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THE UTILIZATION OF GRASS BY RUMINANTS

Morning Session

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The efficient use of grass*

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The output of animal products from grassland depends on the quantity and quality of herbage produced, and on the efficiency of utilization of this herbage by the animal; these factors interact, herbage production being affected by method and intensity of use, and efficiency of utilization by the overall level and seasonal distribution of herbage production. However, our ability to grow grass appears in general to be ahead of our ability to use it efficiently, and it was to consider this problem of utilization that this Symposium was arranged. Efficiency of utilization itself depends both on the proportion of the herbage grown that is eaten by livestock, and on the efficiency of conversion into animal products of that herbage. These two requirements are often contradictory, and an analysis of the causes and nature of this contradiction may help us to develop systems of grassland use that will more efficiently exploit the herbage we grow.

It is useful first to consider the efficiency with which the ruminant animal uses the food it eats. The 500 lb bullock at maintenance (i.e. neither gaining nor losing weight) requires some 4 lb starch equivalent (SE)/day, whereas the same animal gaining 1, 2 or 3 lb live weight/day requires about $5\frac{1}{2}$, 7 or 9 lb respectively. These figures, based on *Rations for Livestock* (Evans, 1960) may not be precise, but they are used here to illustrate how efficiency of food conversion increases with rate of animal production. Thus the higher the rate of gain the less is the total SE required per lb gain ($5\frac{1}{2}$, $3\frac{1}{2}$ and 3 lb SE/lb gain at production levels of 1, 2 or 3 lb/day). Such an increase in efficiency of food conversion is a key factor in the intensive pig and poultry industries, but less attention has been given to it in ruminant systems based largely on forages. Much of the current success of feeding beef cattle on diets containing a high proportion of barley, however, seems due to the high food conversion efficiencies achieved, which has directed attention to the low efficiency of conversion of the forage eaten in many grassland systems. This inefficiency is because many herbage-fed animals have a low daily intake of nutrients, of which the majority is used for maintenance, and relatively little for production; as a result the nutrient requirement per unit of production is high. It seems clear that to increase the efficiency of conversion of the herbage eaten we must increase the daily intake of nutrients by the individual animal. This requires a study of the factors that determine

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nutrient intake, and their interaction when animal and grass are put together in different systems.

Nutrient intake is determined by the total dry-matter intake of the animal (I) and the nutritive value per unit of intake; the latter depends on the extent to which the animal digests its food (D), and the efficiency with which it absorbs and utilizes what it digests (E). Thus nutrient intake can be expressed as $I \times D \times E$. In succeeding papers, Blaxter (1964), Rook (1964) and Campling (1964) consider detailed aspects of I and E. In this paper I wish to discuss in particular the way in which different methods of managing and using grass affect the quantity and digestibility of the herbage eaten, and then to consider how grassland management systems might be developed to allow increased efficiency of utilization, and conversion into animal products, of the herbage grown.

Digestibility

Much information on factors determining the digestibility of grass has been gained in the last 10 years (although much of it serves mainly to confirm the conclusions of Woodman and his co-workers at Cambridge (Woodman & Norman, 1932)); the scale on which we can investigate herbage digestibility has been increased by the introduction of the laboratory in vitro digestibility technique (Tilley & Terry, 1963), which enables the digestibility of many more samples to be determined than has been possible with animals, and also allows digestibility determinations on fractions of herbage—e.g. leaf and stem—which it would not be possible to handle in animal experiments. A more rational picture of the factors determining herbage digestibility now begins to emerge. We know for instance that the digestibility of herbage during its first uninterrupted growth in spring is determined mainly by its species and stage of growth, each variety having a characteristic relationship between its digestibility and stage of maturity (Minson, Harris, Raymond & Milford, 1964). These relationships have been repeatable in different years, and, by making slight allowances for the effect of the earliness or lateness of a particular season, it is possible to predict the digestibility of first-cut herbage with reasonable accuracy from the date of cutting. We have found that differences between varieties cannot be accounted for solely on the basis of stage of maturity, and that certain grasses are characteristically more digestible than others. In particular, the ryegrasses have consistently been more digestible than some cocksfoot varieties (e.g. S.37, S.143 and Germinal). It seemed at first that *Lolium* was inherently more digestible than *Dactylis*, but recent work at Cambridge (Dent, 1963) has shown that other cocksfoot varieties (notably Scotia and Roskilde II) are almost as digestible as ryegrass. Current work at Aberystwyth is aimed at breeding for high digestibility in cocksfoot, using the in vitro method to select high-digestibility genotypes within a population of cocksfoot plants (Cooper, Tilley, Raymond & Terry, 1962).

Characteristic differences in digestibility between species and varieties are also found in regrowths under a cutting system; thus regrowths cut at monthly intervals from June to September have shown a remarkably uniform level of digestibility for each variety, mean figures ranging from 78% digestibility of the dry matter for S.23

and S.24 to 72% for S.37 and Germinal cocksfoot (Minson *et al.* 1964). The digestibility of herbage under grazing conditions is, however, complicated by the possibility of selection of feed by stock. This means that animals may not consume herbage of the same digestibility as that which a mowing machine would cut; furthermore, grass not eaten at one grazing will continue to grow more mature and depress the overall digestibility of the herbage available at later harvests. This is most noticeable in the spring, when grasses produce stems and seed heads. When the first growth is used, any shoot that is cut or grazed so that the developing ear is removed is stimulated to produce new tiller growth, which will be of high digestibility at the next harvest 4–6 weeks later. A shoot that is cut off above the height of the developing ear will continue to mature, so that its digestibility a month later will be low. Thus, the digestibility of the regrowth will depend on the proportion of new young tillers to older mature shoots, which is largely determined by the stage of development and intensity of defoliation of the first growth. From this regrowth stock will attempt to select the young shoots and reject the older material. The rejected herbage will remain to depress still further the digestibility of subsequent regrowths. As a result (Tayler & Deriaz, 1963) there may be a progressive decline in the digestibility of the herbage grazed, and high grazing pressure will further reduce the animal's ability to select feed of high digestibility from swards containing an accumulation of mature material.

It has of course long been recognized that this problem can be partly overcome by topping swards, or by taking cuts for conservation, but the latter in particular are seldom sufficiently integrated with grazing in pasture management systems. In fact, because conserved feeds have so often had a low potential for animal production, and because of excessive losses in many conservation methods, the proportion of the herbage grown that has been conserved has often been kept to a minimum. As a result cutting has had little effect on the quality of grazed pastures, particularly after midsummer.

However, it is now more widely recognized that conserved feeds need not be of low feeding value, and that hay and silage made from crops of high digestibility are themselves highly digestible. In experiments at Hurley for instance the digestibility of silage made from crops ranging in digestibility from 55 to 80% has been almost identical with that of the herbage cut (Harris & Raymond, 1963). Although there may be some depression in digestibility when high-temperature silage is made or when effluent loss is considerable, at least in some of the reports of a reduction in digestibility during ensilage it is likely that this was because allowance was not made for volatile losses during dry-matter determinations on the silage (see Wilson, 1962). With hay there is generally some depression in digestibility due to loss by respiration, leaching, and mechanical damage during making, but this can be reduced by quick haymaking techniques and barn drying and hay digestibility is then only a little lower than that of the crop cut (Shepperson, 1960). We can, therefore, make hay and silage of high digestibility from a crop which is itself of high digestibility and we can also make a reasonable estimate of hay or silage digestibility from a knowledge of the digestibility of the herbage conserved.

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Intake

I will only comment here on a few aspects of herbage intake. It is now clearly established that for a feed to be eaten in large amount it must be highly digestible (Blaxter, Wainman & Wilson, 1961); it is, however, difficult in practice to ensure that the animal in fact eats as much of the feed as it theoretically could on the basis of the digestibility of that feed. At times, the intake of herbage feeds seems to be depressed by factors that make them unpalatable; it may be an intrinsic factor in the herbage (e.g. as with *Phalaris arundinacea* L.) (Roe & Mottershead, 1962) but more often it seems due to external factors such as mould in hay, and the soiling with excreta of pasture. Intake of silage, and particularly of high-digestibility material, is often lower than expected (Harris & Raymond, 1963), but the reasons are not clear. It is known that intake can be increased by prewilting the herbage before ensilage (Murdoch, 1960) but, until intake of silage can consistently be raised to the level of intake of the same herbage conserved as hay, it must be at some nutritional disadvantage compared with hay.

In the field, however, it seems to be availability of feed that most frequently determines the intake of grazing animals, intake being depressed when the amount of available herbage falls below a certain level, as may occur particularly when grazing pressure is high. The effects of low availability can be accentuated by soiling by dung and urine—which is also greatest in high-intensity systems—by fungal infection of the herbage, and by the presence of mature residues which the animal tries to avoid eating.

It is useful now to consider how these two main factors determining level of animal production—intake and digestibility of herbage—are affected by the method of pasture management. It seems that, at any one grazing, it is necessary to remove a high proportion of the herbage available so as to avoid mature residues in the regrowth which will reduce its digestibility. To do so requires close defoliation, which, however, tends to reduce intake, and may also reduce the digestibility of the herbage eaten because the stock are restricted in their selection of feed. Conversely, a low intensity of defoliation, which may be necessary to ensure high intake and digestibility at the current grazing, will produce a regrowth which if grazed intensively will lead to a low intake of low-digestibility herbage.

This contradiction between, on the one hand, high intake and high digestibility, which are necessary for high production and food conversion efficiency by the individual grazing animal, and, on the other, the need for close defoliation if a high proportion of the herbage grown is to be eaten, and to ensure a highly digestible regrowth, poses, I believe, the main problem in the efficient use of grass. This problem is summarized in Fig. 1; as we increase grazing intensity animal output per acre rises, because of the increased numbers of animals, but is achieved at the expense of a decreased output by the individual animal. (Output per animal at very low grazing intensity may also be low, because the herbage available is of low digestibility, but such a level of pasture management is not relevant to the present discussion.) This effect has become clear from many experiments, such as those

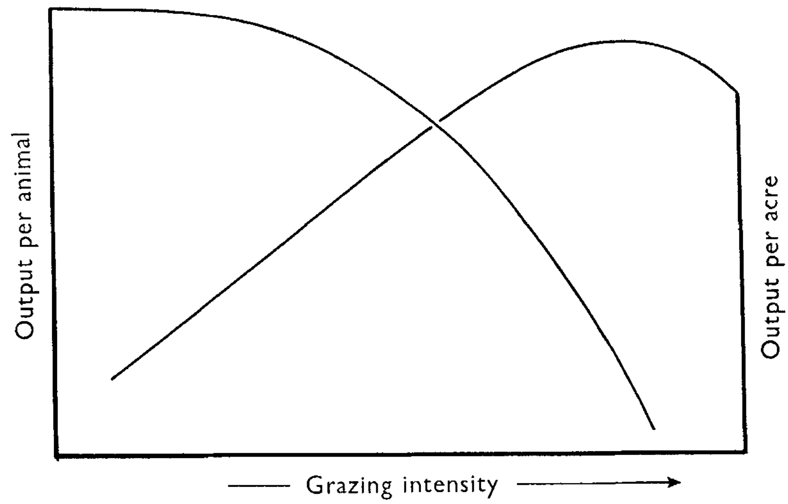

Fig. 1. The responses in animal output, per animal and per acre, to increasing grazing intensity in pasture systems (see also Mott, 1960).

reported by McMeekan (1960) and by Alder (1964) in an experiment to study the interactions between stocking rate and levels of nitrogen fertilizer on daily gains of cattle.

Obviously the exact relation between output per acre and output per animal must differ in different situations and with different classes of stock, and with the seasonal pattern of herbage production relative to animal requirements. However, it does appear in general that any attempt to graze a high proportion of the herbage grown leads to lowered production by the individual animal. This is a trend opposite to that in non-ruminant feeding and in cereal feeding of ruminants, in which the aim is to increase the level of production of the individual animal, and so to increase its food conversion efficiency. The practical consequences will of course differ for different animal products and in different economic conditions; thus where output is of an immediately saleable product, such as milk or butterfat, it may be economic to accept a lowered output per animal if output per acre is high, but where output is in terms of weight gain, and high output is achieved at the expense of slow rates of gain by the individual animals, the consequences may be more serious. Not only has the slow-gaining animal to be fed for a longer period, but it generally also has to be fed to a higher weight than the rapidly growing animal before it is fit to market. A simple analysis shows that, as a result, its total food requirement, expressed as SE/lb meat produced, may be two to three times as great as that of the rapidly gaining animal.

It is therefore important to investigate grassland utilization systems in which a high proportion of the herbage grown is eaten, and yet in which individual animal performance (and so food conversion) is high. Though the need for such systems is most urgent in meat production, the need for high conversion efficiency of grass feeds must increasingly become relevant in the dairy industry.

One can visualize several methods of approach.

(a) The combination of low-pressure grazing during periods when enough high-quality herbage is available, with intensive conservation of surplus herbage, and the use of the conserved products at any time when grazing is inadequate for high daily animal gains (principally during the winter, but also during periods of grass shortage in summer). It is important not only that as much as possible of the surplus herbage should be conserved efficiently, but that the digestibility and intake of the conserved feeds should allow high animal production. The high potential of silage for animal gains has been demonstrated by Dodsworth & Campbell (1953) and Morrison (1960). As noted above, however, the potential of silage for high animal production may sometimes be limited by low daily intake, and wilting may be important in ensuring silage of high production potential. High-digestibility hay will also give rapid animal gains: from September 1962 to May 1963 young Friesian steers were fed at Hurley solely with barn-dried hay, of mean digestibility 72%, and although during much of the winter the cattle were in yards with mean temperatures close to freezing, average gain per day over the whole 7-month feeding period was 1·8 lb.

It does seem that conservation has often failed because (1) losses in conservation have been very high and (2) the quality (digestibility and intake) of conserved feeds has been so low that animal production in winter has only been achieved with supplementary feeding. However, integration of low-pressure grazing with intensive conservation (involving at times the cutting of relatively small crops) to give uniform high animal gains at all times of year now seems technically possible. Further, as the feeding potential of such feeds is increased, it is likely that we can justify more efficient conservation processes.

(b) In many enterprises not all the animals are required to be at a high level of output. Thus with ewes and lambs forward-creep grazing is designed to allow the lambs free access to high-quality herbage, and to follow them by the ewes, intensively stocked, whose food requirements are not as critical towards the end of their lactation. This system may also confer some degree of parasite control but, with the increasing effectiveness of anthelmintic drugs, any advantages are likely to be mainly nutritional.

Similarly, under rotational grazing of the dairy herd, the high-yielders can graze first, and be followed by the lower-yielders, and then by dry cattle to clean up the rejected herbage. The dairy herd needs a considerable quantity of conserved feeds in winter, so that this system of grazing would also be integrated with conservation.

(c) It should be possible to give supplements to animals grazing at high intensity, to a level of nutrient intake at which they would be at high individual production. It does seem that much of the failure of supplementary concentrate feeding at pasture has been because the interaction with grazing intensity has not been understood. Thus in experiments in which half the animals grazing a paddock are given concentrates, if the overall level of stocking is such that the herbage alone can give a reasonable level of animal production, the supplement will give little more than nutritional substitution for herbage, and little response to it can be expected. It seems likely that only at high grazing intensities, or on pastures of low digestibility, will supplementary feeding have marked effects on individual animal production. The effective use of concentrates with conserved feeds in winter suggests that supplementation rather than substitution must be possible at pasture; however, that we know little even about the interaction between conserved and supplementary feeds is shown by the experiments reported by Blaxter & Wilson (1963); the intake of poor hay plus concentrates was in fact higher than that of good hay offered with the same amount of concentrates. Only when we understand the interaction between concentrates and herbage feeds logically, rather than empirically, shall we be able to supplement high-intensity grazing to ensure a high individual level of production.

(d) A combination of systems based on feeding with cut forage ('zero grazing') and with stored forage should, in theory, combine high output per acre with high output per animal throughout the year. That this is seldom achieved is perhaps mainly because the conditions required for high $I \times D \times E$ have not been satisfied. Successful 'zero grazing', which necessitates a uniform supply of high-quality forage for daily cutting, presents considerable problems of management, and may have to place some reliance on lucerne, which is of relatively low digestibility, for summer feed supply. Other summer-growing forages might help (sainfoin is more digestible than lucerne, and with improved cultural methods, including the use of grass-killing chemicals, might play a more useful part in forage production), as would the use of conserved feeds; the stored forage would here act as a buffer against fluctuations in the availability of feeds of adequate quality for 'zero-grazing', and so would itself have to be of high animal-production potential, unless concentrates were to be used. Clearly the problems of alternate feeding with fresh and conserved forages, with or without concentrates, need study; when the factors controlling I and D, in particular, are better known, it should be possible to develop models for forage production, indicating the proportions of forage to be given either directly or after storage, and their integration with concentrate feeds, which could then be tested in animal experiments, and the results subjected to economic analysis.

These are some possible methods of combining high output per acre and per animal in the same system. Some are already technically feasible; something of this sort will in fact become increasingly necessary as the level of herbage production increases and, with it, the problem of using this herbage in mainly-grazing systems. However, a clear distinction must be made between what is technically possible and what is economically desirable, and the critical study of interactions between the technical and economic aspects of forage systems may demand a new type of econometric analysis, on the lines of that suggested by Blaxter & Wilson (1963).

Thus, if we can increase the daily rate of gain of the 500 lb bullock from 1 to 2 lb, we reduce the amount of SE required per lb gain by some 40%. To do so we must increase its daily food intake from $5\frac{1}{2}$ to 7 lb SE, which might be achieved by reducing grazing intensity in the field, by feeding with digestible conserved forage, or by supplementary feeding. These methods are already technically possible: however, we could well obtain invalid economic conclusions if we analysed any one of them as an isolated technique. Thus, as Blaxter & Wilson (1963) have emphasized, the stage of maturity at which a crop is cut will not only determine the digestibility and yield

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of that cut, but will also affect the yield of the regrowth; each cut is both a harvest itself and a treatment for the next harvest, and we must know the total annual production, its quality and its distribution, to get a reasonable evaluation. We might also raise daily gain from 1 to 2 lb by feeding with heavily wilted silage. This might demand an airtight silo, as against a trench silo suitable for unwilted silage; the technical possibility of feeding with wilted silage would then have to be considered in relation to the costs involved in wilting and airtight storage on the one hand, and the higher efficiency of the conservation process and the higher animal production obtained on the other. Again this cannot be considered in isolation; wilting silage and barn hay drying both permit the conservation of crops that cannot effectively be stored by traditional methods and, unless their potential is fully exploited, their economic possibilities may be misunderstood.

These are essentially input–output relationships: is the increased cost per unit SE justified by an increased efficiency of conversion of this SE into animal products? We perhaps sometimes overemphasize low cost per lb SE from herbage feeds, when a somewhat more expensive feed would give a lower cost of SE per unit of animal production. These relationships should first be studied in critical experiments on the small-plot scale, which allow an understanding of basic nutritional mechanisms, rather than in full-scale tests, which may be easier to analyse in economic terms, but must be carried out at a limited number of levels of the variables involved, and so can seldom elucidate mechanisms. This may mean that the economist should become more involved at the small-plot scale—the possibility of developing models for systems based on the use of cut fresh grass from small-plot studies of the yield and digestibility of different forages under different harvesting patterns has already been suggested—and it should be possible at that stage to make a preliminary economic analysis of different systems. Admittedly much of the necessary ancillary information is lacking—on the relation between method of conservation and efficiency of food utilization, on effect of method of feeding (e.g. frequency of feeding) on forage intake and feed conversion, on supplementary feeding and the like, but preliminary analysis at the small-plot scale may indicate more clearly the additional information needed before large-scale trials can sensibly be planned. Economic considerations should hardly come into the planning of these studies, but economic analysis of the results could be useful in formulating programmes of larger-scale studies, particularly when several pieces of information are to be combined in a system of grassland management. The main interest of the nutritionist must be in pasture–animal interactions, and his aim must be for as much of the herbage as possible to be consumed by high-producing animals, so as to obtain high conversion efficiency of the herbage grown. The economic optimum may well not be maximum production per animal, but only if we have a logical understanding of the nutritional background shall we in fact be able to make any valid prediction of the economic optimum.

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Utilization of the metabolizable energy of grass*

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A convenient way of measuring the energy which grass or indeed any food supplies to an animal is as its metabolizable energy. Metabolizable energy is defined as the heat of combustion of the food less the heat of combustion of the faeces, the urine and the combustible gas, mostly methane, which are produced from it. It is usually expressed as kcal metabolizable energy/g dry food and the definition is strictly in terms of measurable quantities, measurement of methane involving use of a respiration chamber. The calorific value of the dry matter of grass, or the organic matter of grass, is subject to relatively little variation. Hutton (1961, 1962), for example, found the calorific value of pasture grass to range from 4·32 to 4·56 kcal/g dry matter, a variation largely associated with the protein content of the grass. The main determinant of the metabolizable energy of grass per unit dry weight or per unit organic matter is undoubtedly the loss of energy in the faeces. Faecal losses of energy rarely fall below 15% but can rise to 60% of the heat of combustion of the grass. Loss of energy as methane rarely exceeds 10% of the energy of the grass and loss of energy in urine rarely exceeds 9% of the energy of the grass. Losses of energy both in urine and as methane vary over a considerably smaller absolute range than does the faecal loss of energy. Indeed, the metabolizable energy of grass and grassland products can be estimated with little error by multiplying the apparently digested energy of grass (heat of combustion of grass less heat of combustion of faeces) by 0·82. This factor applies to artificially dried grasses varying in protein content from 5·1 to 22·6% (Armstrong, Blaxter & Waite, 1964), to a dried lucerne (Bateman & Blaxter, 1964), to grass silages (J. L. Clapperton, 1963, unpublished) and to fresh pasture grass (Blaxter, Ekern & Sawers, 1963, unpublished). Alternatively, but with a slightly greater error, the metabolizable energy of grass can be estimated by assuming that each g digested organic matter has a metabolizable energy value of 3·6 kcal.

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