NUTRITIONAL REQUIREMENTS OF DAIRY CATTLE

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SUMMARY

Trials conducted over two separate seasons are described in which identical twin milking cows were fed cut pasture in stalls for a period of 24 weeks which embraced the major part of the lactation of the animals concerned. Using multiple regression methods, the data were analysed to determine how the intake of the animals was related to their productions, liveweights and weight gains. Highly significant relationships were demonstrated. Estimates of the amounts of digestible organic matter eaten by these animals for purposes of maintenance, milk production and liveweight increase were compared with and found to be higher than the allowances provided by the conventional feeding standards, but lower than those previously found by the writer for free-grazing animals. The general significance of the findings is discussed, and it is suggested that the results provide an explanation for the substantial discrepancies which have usually been found between herbage intake estimates based on clipping techniques and those calculated from animal liveweight and production data by the reverse use of the conventional feeding standards.

TO SOME EXTENT the title of this paper is misleading, for throughout the concern will be not so much with the nutritional requirements of cattle as with the quantities of nutrients they do in fact consume, and with how these quantities may be related to liveweight and production.

Our scientific knowledge of the nutrition of dairy cattle has been gained almost entirely from work carried out overseas during the last 100 years or so, and, on the whole, stems from two main types of investigation: first, those concerned with establishing the relative nutritive values of different feeds, and, secondly, trials to find out the quantities of nutrients required by different animals.

In most of the textbooks that deal with the feeding of dairy cows, we find this information conveniently summarized in two sets of tables: one set that lists the protein and energy values of a wide range of stock feeds, and another that gives "feeding standards", that is, the amounts of protein and energy required by different classes of dairy stock. The idea behind these feeding standards is that the total feed eaten by any particular animal may be considered as the sum of several separate portions—first, one which is used solely for maintaining the body in healthy but non-productive condition and at more or less constant bodyweight and, added to this, further portions which are used for the productive purposes of forming milk or laying on fat or flesh.

In stating an animal's requirements, it is recognized that those for maintenance depend upon the weight or metabolic size of the animal, those for milk secretion on the energy content of the milk produced, while needs for body gains depend upon factors, such as the state of maturity, or the rate of gain, which influence the energy content of the weight increment.

In Britain, the commonly accepted feeding standards and tables of nutritive values are those contained in the English Ministry of Agriculture and Fisheries Bulletin No. 48, *Rations for Livestock* (Woodman, 1954), in which energy values and requirements are expressed in terms of Kellner's starch equivalents. In the United States, however, energy values are more usually expressed in terms of total digestible nutrients, and the T.D.N. standards given in Morrison's textbook *Feeds and Feeding* (Morrison, 1957) are widely used.

There is no doubt that, in those countries where dairy cattle are commonly housed indoors and fed individually for substantial periods each year, these feeding systems have proved of the greatest value. Obviously, however, it is most unsafe to assume that the feeding standards used for determining the level at which stalled cattle should be fed on rations composed largely of concentrated feeds, can be used as a basis for calculating the requirements of cows farmed under New Zealand conditions.

In this country we take advantage of our favourable climate both to grow cheap feed—mainly in the form of pasture—and to avoid the costs of harvesting this feed and of housing our stock. Nutritionally, as a result, our herds, over much or all of the year, are virtually completely dependent upon three bulky, low-energy feedstuffs—pasture, silage and hay—all of which vary enormously in quality. Animals under this system cannot be rationed individually according to liveweight and level of production. Cows are normally grazed as a single group at pasture, and in practice it is seldom that the intake, even of the group as a whole, can be controlled with any accuracy. It is clearly both of interest and importance to know just how much individual animals do eat under these conditions, and whether this is at all closely related to liveweight and productive performance, and also how it is influenced by the amount and type of pasture available.

These are matters which have been under investigation at Ruakura for some time. Studies on the intake of free grazing dairy cows were reported some four years ago (Wallace, 1956), and since then work has been extended to cows fed pasture in stalls.

Let us consider first the results obtained with freely grazing animals. The intake studies reported (Wallace, 1956) were made on milking cows over six separate seasons. The animals varied widely in respect of age, liveweight, level of production, and liveweight increase. Intakes were measured by the chromium marker-faecal nitrogen method in terms of digestible organic matter (D.O.M.). On the basis of an appraisal of the overall results, it was suggested that over fairly long periods daily average D.O.M. consumption of free grazing dairy cows could be predicted with reasonable accuracy under a variety of grazing management conditions by means of the provisional equation:

$$\text{D.O.M.} = 0.35\,\text{F.C.M.} + 0.08\,\text{L.W.}^{0.73} + 3\,\text{L.W.I.}$$

where D.O.M. = mean daily intake of D.O.M. (lb)

F.C.M. = mean daily fat corrected milk production (lb)

$\text{L.W.}^{0.73}$ = mean liveweight (lb) raised to the power 0.73

L.W.I. = mean daily liveweight increase (lb)

On the basis of the nutrients allowed for maintenance and milk production by this provisional equation, and assuming that, for the pastures concerned, a pound of D.O.M. contained approximately 1.04 lb of T.D.N. or 0.92 lb of S.E., it was estimated that free-grazing dairy cattle would consume approximately 0.36 to 0.37 lb of T.D.N. or 0.32 lb of S.E. per pound of F.C.M. produced: also that a lactating cow of 1,000 lb liveweight would consume about 12.9 lb of T.D.N. or 11.4 lb of S.E. for maintenance purposes. These estimated consumptions are considerably in excess of those provided by the commonly accepted feeding standards for stall-fed cattle, particularly in the case of maintenance.

Before discussing the significance of the higher figures given by this Ruakura equation, some more results obtained in trials recently conducted at Ruakura in which milking cows have been fed freshly cut pasture in stalls over extended periods can be presented. Thanks are due to Dr J. B. Hutton for permission to analyse the data in the way done here, for the figures are his and the animals concerned are some of those which he has been using to investigate the important problem of whether cows fed pasture *ad lib.* eat more than they actually need to sustain production.

During the 1958-59 season, 8 sets of lactating, identical twin cows (3 sets of 2-year-olds and 5 of 3-year-olds) which had calved between July 7 and August 26, were fed freshly cut grass in stalls for some months. Throughout the trial one member of each set was fed *ad lib.*, while an attempt was made to restrict the intake of its twin as far as possible without any appreciable drop in production. In the 1959-60 season, a further 10 sets of twins (4 sets of heifers, 3 of 3-year-olds, 2 sets of 4-year-olds and one of 6-years) which calved down rather earlier (between June 18 and August 1) were used, and essentially the same procedure followed. During both seasons, intake, liveweight and production records were obtained over the 24-week period from November 6 until April 21, and it is the data from these periods of 24 weeks common to both years that will be considered here.

Although the cows were fed in stalls throughout, they did not remain inside all the time. After finishing their evening meal at 7 p.m. they were fitted with muzzles to prevent grazing and turned out into a small holding paddock, where they remained overnight until brought indoors again for feeding at 5 a.m. They had a further period of two hours out of doors each day between 1 p.m. and 3 p.m. Thus they spent approximately 12 hours out of every 24 outside, exposed to normal weather conditions although not able to forage for food. It is difficult to assess the extent to which their requirements were affected by this method of handling as opposed to more conventional stall-feeding procedures on the one hand, and, on the other, to normal free-grazing management.

In this paper the concern is not with the differences between the groups on *ad lib.* and on restricted diet, although, as mentioned before, these are matters of great interest. The aim is to compare the amounts of material actually eaten by these cows with the quantities that they might have been expected to consume on the basis of the commonly accepted feeding standards.

In the first year, the D.O.M. content of grass fed to the stalled cows was determined during successive weeks by conducting a continuous series of digestibility trials with the same herbage. For this, three sets of dry twin cows were employed. One from each set was fed at approximately maintenance level and the other at a considerably higher one. In estimating the

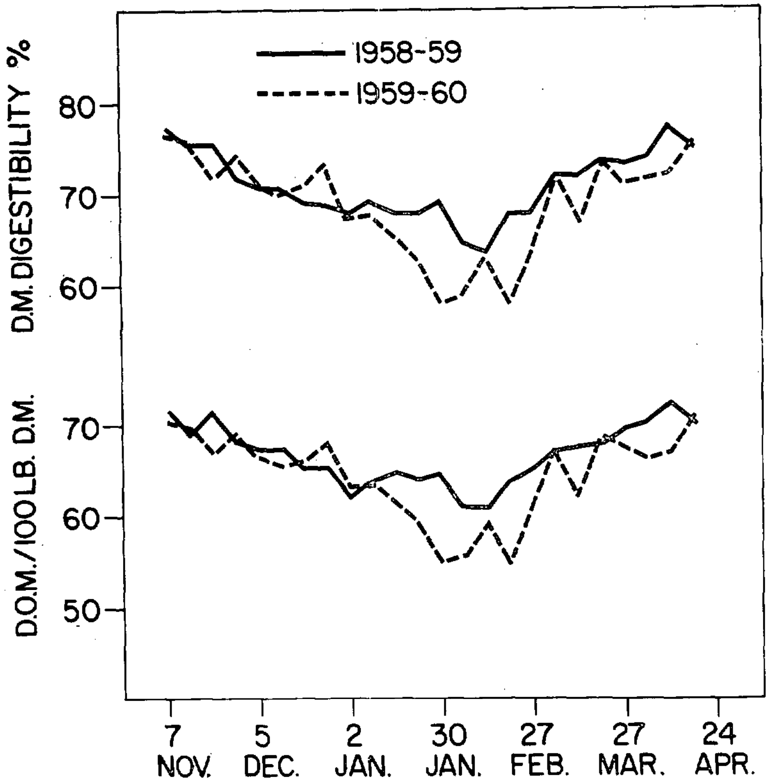

Fig. 1: Changes in D.M. digestibility and D.O.M. content of dry matter during successive weeks.

D.O.M. content of the herbage fed each week, the mean value obtained by averaging the results for the six animals has been accepted. In the second season dry animals were not used. Instead, each week a complete collection was made of all faeces voided by three sets of the stalled milking cows, and the D.O.M. values again obtained by averaging the results for the six animals. The changes that occurred in dry matter digestibility and the D.O.M. content of the pasture during the two seasons are illustrated in Fig. 1. Each day throughout the trial all feed offered to and refused by the stall-fed cows was carefully weighed and sampled for dry matter determinations, so that accurate records of intake could be secured. The cows were milked twice daily. They were weighed five times a week in the first season and, except when on digestibility studies, daily during the second.

TABLE 1: MEAN DAILY PRODUCTION, LIVEWEIGHT AND WEIGHT GAINS OF STALL-FED CATTLE

	1958-59	*1959-60*	*Both Seasons*
Average:			
Liveweight (lb)	752	765	759
F.C.M. (lb)	21.0	22.6	21.9
Liveweight Increase (lb)	0.46	0.33	0.39

Mean liveweights during successive weeks have been obtained by averaging the daily values; weight changes during any particular week were calculated by halving the differences between the average weights during the preceding and succeeding week. Weights at the beginning and end of the trial periods were estimated by averaging the weights obtained during the week preceding and succeeding the days on which the trial started and finished respectively.

Over the 24 weeks trial period in the first season, for different individuals, average liveweights ranged from 637 to 891 lb, mean daily F.C.M. productions from 17.4 to 25.0 lb, and mean daily liveweight gains from 0.05 to 0.93 lb. In the second season the spread in average liveweight was from 576 to 1,051 lb, in mean daily F.C.M. production from 11.2 to 30.1 lb and in mean daily liveweight gain from 0.02 to 0.60 lb.

The average production, liveweights, and liveweight gains of the 8 sets of cows used in 1958-59 and of the 10 sets used in 1959-60 are shown in Table 1.

TABLE 2: COMPARISON OF ACTUAL INTAKES WITH ESTIMATES BASED ON FEEDING STANDARDS

	Intake per Day (lb)		
	1958-59	*1959-60*	*Both Seasons*
D.O.M.:			
Actual	15.8 (100)	16.0 (100)	15.9 (100)
Ruakura Standard*	18.8 (119)	19.1 (119)	19.0 (119)
T.D.N.:			
Actual	16.5 (100)	16.7 (100)	16.6 (100)
Morrison Standard†	12.9 (79)	13.5 (81)	13.3 (80)
S.E.:			
Actual	14.6 (100)	14.7 (100)	14.7 (100)
Woodman Standard	10.3 (71)	10.8 (73)	10.6 (72)

Figures in parentheses denote relative consumptions.

*D.O.M. = 0.35 F.C.M. + 0.08 L.W.$^{0.73}$ + 3.0 L.W.I.

†*Feeds and Feeding*, 22nd edition.

NOTE: In calculating actual T.D.N. and S.E. consumptions, 1 lb of D.O.M. has been assumed equivalent to 1.04 lb of T.D.N. or 0.92 lb of S.E.

Table 2 gives the actually measured intakes expressed in terms of D.O.M., T.D.N. and S.E. Intakes calculated by the "reverse" use of the *Rations for Livestock*, Morrison, and Ruakura feeding standards are shown for comparative purposes. In estimating requirements by the Woodman and Morrison (22nd edition) standards, no allowance has been added for the weight gains, as cattle fed according to the recommended allowances are usually expected to remain in normal condition. Any adjustments for weight gains would, in fact, be small and not greatly affect the figures given in the table. Morrison does propose an additional allowance for milking heifers and 3-year-olds, but, even were an attempt made to correct for this, the upward adjustment would not amount to more than about a pound of T.D.N. per day.

In Table 2, to make comparison easier, the values estimated by reverse use of the feeding standards have been expressed as a percentage of the experimentally determined figures. It may be noted that, whereas the Ruakura provisional standards have over-estimated intake in terms of D.O.M. by 19%, the Morrison standards have under-estimated them in terms of T.D.N. by about 20%, while the *Rations for Livestock* standards have under-estimated S.E. consumption by almost 30%. In this connection it is of interest to note that Blaxter (1956) considers the British standards to be lower than the American, and that they should be upgraded by about 10%.

In order to ascertain how the feed consumed by the experimental cows was utilized for maintenance and production purposes, the regression of D.O.M. intake on the three variables, F.C.M. production, $L.W.^{0.73}$ and weight gain, has been calculated using the average values obtained for each cow over the 24-week period. The regression equation is shown below:

$$D.O.M. = 0.33\, F.C.M. + 0.063\, L.W.^{0.73} + 2.0\, L.W.I.$$

where D.O.M. = Average daily intake of D.O.M. (lb)

F.C.M. = Average daily F.C.M. production (lb)

$L.W.^{0.73}$ = Liveweight raised to the power of 0.73

L.W.I. = Average daily liveweight increase (lb)

The above equation was calculated by pooling the information obtained for both the *ad lib.* and the restricted cows during the two seasons, and is thus based on a total of 36 sets of observations. The regression coefficients for F.C.M. and $L.W.^{0.73}$ are both significant at the 1% level and that for the L.W.I. at the 5% level.

TABLE 3: COMPARISON OF ALLOWANCES PROPOSED BY DIFFERENT FEEDING STANDARDS

Feeding Standard	*Environmental Conditions*	*Allowance (lb) for: Production 1 lb F.C.M.*			*Maintenance of 1,000 lb cow*		
		DOM	*TDN*	*SE*	*DOM*	*TDN*	*SE*
Ruakura	Free-grazing	0.35	0.36	0.32	12.4	12.9	11.4
Ruakura	Stall fed—part time outdoors	0.33	0.34	0.30	9.8	10.1	9.0
Morrison*	Stall fed indoors		0.32			7.9	
Woodman†	Stall fed indoors			0.26			6.0

*22nd edition. †Bulletin 48.

If factors of 1.04 and 0.92 respectively are again used for converting D.O.M. units to T.D.N. and S.E., it may readily be calculated that the 0.33 lb D.O.M. which the above equation indicates as necessary for the production of a pound of F.C.M. is equivalent to 0.34 lb of T.D.N. or 0.30 lb of S.E. Similarly the coefficient of 0.063 for L.W.$^{0.73}$ in the equation implies that the daily maintenance requirement of a 1,000 lb cow is approximately 9.8 lb of D.O.M., equivalent to 10.1 lb of T.D.N. or 9.0 lb of S.E.

It is of considerable interest to compare these allowances for maintenance and production with those indicated by the

TABLE 4: AGREEMENT BETWEEN ACTUAL AND PREDICTED D.O.M. INTAKES OF INDIVIDUAL COWS

1958-59		*1959-60*	
Actual (lb/day)	*Predicted (lb/day)*	*Actual (lb/day)*	*Predicted (lb/day)*
17.51	17.10	19.12	18.58
16.96	17.29	19.00	18.08
16.81	15.79	18.59	17.53
16.79	16.12	18.54	19.12
16.56	15.09	18.24	17.43
16.49	17.29	17.75	18.58
16.27	14.91	17.66	16.98
16.05	16.98	16.86	16.86
15.97	16.96	15.74	15.26
15.64	15.98	15.70	16.58
15.47	15.38	15.69	16.85
15.10	14.17	15.17	15.26
15.03	15.50	15.03	16.07
14.66	14.81	14.94	13.50
14.47	14.71	14.41	15.81
13.29	13.69	14.03	13.56
		13.93	13.98
		13.75	13.76
		13.50	13.63
		12.69	13.99

Ruakura equation for free grazing cows, as well as with those proposed in the commonly accepted feeding standards. The relevant data are summarized in Table 3.

It may be seen that the allowances indicated by the new equation relating to cattle fed pasture in stalls are considerably lower than those derived from the equation previously developed for free-grazing cattle. However, they are—particularly in the case of maintenance—well above those proposed by either the Morrison or the Woodman standards.

The equation given above has been used to predict the average intakes of the individual animals from their mean liveweight and production data, and the degree of agreement between these predicted values and the actual intakes is illustrated in Table 4. The equation enables intakes of the individual animals to be predicted with a coefficient of variation of 5.3%.

The changes in average liveweight and production that occurred over the 24-week period are illustrated in Fig. 2, which also shows how average intakes fluctuated.

To test the general usefulness of the equation at different stages of the season it has been used to predict the average level of consumption of the cows during successive weeks of the 24-week period, and Fig. 3 shows how these estimates compare

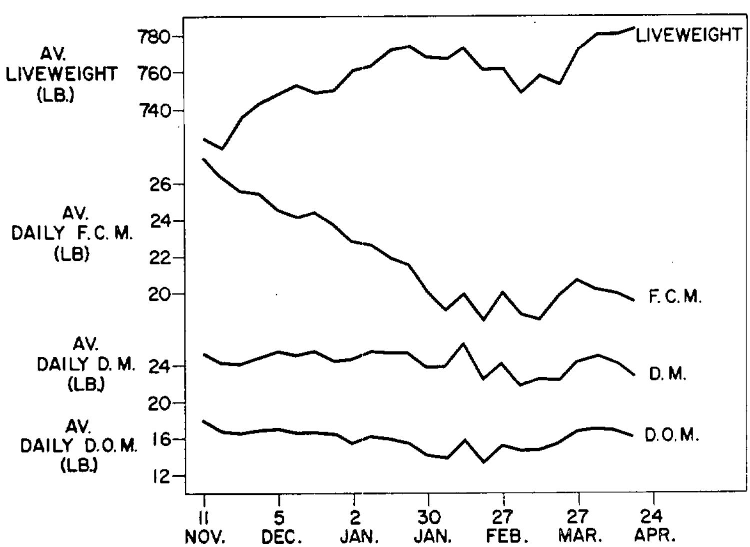

Fig. 2: Mean daily liveweight, production, D.M., and D.O.M. intake for stall-fed cattle during successive weeks.

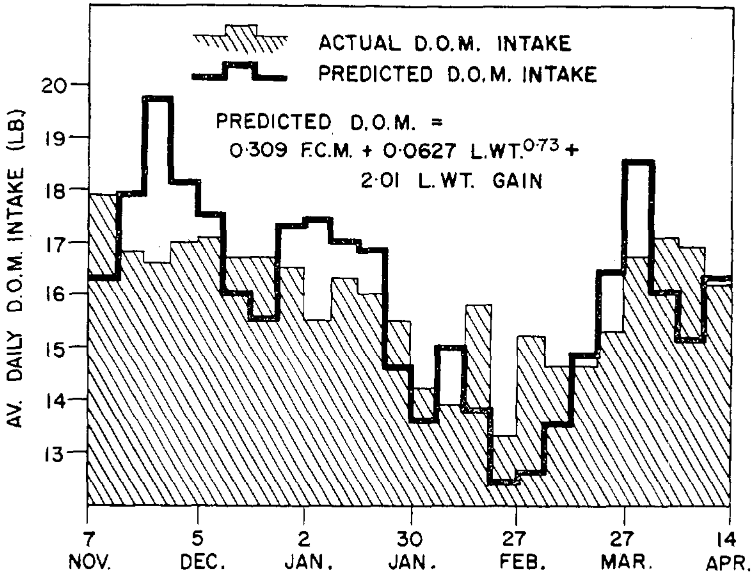

Fig. 3: Comparison of actual and predicted intake of stalled cows during successive weeks.

with the mean intakes actually recorded. It is particularly satisfactory to find that the predicted and actual values follow the same general trend, with actual D.O.M. intakes tending to follow the changes in herbage quality (Fig. 1), falling off during November, December and January, and reaching their lowest levels in February but rising thereafter during March and April.

Most of you will appreciate the very real problems involved in determining accurately the true bodyweight gains of cattle, particularly over short periods of time, owing to variations in the contents of udder, bladder and alimentary tract. It is considered that the rather erratic discrepancies between predicted and actual intakes that occurred from one week to another are due to errors in estimating liveweight changes. In Fig. 4 the weekly differences between actual and predicted intakes have been plotted against the weekly weight changes, and clearly there is a real relationship between the two variables of such a nature that predicted intakes were usually too high during weeks when the animals gained weight, and too low during weeks in which liveweight fell. From this it appeared that in predicting intakes over short periods such as a week, more accurate results might be obtained by a regression equation that contained only two inde-

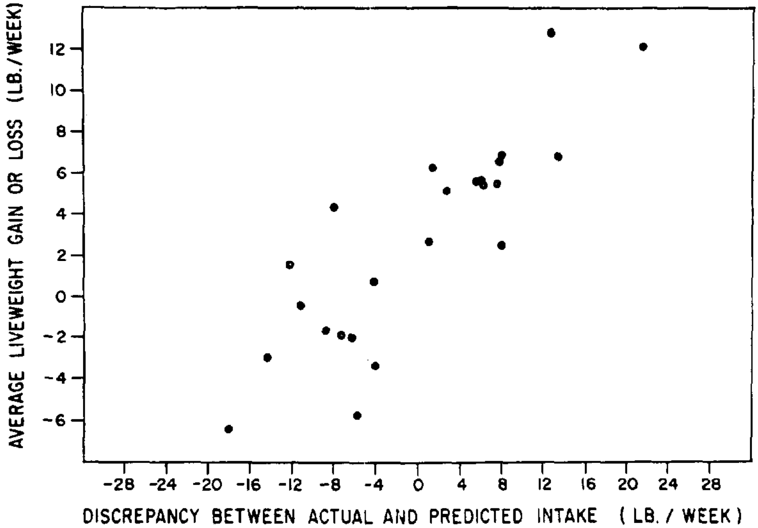

Fig. 4: Relationship between weekly liveweight changes and discrepancies between actual and predicted intake.

pendent variables—F.C.M. and L.W.$^{0.73}$. When liveweight gains were omitted from consideration in this way, the following equation was derived from the mean values of the 36 animals:

D.O.M. = 0.27 F.C.M. + 0.08 L.W.$^{0.73}$

Figure 5 shows how average weekly D.O.M. intakes predicted by use of this equation agree with the actual values. Many of the rather erratic week-to-week discrepancies are eliminated, but the equation clearly tends to over-estimate intakes during the period in mid-summer when D.O.M. intakes were in fact low and the cattle were consistently losing weight.

In comparing the results obtained at Ruakura with those of other workers, the main differences that stand out are, first, the higher values for maintenance given by the equation, and secondly, the fact that it has been possible to relate D.O.M. intake not only to liveweight, but also to milk production.

It must be appreciated that the feeding standards themselves rest upon an experimental basis of some slenderness, and that no claim is made that the statements of requirements are accurate or precise. Woodman (1936, 1948), for instance, described them merely as "guides to feeding practice" and Morrison (1957) states that they "can be only approximate guides." The standards have in fact been modified from time to time.

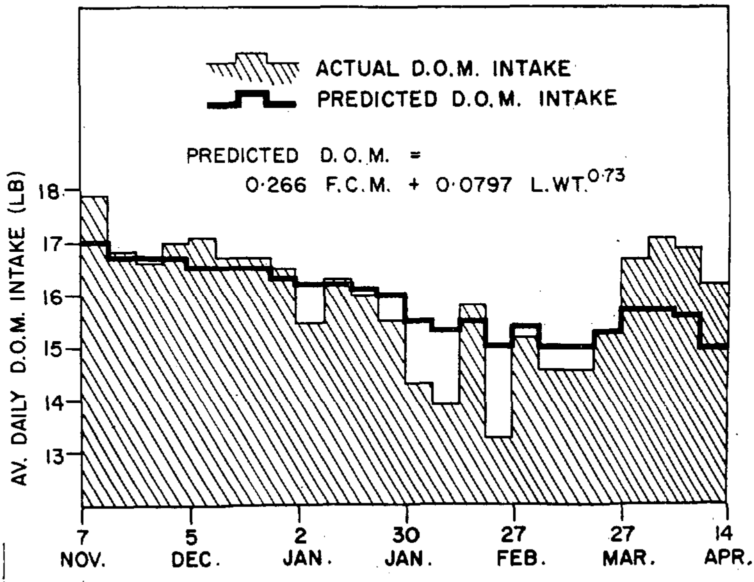

Fig. 5: Comparison of actual and predicted intake of stalled cows during successive weeks.

Other points which must be considered in relation to the high values obtained for maintenance at Ruakura are the nature of feed used, the techniques adopted in measuring intakes, and the method employed in apportioning intake between maintenance and production. It is generally admitted that the digestible nutrients of fibrous feeds, such as pasture, provide proportionately less net energy than do those of carbohydrate concentrate feeds which are commonly fed in quantity to stalled cattle. Thus, on pasture diet proportionately more digestible nutrients will be needed to support an animal of any given level of liveweight or production.

There is no reason to suppose that intakes were overestimated in the stall feeding trials, but it is certainly not impossible that the chromium-faecal nitrogen methods used with the free grazing animals gave biased estimates. For instance, in calculating intakes it was assumed that all the chromium fed appeared in the faeces, and that the concentration of chromium determined from the bulked grab samples taken at the morning and evening milkings was truly representative of the mean concentration of chromium in the whole faeces. Subsequent work suggests that some small loss of chromium may have occurred during the milling of the dried faeces, which would have resulted in faecal outputs, and hence intakes, being over-estimated. Further, it now seems probable that application of Lancaster's original equation (Lancaster, 1954), which was used for deriving intake factors from faecal nitrogen concentrations, may well have resulted in some over-estimation of intake during periods when the pastures were of comparatively low digestibility.

In the Ruakura investigations, the multiple regression technique was employed to estimate the proportion of the feed eaten which was associated with liveweight, milk production and liveweight increase. The Ruakura estimate for maintenance is thus one which refers only to lactating cows liberally supplied with pasture and permitted to eat to appetite. Morrison's maintenance standards, on the other hand, were arrived at in a very different way. They are based on results obtained by Haecker, who conducted stall feeding trials over several years and determined the nutrients needed to maintain dry cows at more or less constant weight over extended periods.

It is well known that when intake is increased the efficiency of feed utilization falls. Digestibility is depressed to some extent, and with pasture, Dr Hutton (pers. comm.) has found that accompanying this fall in digestibility is a diminution in the energy content of each unit of the apparently digested nutrients. The percentage net availability of the metabolizable energy is also known to decline with increased feed intake (Blaxter, 1950). The over-all effect of increased intake is thus a considerable depression in the net availability of the gross energy—an effect which has been clearly demonstrated with cattle by Forbes *et al.* (1928, 1930) and Mitchell and Hamilton (1932). As a result, even if net energy requirements for maintenance were in no way increased by lactation, a higher digestible nutrient intake would in fact be required to supply maintenance needs. These aspects have not been given the consideration they deserve by those who have expressed surprise at the high maintenance requirements indicated by the Ruakura equation.

If these points are considered, only part, and perhaps a fairly small part, of the increase in maintenance requirements above those of the conventional standards need be ascribed to additional energy expended during grazing.

As to milk production, it is noteworthy that, in the stall feeding trials, as in earlier work with free grazing animals, it has proved possible to establish highly significant relationships, not only between the level of intake of the animals and their liveweights, but also with the amount of milk produced. Many workers have been able to show the dependence of intake upon liveweight, but not all have been able to demonstrate that milk production also plays a governing part. Corbett (1960), for instance, tried to develop a regression equation relating intake with liveweight, milk production and weight changes, but found that only liveweight gave useful information. Ivins (1959) goes so far as to state that "to use figures for milk production or liveweight gains as measures of grassland output to a great extent implies that consumption of herbage by the animal is directly related to the level of production, and unfortunately this does not prove to be so." Needless to say, the present author cannot agree with this.

Failures to establish useful relationships between the intake of nutrients from pasture and the liveweight and production performance of dairy cattle appear to stem mainly from the use of inadequate data. When a few animals are studied over comparatively short periods, experimental errors may quite obscure the true relationships that exist.

In a paper delivered at a recently held International Grassland Congress, Corbett (1960) has criticized the Ruakura equation for estimating the intake of free-grazing cattle and described experiments conducted at the Rowett Research Institute which, he claims, failed to show any marked increase in animal's maintenance costs during strip grazing compared with indoor feeding. Indeed, his calculations suggest that the maintenance costs of his milking cows were some 21% higher indoors than out, a result sufficiently surprising to make one question the general reliability of the data presented.

Nevertheless, it must be stressed that the Ruakura equation refers to cows abundantly supplied with pasture of high quality. The extent to which efficiency of food conversion can be improved by restriction of intake is a matter still under investigation. Dr Hutton (pers. comm.) already has clear evidence that, at least with cows fed pasture in stalls, efficiency can be improved by imposing some degree of restriction.

In the past many attempts have been made to relate pasture output, in terms of utilized nutrients estimated from animal production data, to utilized outputs estimated from herbage sampling techniques, applied to the same pastures. Usually substantial discrepancies have been found and herbage yield estimates have considerably exceeded estimates based on animal nutrient requirements (MacLusky, 1959). On the basis of the Ruakura findings this is not in the least surprising.

All will agree that we still know only too little about the general level of efficiency with which cows convert pasture to saleable dairy produce, but at least the problem is one that is being actively attacked.

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