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NUTRIENT REQUIREMENTS OF NEW ZEALAND DAIRY CATTLE

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AT THE 21st Conference of this Society, Wallace (1961) summarized available information on the feed consumption of milking cows fed to appetite throughout their lactations on grazed or cut herbage. In the following two years, further data were added (Hutton, 1962a, 1963) and, in two of these publications, attempts were made to determine for pasture herbages the quantities of nutrients required separately for maintenance and production. These involved using least squares analysis to partition between-cow variance in mean digestible organic matter intake (DOMI), between milk yield, expressed as fat corrected milk (FCM), maintenance which was assumed to be proportional to $LW^{0.73}$, and liveweight change (LWC).

Compared with estimates of feed requirements derived from the overseas feeding tables of Morrison (1957), N.R.C. (1956), Woodman (1948) and Evans (1960), invariably intakes of pasture-fed animals appeared excessively large. Because these biases applied both to grazed and stall-fed cattle, they could not be attributed primarily to energy costs of grazing and locomotion. Rather it appeared digestible nutrients from pasture were less efficiently used by dairy cows than those provided by alternative, equally digestible fodders, and results of the regression analyses were interpreted by some as showing that pasture-fed dairy cows had particularly high maintenance requirements.

Further information on the intake of grazed cattle has been obtained at Ruakura during the past five years, specifically under conditions of extremely intensive grazing management. During this period also, tables of feed requirements and estimates of the feed values of many common fodders have been revised in the United Kingdom (A.R.C., 1965) and in the United States (N.R.C., 1966). In addition, a considerable amount of data specific to dairy cattle has been published by the USDA from its Energy Metabolism unit at Beltsville (Flatt *et al.*, 1965a, b,

TABLE 1: STANDARD CONVERSION FACTORS APPLIED TO ALL ESTIMATES OF FEED REQUIREMENTS

1. *Feed:*	
1 kg pasture herbage dry matter	= 4.4 Mcal Gross Energy
	= 3.1 Mcal Digestible Energy
	= 2.6 Mcal Metabolizable Energy
1 kg pasture herbage digestible organic matter	= 4.5 Mcal Digestible Energy*
	= 3.8 Mcal Metabolizable Energy
	= 1.02 kg Total Digestible Nutrients
	= 0.89 kg Starch Equivalent
2. *Milk:*	
1 kg 4% fat corrected milk	= 0.75 Mcal Net Energy†
3. *Metabolic Body Size:*	
Metabolic body size	= liveweight$^{0.75}$‡
4. *Liveweight Change:*	
1 kg liveweight change (LWC)	= 3.5 Mcal Net Energy§

*Hutton (1963).
†Overman and Gaines (1933).
‡Kleiber (1964).
§Ellenburger *et al.* (1950).

TABLE 2: ESTIMATES OF ENERGY REQUIREMENTS FOR INDIVIDUAL PRODUCTIVE FUNCTIONS

	Source of Data		
Function	*N.R.C. (1966)*	*A.R.C. (1965)*	*USDA (1967)*
1. Maintenance (m)			
[Mcal ME/kg LW$^{0.75}$/day]	0.120	0.097	0.110*
			0.148†
2. Lactation (l)			
[Mcal ME/kg FCM]	1.20	1.07	1.14
3. Pregnancy (p)			
(i) [Mcal ME/kg LW$^{0.75}$/day]	0.216	0.122	0.140
(ii) Total Mcal‡	640	200	240
4. Locomotion (a)			
[Mcal ME/100 kg LW/mile walked]		0.108	
5. % efficiency of conversion of ME (k)			
k_m	75	73	66
k_l	62	70	66
k_{t+} (body tissue gain)	55	52	66
k_{t-} (body tissue loss)	70	70	66
k_p	—	25	25
k_a	—	73	—

*Non-lactating, non-pregnant cow.
†Lactating non-pregnant cow.
‡ME additional to maintenance needs of a 340 kg non-pregnant cow.

1967a, b, c). This paper will be limited therefore to examining the extent to which the new information can assist with providing an explanation of the differences in energy requirements described, and a somewhat sounder basis than is available at present from which to prepare lists of feed requirements and feed values applicable to pasture-fed milking cows. Since many of the results appearing in this presentation have been derived from experiments made in New Zealand, this approach is preferred to a more comprehensive examination of nutrient needs of dairy young stock and mature dairy cows, including protein, minerals and vitamins as well as energy, for this would depend very heavily upon overseas data (see A.R.C., 1965; N.R.C., 1966; Cuthbertson, 1969).

Both the British and North American tables of feed requirements depend on factorial expression of these, and the recent revisions have produced some changes in estimates of the quantities of energy required for maintenance, and various productive functions. These will be considered as they appear in the N.R.C. (1966) and A.R.C. (1965) publications and included also will be the more recent data of Flatt *et al.* (1965a, b, 1967a, b, c). Subsequently, intakes predicted by applying these standards to previously published and some unpublished performance data from lactating and non-lactating cows will be compared with the pasture herbage intakes of these animals estimated indirectly in the field by the faecal Cr_2O_3–nitrogen, or faecal Cr_2O_3–*in vitro* digestibility methods, and measured directly under conditions of stall feeding.

To facilitate comparisons between feeding standards and to enable these final calculations to be made, a series of common conversion factors has been derived and is presented in Table 1. These are means appropriate to pasture herbage available on average during the year.

Table 2 is a summary of the main feed requirements for lactating and pregnant dairy cows included in each set of feeding standards.

N.R.C. ESTIMATES OF FEED REQUIREMENTS

These are now expressed in metric units and include requirements expressed as metabolizable energy (ME).

MAINTENANCE

At 120 kcal ME/kg $LW^{0.75}$/cow/day this remains unchanged near the upper limit of most measurements made in respiration chambers with non-lactating dairy cattle (van Es, 1961; van Es and Nijkamp, 1966; Flatt and Coppock, 1965; Flatt *et al.*, 1965a, b; Hashizume *et al.*, 1964). It includes an activity allowance for stalled but not for grazing cows, which authors of the N.R.C. bulletin suggest may require 25 to 100% more energy depending upon the level of activity.

Lactation

Quantities of nutrients per kg milk have been raised with increasing production. Thus cows producing less than 20 kg (FCM) daily receive 1.20 Mcal ME/kg 4% milk, slightly more than the previous standard allowance (1.17 Mcal ME). For those yielding 20 to 35 kg and more than 35 kg, allowances increase by 12 and 25%, respectively. This is to adjust mainly for the marked depression of ration digestibility which occurs with high producing cows fed high grain and medium-low roughage diets (Moe *et al.*, 1965). Because plane of nutrition has a much smaller effect on apparent digestibility of pasture herbage than with most rations available in the feedlot, this effect is much less significant in the New Zealand environment.

Pregnancy

Pregnancy allowances prescribe an 80% increase in the maintenance ration during the last 60 to 90 days of pregnancy. This is for pre-partum "steaming up" or challenge feeding in addition to meeting the needs of the foetus, the increased basal metabolism of the pregnant cow and mammary gland growth. The extra energy required for foetal growth alone is relatively small. Eckles (1916) has estimated that the 6.8 to 9.1 kg DM comprising the Jersey calf and accompanying tissues and fluids is equivalent in energy content to 50 to 77 kg of Jersey milk. Accepting the efficiency of conversion of ME for reproduction is 25% (van Es, 1961), this requires approximately 220 Mcal ME, equal to the maintenance needs of a dry 340 kg cow for only 3 weeks. Table 2 shows that, for a 340 kg cow increasing to 380 kg liveweight at term, the N.R.C. allowance is nearly 3 times this quantity of extra nutrients.

A.R.C. Estimates

The recent revisions of the energy requirements of dairy cows (A.R.C., 1965) have not changed very greatly the means of assessing or the magnitude of estimates of the nutrient needs of pasture-fed cows. In contrast to the tables of Woodman (1948) and Evans (1960), requirements are expressed as net energy (NE), and feedstuffs are described in terms of metabolizable energy (ME). These are used with indexes of the efficiency of conversion of ME for maintenance (k_m), body tissue gain (k_{t+}) and loss (k_{t-}), milk secretion (k_l) and gestation (k_g), which vary with the ME content of the ration, to calculate daily feed requirements as ME and these can then be converted to weight of dry or fresh fodder. As with the N.R.C. standards, adjustments are made to the percentage metabolizability of the ration according to varying planes of nutrition. These are applied to liveweight gain as well as lactation.

Maintenance

A mean fasting heat production of 71 kcal/kg $LW^{0.75}$ has been accepted. This is essentially the same as Woodman's earlier starch equivalent value, and on a diet of average pasture herbage (Table 1) represents a requirement of 97 kcal ME/kg $LW^{0.75}$ daily, approximately 80% of the comparable requirement included in the N.R.C. tables. This difference arises from the use of alternative methods for determining maintenance needs; one depending on fasting heat productions (A.R.C.), the other on heat productions of non-lactating cows at zero energy balance (N.R.C.).

For grazing cattle, an additional allowance is made for the energy expenditure associated with walking equal to 79 kcal NE/100 kg LW per mile. For Jersey cows of 340 kg average liveweight walking 2 to 3 miles daily, this increases the estimated daily maintenance requirement to 100 kcal ME/kg $LW^{0.75}$.

Lactation

For most diets fed to milking cows, (k_l) varies between 61 and 70%, being at its highest for rations ranging between 2.2 and 3.0 Mcal ME/kg DM. As most dairy pastures fall within these limits, the estimated ME requirement for milk (1.07 Mcal/kg FCM) is appreciably lower than advocated by the N.R.C.

Tissue Gain and Loss

Dairy cows invariably lose weight in early lactation and regain it either in late lactation or during the dry period.

The compilers of the N.R.C. and A.R.C. tables consider the efficiencies of these energy transformations are similar for lactating and non-lactating animals. For tissue gain they vary between 44 and 58% for rations containing 2.2 to 3.0 Mcal ME/kg DM (A.R.C.) but the mobilization of body reserves of energy (tissue loss) is considered relatively efficient at about 70%. Although N.R.C. estimates for milking cattle do not specify additional amounts for liveweight gain during lactation, comparisons of the total daily requirement of growing heifers and mature cows of similar liveweights show a k_{t}- coefficient of 50 to 55%.

Pregnancy

Pregnancy requirements are considered covered by increasing the level of feeding above maintenance by 5% 3 months pre-partum, and making, successively, increases of 17% one month later and of 45 and 50% in the last two fortnightly periods before calving. For Jersey cows of 340 kg liveweight, the additional feed is equivalent to 180 to 200 Mcal ME.

ESTIMATES OF USDA WORKERS AT BELTSVILLE, MARYLAND

A series of very comprehensive energy balance studies with dairy cattle have been presented by workers at Beltsville (Flatt and Coppock, 1965; Flatt *et al.*, 1965a, b, 1967a, b, c).

Maintenance

Estimates of maintenance have been made with non-lactating non-pregnant, non-lactating pregnant and lactating cows. Those in the first two categories generally have been fed estimated NE sufficient to maintain zero energy balance. Maintenance requirements are calculated by adjusting total heat productions for any small positive or negative energy balances which occur, and alternatively by estimating the regression of total energy balance on ME intake when each has been expressed relative to metabolic body size. As shown in Table 2, for non-lactating, non-pregnant cows the mean of all data is 110 kcal ME/kg $LW^{0.75}$, about mid-way between the N.R.C. and A.R.C. estimates.

This statistical approach to the estimation of maintenance requirements was extended by these workers (Flatt *et al.*, 1967c) to trials on especially selected high producing Friesian cattle. Cows were fed rations varying widely in roughage to grain ratios, but with similar apparent digestibilities to average and high quality pasture herbages, and energy balances were made in early, mid and late lactation. The average intake for all trials was 294 kcal ME/kg $LW^{0.75}$ or 2.7 times the maintenance requirement of a non-pregnant non-lactating cow. Energy balances comprising milk yield and either body tissue loss or gain, and ME intake were both calculated per unit metabolic size. As in previous studies, the relationships between the two variables were established by two linear regressions in which each was treated successively as the independent and dependent term.

These equations are:

$$\text{EB/kg } LW^{0.75} = 0.66 \text{ ME/kg } LW^{0.75} - 93.1$$

and $$\text{ME/kg } LW^{0.75} = 1.45 \text{ EB/kg } LW^{0.75} + 148.2$$

They are both linear for a complete range of situations in which at one extreme lactating cows were catabolizing on average 10 Mcal of energy per day as body tissue and at the other regaining this at the rate of 7 Mcal/day. These relationships have been interpreted as showing that, for the lactating cow and for rations of comparable digestibility, the efficiency with which ME is used for most productive functions is virtually constant. As shown in Table 2 for the experiments reported, the common *k* value was 66%, and the estimated maintenance requirement of the milking cows at zero energy balance, 148 kcal ME/kg $LW^{0.75}$. The latter is 53% and 23% higher than the respective maintenance estimates provided in the A.R.C. and N.R.C. tables, and must be attributed to a generally increased rate of metabolism during lactation. The common *k* value denotes that lactating cows convert ME to body fat and protein at an appreciably lower energy cost per kg than do fattening cattle, and that this transformation of energy can be as efficient as the production of milk, the catabolism of body tissue, and the utilization of ME for maintenance.

Milk Production

The nutrient requirement for milk is 1.14 Mcal ME/kg FCM, mid-way between the A.R.C. and lowest N.R.C. estimates.

Pregnancy

Flatt *et al.* (1967a) used techniques similar to those reported for non-lactating cows to measure the feed require-

TABLE 3: DETAILS OF THE GROUPS OF COWS STUDIED DURING LACTATION AND COMPARISONS OF ACTUAL WITH ESTIMATED INTAKES

Author	*Trial*	*Year*	*No. of Animals*	*Period (wk)*	*FCM (kg/day)*	*LW (kg)*	*LWC (kg/day)*	*ME/ Mcal/day*	*ME/kg* $LW^{0.75}$	*Intake Differences (Actual — estim.) Mcal ME/day* A.R.C.	N.R.C.	USDA
Wallace (1956)	Twin uniformity	1948-9	30	32	7.17	350	0.277	29.7	366	11.5	9.7	7.2
	HP post-calving	1950-1	22	26	10.07	356	0.272	33.5	409	12.1	8.9	7.6
	LP post-calving		22		8.62	329	0.236	30.9	400	11.8	8.9	7.6
	HP pre- & post-calving	1951-2	22	20	11.11	360	0.386	36.4	440	13.0	9.7	8.6
	LP pre- & post-calving		22		9.21	318	0.358	33.0	438	12.7	9.8	8.7
	HP pre-calving	1952-3	19	32	10.52	394	0.299	39.0	441	16.2	12.8	11.4
	LP pre-calving		19		9.75	442	0.336	38.5	399	15.4	11.9	10.3
	Jersey	1953-4	16	18	8.35	359	0.318	34.7	421	14.8	11.8	10.4
	Friesian		14		16.69	495	0.345	51.7	493	20.2	15.6	14.1
	Jersey	1954-5	16	22	13.88	375	0.136	40.4	474	15.5	11.7	10.4
	Friesian		15		16.69	518	0.222	49.4	455	18.3	13.6	11.9
Wallace (1961)	Twin cows stall fed cut grass	1958-9	16	24	9.53	341	0.209	27.4	345	8.1	5.0	3.7
	Twin cows stall fed cut grass	1959-60	20	24	10.25	347	0.150	27.8	346	8.0	4.8	3.4
Hutton (1963)	Twin cows stall fed cut grass	1960-1	6	36	14.06	330	0.001	30.0	387	7.4	3.8	2.5
	Twin cows stall fed cut grass	1961-2	7	36	15.15	361	0.098	32.1	388	7.4	3.6	2.4
Hutton (1968)	Grazed twins	1965-6	36	37	10.73	330	0.143	26.3	340	5.6	2.4	1.1
	Grazed twins	1966-7	36	41	12.67	348	0.236	28.5	354	4.7	1.2	0.1
	Grazed twins	1967-8	36	37	12.26	340	0.089	23.4	293	1.1	— 2.3	— 3.7

ments of cows over the period 100 to 247 days of pregnancy. The added energy expenditure associated with foetal growth and increased basal metabolism of the cow were equated by a 27% increase in the maintenance requirement during the period 70 to 30 days pre-partum and a further increase to 54% in the final 30 days. The additional nutrients involved were estimated as 240 Mcal ME for a 340 kg cow.

INTAKE OF PASTURE FEEDSTUFFS DURING LACTATION AS ESTIMATED FROM FEEDING TABLES

Table 3 summarizes the results of applying the three sets of independent standards (see Table 2) to the prediction of intake of cattle either grazed or stall-fed on pasture herbage in a wide range of experiments made at Ruakura. Differences between the actual feed intakes and those estimated by applying each set of factors are given. The closest agreement is with the USDA, and the worst with the A.R.C. standards. Although the intakes reported by Wallace (1956) for grazing cattle continue to differ markedly from any of the estimates, agreement between sets of data which include the more recent stall-feeding and grazing trials, is relatively good. Grazing management experiments are now made at much higher carrying capacities than previously, and the lower mean liveweights and liveweight changes in Table 3 which relate to these conditions reflect to some extent the reduced individual cow intakes compared with those obtained in earlier trials. As a consequence of the less stringent grazing practised at Ruakura in the period 1948-55, these data suggest that at that time feed intake for most of the lactation period was approximately four times the maintenance requirement of a dry cow. These are high levels but are achievable by cows fed to appetite and this should be acknowledged by those who in the past have questioned the accuracy of these data.

In the more recent field studies, individual cow intakes have fallen to 3 to 3.5 times maintenance, and this is similar to the data contained in Table 3 for 1958-59 and 1959-60 relating to stall-fed cows of which 40% were exposed to some degree of feed restriction.

Even at this level they exceed considerably the relative intakes of the milking cows included in energy balance studies to date. For these, intakes have not exceeded three times maintenance, and since there is some evidence with lactating goats that heat production can increase at a proportionately faster rate than ME intake (Armstrong and Blaxter, 1965), it is conceivable that, under conditions of extremely high intake, a comparable response might account for at least part of the discrepancy between the measured intakes of Wallace (1956) and the quantities predicted from feeding tables.

FEED INTAKE AND REQUIREMENTS DURING THE DRY PERIOD

Data contained in Table 4 describe the duration of the dry period, mean liveweights of cows during this time, and the quantities of feed consumed in each of three years of the intensive grazing and management experiment referred to previously in Table 2. Between 13 and 21% of total ME was consumed during the dry period.

TABLE 4: FEED CONSUMPTION DURING THE DRY PERIOD OF GRAZED DAIRY COWS

	Length of Period (days)	*Total Feed (Mcal ME)*	*% of Annual ME Intake*	*Mean LW (kg)*	*kcal ME/kg $LW^{0.75}$*
1965-6	103	1,800	21	351	217
1966-7	76	1,250	13	377	194
1967-8	107	1,450	19	354	165

Compared with the A.R.C. and USDA estimates, the intake of ME/kg $LW^{0.75}$ appears particularly high. There are several reasons for this, probably the most important being the practice in summer and autumn of continuing to graze with the milking herd those cows which dried-off first, since, until about 25% of the cows had ceased lactating, they represented an inconveniently small group to manage separately. During this time these cows ate appreciably more than their maintenance ration. Second, winter management practices which require on-and-off grazing appear to increase the errors of estimating faecal outputs with indigestible markers and usually cause an upward bias in estimates of intake. However, on-off grazing is frequently unavoidable in wet weather. Third, the estimates of requirements derived from feeding tables have been made under conditions of stall feeding or energy balance. In practice, pregnant cattle are frequently exposed to wind, rain and cold and A. D. H. Joblin (unpubl.) has shown with fattening cattle under environmental conditions similar to those experienced in the present trial a 20% increase in winter feed requirement associated with feeding some cattle out of doors as contrasted with others in an enclosed barn. By taking account of these factors it should prove practicable to reduce the mean 95-day requirement from 1,500 to 1,350 Mcal ME. Of this, 300 Mcal represents the requirement for foetal growth and increased metabolism of the pregnant cow.

CONCLUSIONS

During the past decade little additional has been learned to help explain the large differences which Wallace (1956) found between the measurements of intake he made with grazing cows and estimates of dairy cattle needs derived from standard feeding tables. However, under the altered conditions of much higher stocking rates and more intensive systems of grazing management now being used, and with stall feeding, sufficiently close agreement has been achieved amongst various sets of comparable data to justify placing much greater confidence than previously in the practicability of deriving feeding standards, which will have application to grassland feedstuffs, and successfully using them at least with dairy cattle under grazing conditions.

Based on 3 years' experimental data, the mean daily feed consumption of cows grazed the year round at an average stocking rate of 1⅔ to 2 milking cows per acre on typically highly productive pastures was 329 kcal ME/kg $LW^{0.75}$ during a 270-day lactation period. In total this is equivalent to 7,050 Mcal ME or 2,712 kg pasture dry matter, and enabled an average group of twin cows to produce 3,210 kg FCM. The energy transformations involved resulted in a 34.5% mean efficiency of conversion of the ME. This compares with 33.5% recorded by Flatt *et al.* (1967b) with their select group of high producing Holsteins. Since these cows averaged 6,959 kg of milk and 290 kg fat during the lactation period in which the energy balances were made, the comparison reflects great credit both on the ability of average New Zealand Jersey crossbred cows to convert pasture DM to milk energy and on the capacity of this feedstuff to sustain such a high level of efficiency. By including 1,350 Mcal ME for the dry period, the average annual requirement of these grazing cattle is raised to 3,230 kg pasture DM and for the year establishes a requirement of 1 kg DM/kg FCM or 25 kg DM/kg butterfat.

Thus an acre of highly productive land yielding 6,250 kg utilized DM/acre/annum can be expected to yield 250 kg butterfat if grazed with average milk producers such as were used in the present trials.

These are useful averages from which workable tables of feed requirements can be assembled. To find greatest application, however, tables of feed requirements must try to take account increasingly of all factors which determine variations in animal response. This is particularly important in a grassland environment where feed supply and use are not easily controlled, where the number of economically usable alternative fodders is not large, and within which decisions made, and responses obtained in consequence at critical periods in the productive cycle of plant and animal, determine the level of productivity within and often between years.

Appreciation and investigation of these important interactions will increase the value of feed input-animal response studies providing data of use in a wide range of on-farm situations, and will help to avoid criticisms frequently voiced overseas that energy requirements estimated synthetically by the factorial approach do not agree entirely with results obtained under more practical conditions.

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