rations were exactly specified, the means of the predicted daily gains had coefficients of variation (CV) as great as 41%. If the predictions made with Starch Equivalent systems were excluded, the CV were not much reduced. This variation is due partly to the difficulty in allowing for change in gut fill when expressing an energy gain in terms of liveweight, but the major problem is the variation in the relative amounts of protein tissue and fat that are deposited and comprise the gain. Still more detailed specification than in the ARC (1980) of equivalences between predicted energy gains and liveweight increases for various breeds of animals, allowing for sex differences, current liveweight and rate of gain, might improve accuracy of prediction. This path, however, diverges from development of feeding systems by progressive incorporation of knowledge of processes in the intermediary metabolism and utilisation of nutrients. An alternative approach in the computer models of sheep and cattle nutrition and production of Graham *et al*. (1976) and Graham (1981) should ultimately be more fruitful. Predictions are made of the amount of protein tissue synthesised from absorbed amono acid N, and of the amount of the ME available for production that is used for this synthesis; prediction of the net gain of energy from utilisation of the remainder of the ME available for production allows calculation of the quantity of fat deposited. Liveweight gain is the sum of the predicted protein tissue and fat gains, adjusted to allow for changes in gut fill.

Feeding systems will increasingly be applied by use of computer programmes rather than manuals. The complexities are so great in systems for effective and profitable nutritional management of animals when there is only partial control of feed input, that use of computers is inescapable. With grazing animals the essential first step of predicting pasture intake and the substitution effect of supplements (Freer and Christian 1983) is not otherwise practicable. Approximations do not have to be used to simplify use of the system. There will inevitably be approximations in the inputs such as in the values for the availability and digestibility of the pasture being grazed, and uncertainties in the validity of functions such as those describing the efficiency of utilisation of dietary N and energy. With a computer, however, it is easy to obtain and compare a number of solutions to a nutritional problem based on, for example, more or less pessimistic assessments of the intake and nutritional value of the feed. In any event, actual animal performance should be monitored and compared with prediction.

The solutions should predict the financial as well as the physical result of the nutritional management. The ultimate requirement of feeding systems is that economic benefits from the production of cattle or other livestock, by individual farmers and on a national basis, should not decay at any time of year but should be maximised.

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