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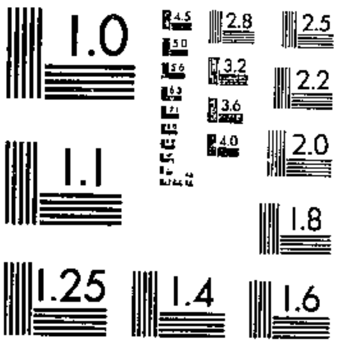

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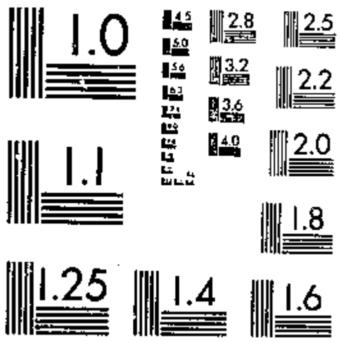

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NATIONAL BUREAU OF STANDARDS-1963-A

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Energy Requirements of Beef Calves for Maintenance and Growth

by

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INTRODUCTION

The energy costs of maintenance and of growth of farm animals ordinarily have not been treated in the past as entities in reports of nutrient requirements. Feed requirements for maintenance plus growth at modal rates of gain, on the other hand, have been well defined (*7, 9*).[2] It is of practical importance that such requirements be known, and also that it be possible to predict, with some degree of accuracy, what will happen to young animals if they subsist on whatever feedstuffs happen to be available, plus, in some cases, supplementary feed.

Under range conditions, many beef calves are forced to spend much of the winter season, or several months during and following a drought, at or near the maintenance level of feed intake. In view of this fact, a knowledge of the energy requirements of young beef cattle for *maintenance* is important. This report represents an attempt to supply some of this needed information.

The maintenance requirement of an animal may be defined as the energy cost of normal nonproductive metabolic processes. In this study, however, maintenance is regarded as the energy utilized by an animal while body weight remains constant. Obviously, the latter definition implies that the energy cost of daily activity, such as

[1] Submitted for publication March 25, 1953.
[2] Italic numbers in parentheses refer to Literature Cited, page 18.

walking and chewing, is part of the cost of maintenance. Such energy costs constitute perhaps 5 percent of the total energy required to maintain constant body weight.

When a young, growing animal is kept essentially in a resting state, the only concerns are the requirements for maintenance and for growth. But even in this rather simple situation it is not an easy task to estimate the fraction of feed intake used for each of these two purposes. Estimates of maintenance requirements of animals of a given size have been made (*8, 10*) by feeding a number of animals of that size at varying levels in the neighborhood of the feed level estimated to be the one that would keep body weight exactly constant.

If the daily energy intake of an animal be represented by f, and the daily gain or loss in body weight by g, the daily maintenance requirement, M, can be estimated by fitting the following equation (in which k represents a constant):

$$f = M + kg \tag{1}$$

The values of g for individual animals will be positive or negative, depending upon whether or not f is higher or lower than the maintenance requirement. But by fitting equation 1 to the data, M, which represents the value of f for which $g=0$, is obtained. The assumption of linearity involved in the use of this equation might well be questioned; there is good reason to suspect that when new tissue is built by an animal at a high level of nutrition its composition differs from that of tissue built at a lower level of energy intake (*8*). But if the levels of feed intake used in the experiment do not depart too widely from M, equation 1 serves well enough.

In the same sort of experiment with animals of varying sizes, allowance must be made for the fact that M is a function of the body weight of the animal. It has been assumed (*2*) that the feed used for maintenance is essentially the amount needed to compensate for the energy loss equivalent to basal metabolism, or the energy utilization of a fasting animal, at rest. Extensive research has indicated that basal metabolism is approximately proportional to the two-thirds power of body weight; actually, experimental data indicate that the exponent is a bit higher than two-thirds (*2, 6*). The "two-thirds-power law," as it applies to basal-metabolism studies, has been rationalized on the grounds that the energy loss of basal metabolism is fundamentally a problem of heat loss. Since the rate of heat loss by an object depends upon its surface area, which in turn is approximately proportional to the two-thirds power of its weight, it seems reasonable when dealing with animals of different body weights to modify equation 1 to read (a representing a constant; w, body weight):

$$f = aw^{2/3} + kg \tag{2}$$

Some years ago a staff member of the Division of Animal Industry (*5*) working with data of this kind fitted an equation of the form

$$f = aw^{b} + kg \tag{3}$$

In that equation no advance assumption is made about the numerical value of b; it is computed from the data along with the numerical values of a and k. Such computations led to numerical values of b which differed widely from two-thirds. What is the reason for the discrepancy? The argument might be advanced that the coefficient of g in the equation should be a variable, perhaps a function both of level of feed intake and body weight rather than a constant. Also, it might be argued that an animal fed at a level high enough to gain weight probably has a higher metabolic rate than a fasting animal or one receiving only enough feed to hold its body weight constant, or that metabolic rate may not be proportional to $w^{2/3}$. These questions were considered when the data on 16 pairs of identical twin calves were analyzed.

EXPERIMENTAL ANIMALS AND RATIONS

The group of animals used in this study was unique in that it consisted of a herd of 16 pairs of identical twins. Ten of the pairs were steers while the remaining 6 pairs were females. Some of the animals were purebred Aberdeen Angus, some were grade Angus, and others were crossbred animals that carried, in some cases, as much as one-half dairy blood.

The fact that each pair was a set of *identical* twins was established first by a critical physical examination and later it was confirmed by a blood test of an antigenic type. Results of the blood test are known to be entirely reliable when they indicate that co-twins are not identical, and they are considered to be at least 90 percent reliable when results of the test indicate that a pair of twin calves is identical. The physical examination plus the blood test, together, constitute the best known method for determining whether or not cattle twins are identical. As pairs of twins grow toward full size, it becomes progressively *less* difficult to detect any pairs that are not identical. The information in this report is based on pairs of twin calves that were determined, beyond reasonable doubt, to be identical twins.

The use of identical twins in biological research has the very great advantage that both the experimental animal and its control have the same inherited characteristics (*1, 3, 4*). Unfortunately, such pairs of twins are extremely rare (*11*). In the analyses that follow, the information is not manipulated as paired data. However, the fact that the data were obtained with pairs of animals having, presumably, equal inheritance would appear to give greater significance to the findings than would be the case had the sample not consisted of pairs of identical twins.

One member of each twin pair was given a limited energy allowance, as low in some cases as maintenance, between the ages of 6 and 12 months, and as low as 80 percent of maintenance between the ages of 3 and 6 or 4 and 8 months, while the other member of each pair was given a more liberal allowance. However, the known nutrient requirements aside from energy were met even when energy allowances were low. At the end of the period of low-energy intake, animals that earlier were given limited allowances were fed liberal rations, and the controls were continued on their liberal allowances.

Figures 1 to 4, inclusive, show pairs of twins before and after restricted rations were fed, and growth curves of the pairs during the period of limited feed intake.

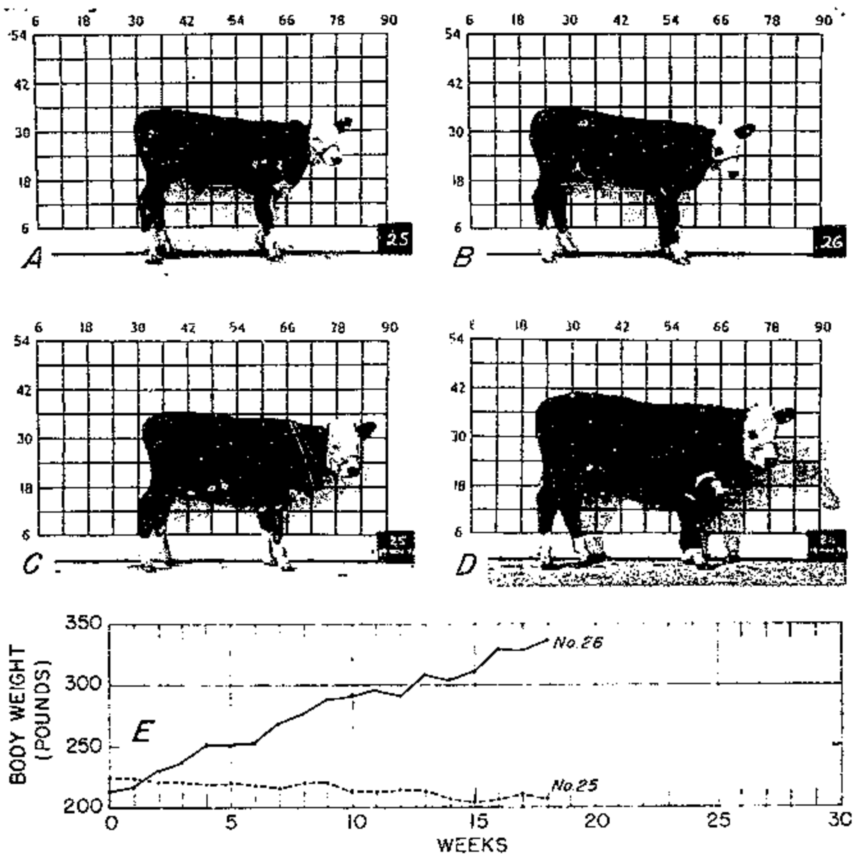

FIGURE 1.—Identical twin calves before and after one co-twin was fed low-energy rations.

A and *B*, twin pair Nos. 25 and 26, at about 4 months of age, weighing 224 and 212 pounds, respectively. *C* and *D*, the same calves at about 8 months of age, after No. 25 had been on 36 percent of a liberal energy ration (submaintenance), and No. 26 had been on 75 percent of a liberal energy ration, for about 4 months. No. 25 weighed 206 pounds; No. 26, 336 pounds.

E, growth curves of twin pair Nos. 25 and 26 from age 4 months to age 8 months.

ANALYSIS OF DATA

The data to be analyzed are given in table 1. The individuals are listed in order of mean daily gain in body weight during the periods included in the study. As the animals' growth curves during these periods are essentially linear, the mean body weight of each individual was used in the calculations. Growth curves are shown in figures 1 through 9.

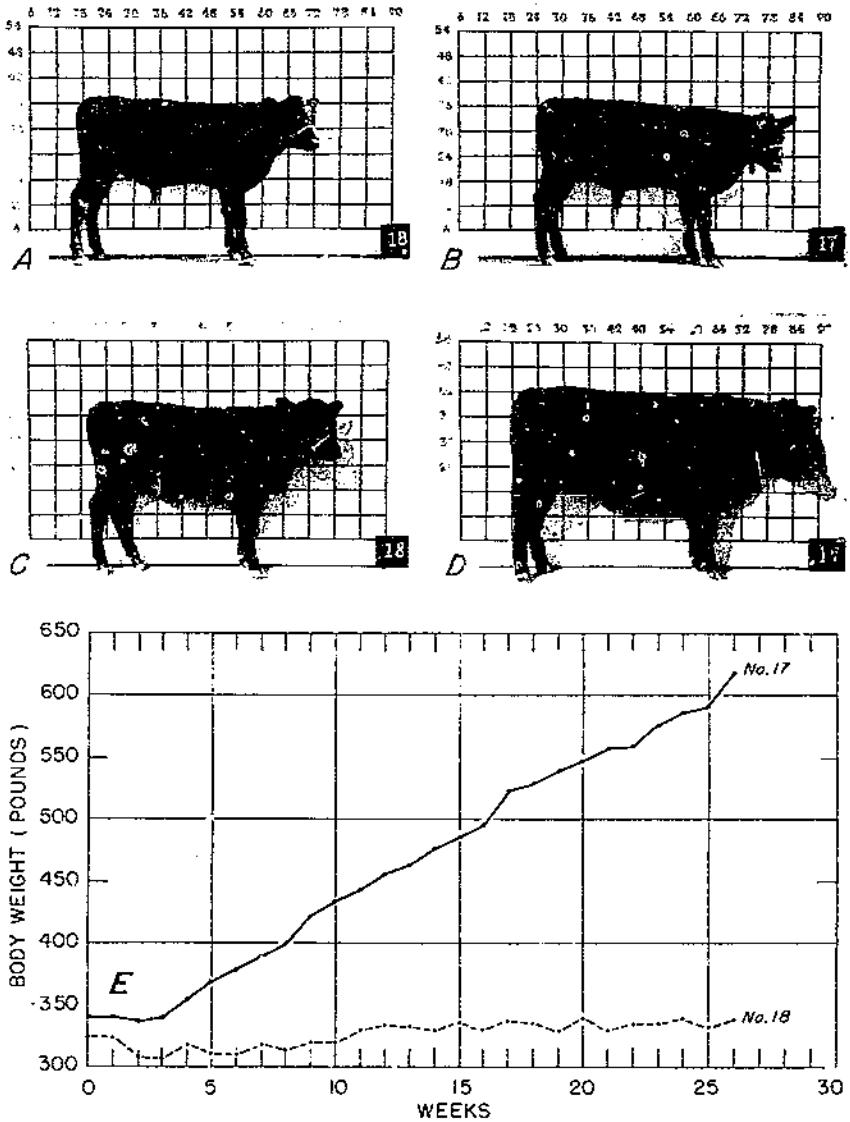

FIGURE 2.—Identical twin calves before and after one co-twin was fed low-energy rations.

A and *B*, twin pair Nos. 18 and 17, at about 6 months of age, weighing 324 and 340 pounds, respectively. *C* and *D*, the same calves at about 1 year of age, after No. 18 had received 48 percent of a liberal ration (about maintenance), and No. 17 had remained on a liberal ration for 6 months. No. 18 weighed 340 pounds; No. 17, 618 pounds.

E, growth curves of twin pair Nos. 18 and 17 from age 6 months to age 12 months.

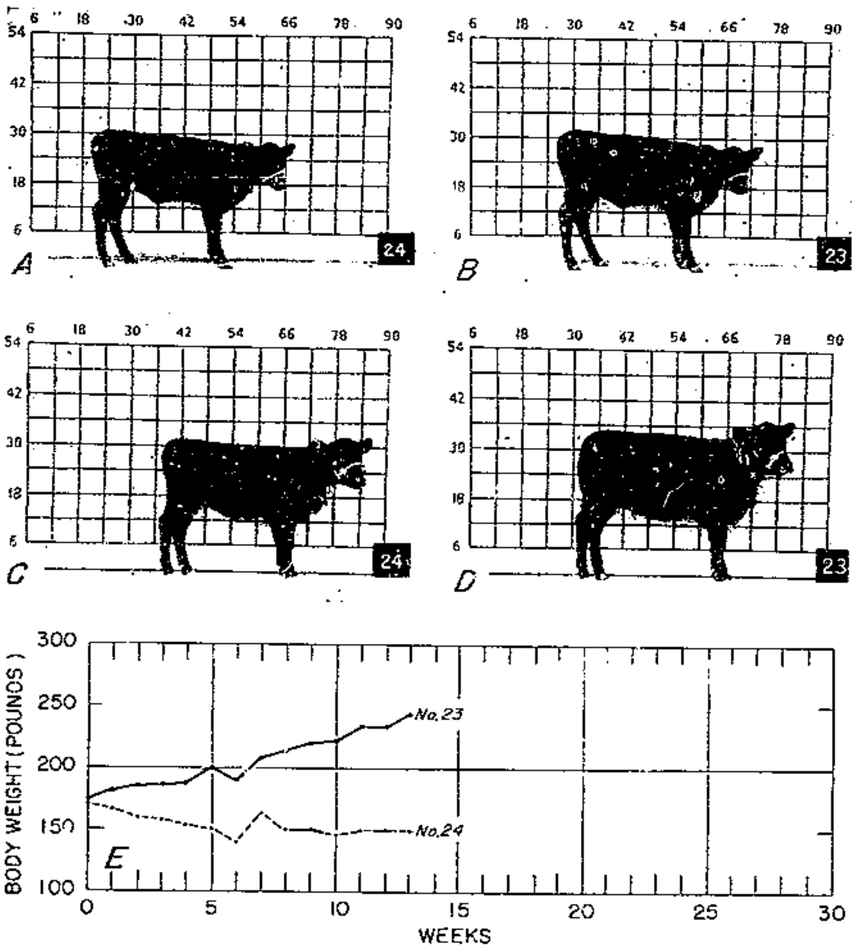

FIGURE 3.—Identical twin calves before and after one co-twin was fed low-energy rations.

A and *B*, twin pair Nos. 24 and 23, at about 3 months of age, weighing 170 and 174 pounds, respectively. *C* and *D*, the same calves at about 6 months of age after No. 24 had received 39 percent of a liberal ration (submaintenance), and No. 23 had received 80 percent of a liberal ration, for about 3 months. No. 24 weighed 150 pounds; No. 23, 244 pounds.

E, growth curves of twin pair Nos. 24 and 23 from age 3 months to age 6 months.

Some exploratory computations indicated that for animals of the same mean weight the relationship between f and g seemed to follow a curve that could be described by an equation, in which e is the base of the Napierian system of logarithms:

$$f = Me^{kg} \qquad (1)$$

The daily feed intake cannot be less than zero, even when g is negative. Furthermore, for reasons already given, there is good reason to expect

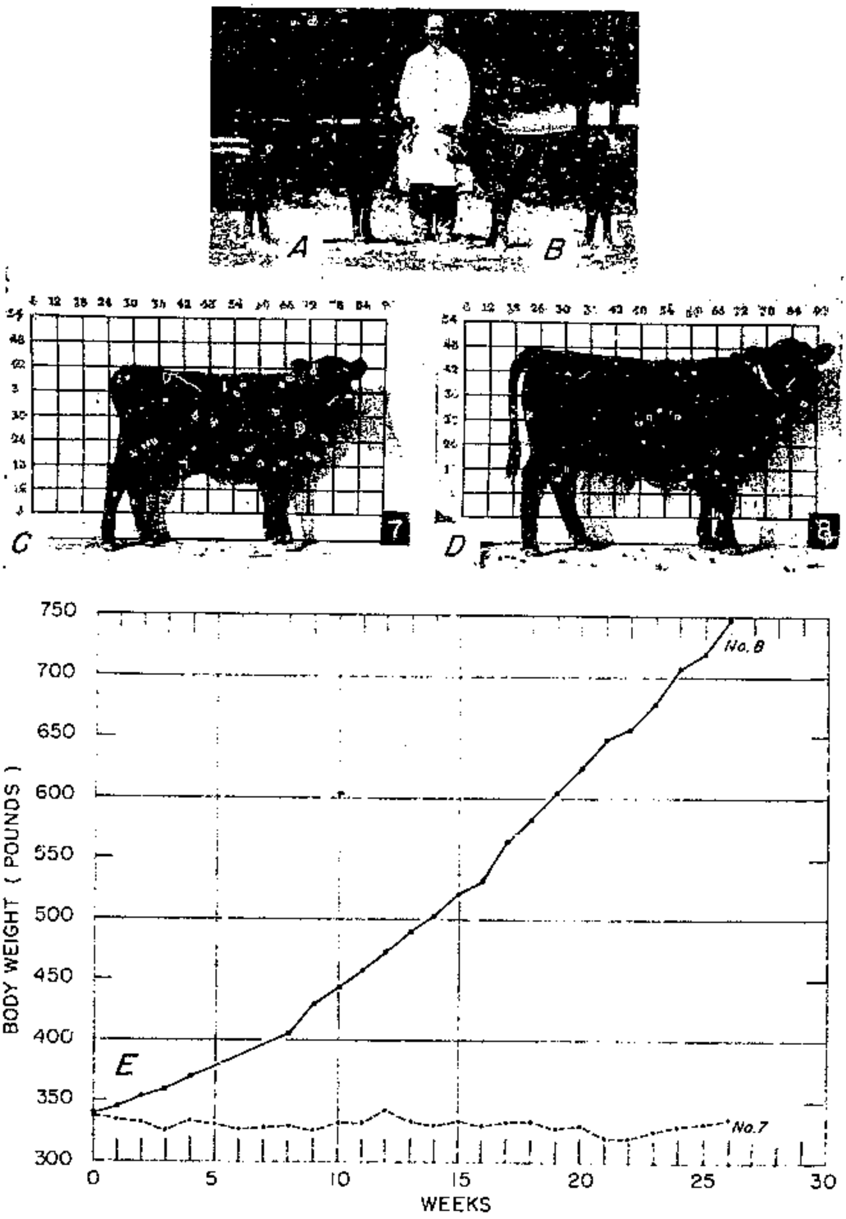

FIGURE 4.—Identical twin calves before and after one co-twin was fed low-energy rations.

A and *B*, twin pair Nos. 7 and 8, at about 6 months of age, weighing 340 and 338 pounds, respectively. *C* and *D*, the same calves at about 1 year of age, after No. 7 had received 47 percent of a liberal ration (about maintenance), and No. 8 had received a liberal ration for 6 months. No. 7 weighed 336 pounds; No. 8, 747 pounds.

E, growth curves of pair Nos. 7 and 8 from age 6 months to age 12 months.

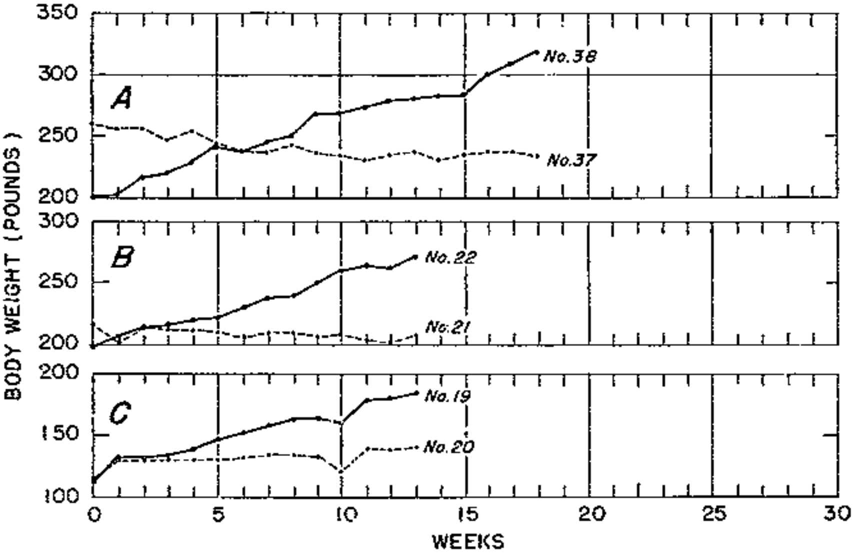

FIGURE 5.—Growth curves.

A, Pair Nos. 37 and 38 (not shown) from age 4 months to age 8 months. No. 37 received 36 percent of a liberal ration (submaintenance) and No. 38 received 73 percent of a liberal ration. The large difference in body weight at 4 months of age was due to the fact that only No. 37 was accepted by the dam. No. 38 was fed milk from a pail until it reached 3 months of age, after which time No. 37 was taken from the dam and both calves were taught to eat solid feed.

B, Pair Nos. 21 and 22 from age 3 months to age 6 months. No. 21 received 45 percent of a liberal ration (about maintenance) and No. 22 received 79 percent of a liberal ration.

C, Pair Nos. 20 and 19 from age 3 months to age 6 months. No. 20 received 45 percent of a liberal ration (about maintenance) and No. 19 received 80 percent of a liberal ration.

the daily feed requirements per unit of gain to increase as g increases. The constant, M, represents the feed intake corresponding to zero gain; in other words, it represents the maintenance requirement.

In interpreting M as the maintenance requirement, this need is defined as the feed intake required to hold body weight constant. But any curvilinear relationship between f and g, of the kind reflected by equation 4, might perhaps be caused in part by higher metabolic rates associated with larger values of g as well as by differences in the composition of the tissues added to the animal body. If that be true, perhaps the maintenance requirement should not be defined as it is here. Since the true reason for such curvilinearity can only be a matter of conjecture as far as the analysis of the present data is concerned, perhaps the safest course is to define the maintenance requirement as the feed intake associated with zero gain. Thereby speculation is avoided as to why the relationship between f and g takes the particular form that it does, and the analysis of the data becomes simpler. It, then, is necessary only to utilize data for animals fed at rather widely different levels of nutrition, in an attempt to calculate values of M that agree with estimates that would be obtained if the animals had all actually been fed at the low levels required to hold their body weights almost exactly constant.

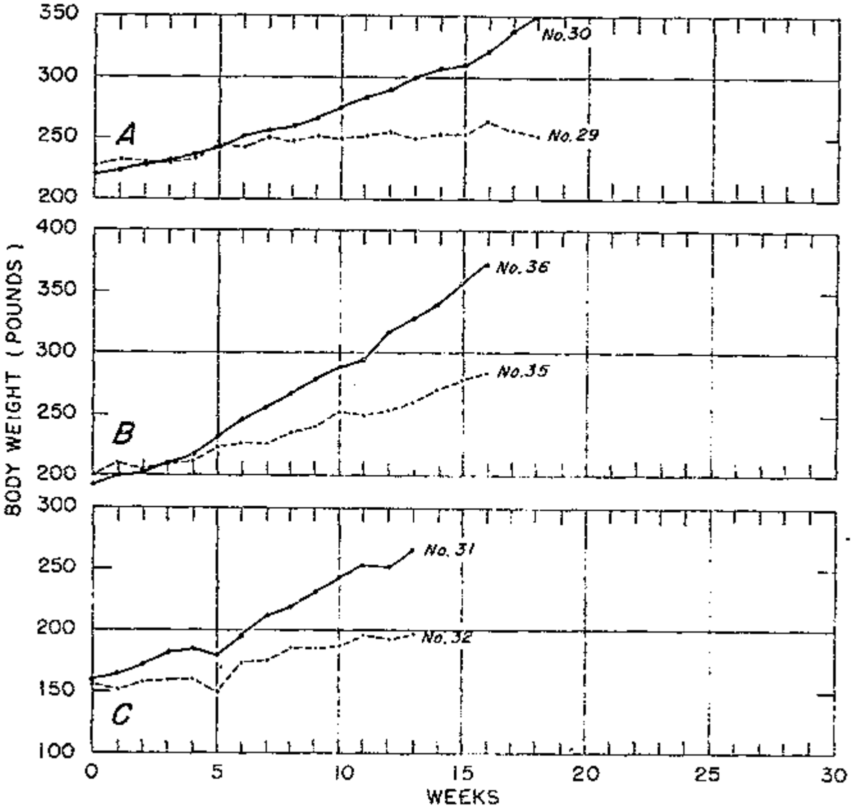

FIGURE 6.—Growth curves.

A, Pair Nos. 29 and 30 from age 4 months to age 8 months, fed 48 percent, respectively, of a liberal ration (about maintenance) and 76 percent of a liberal ration.

B, Pair Nos. 35 and 36 from age 3 months to age 6 months, fed 63 and 94 percent, respectively, of a liberal ration.

C, Pair Nos. 32 and 31 from age 3 months to age 6 months, fed 63 and 94 percent, respectively, of a liberal ration.

As the mean body weights of the individual animals during the experimental feeding periods were markedly different from one another, M in equation 4 must be replaced by a function of w, which logically should be approximately $aw^{2/3}$. However, aw^b was used and the value of b was estimated from the experimental data. The equation to be fitted to the data thus takes the form,

$$f = aw^b e^{kx} \qquad (5)$$

If the numerical value of b is found to be somewhere in the neighborhood of two-thirds, and if the entire equation is found to fit the data

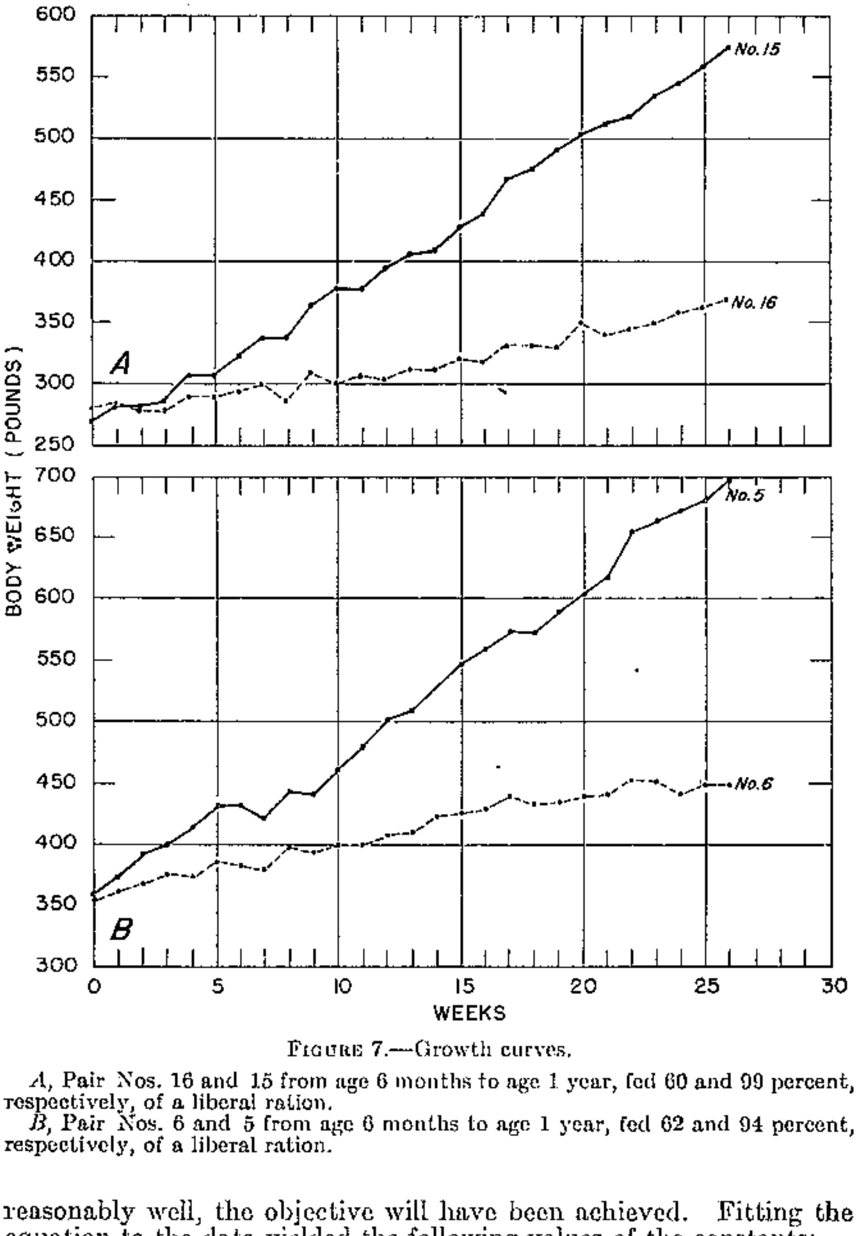

FIGURE 7.—Growth curves.

A, Pair Nos. 16 and 15 from age 6 months to age 1 year, fed 60 and 99 percent, respectively, of a liberal ration.
B, Pair Nos. 6 and 5 from age 6 months to age 1 year, fed 62 and 94 percent, respectively, of a liberal ration.

reasonably well, the objective will have been achieved. Fitting the equation to the data yielded the following values of the constants:

$$a = 0.0582$$

$$b = 0.6686$$

$$k = 0.4854$$

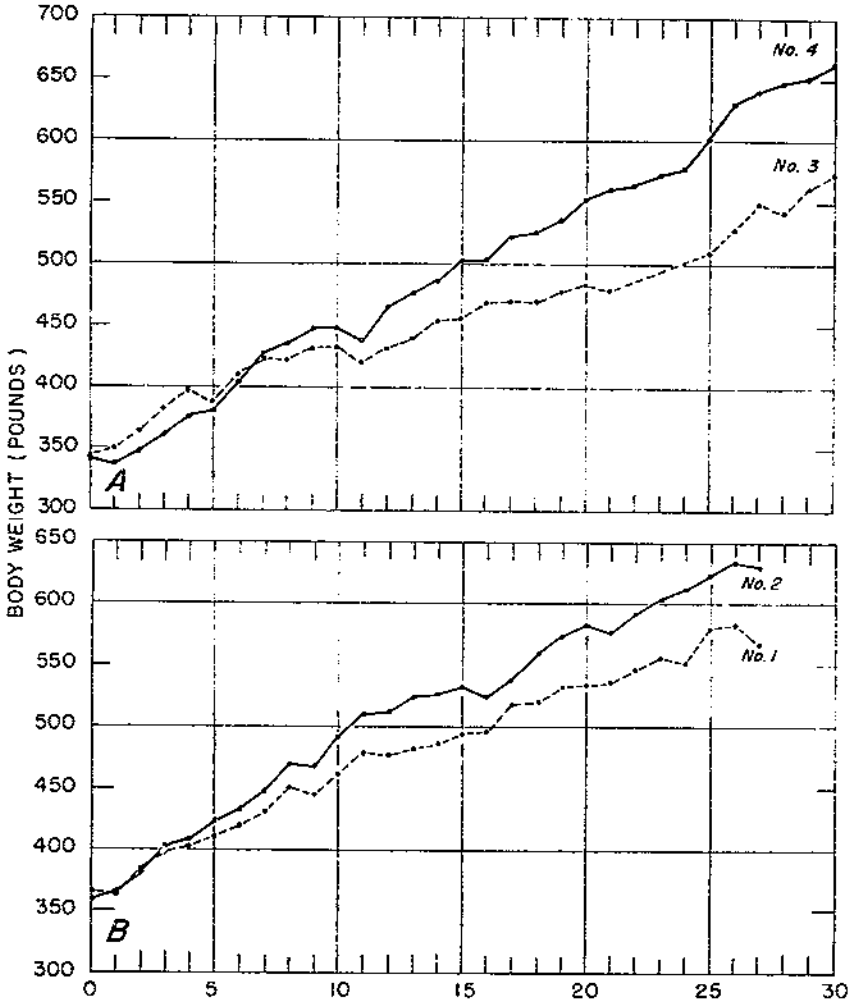

FIGURE 8.—Growth curves.

A, Pair Nos. 3 and 4 from age 7 months to age 14 months, fed 70 and 86 percent, respectively, of a liberal ration.

B, Pair Nos. 1 and 2 from age 6 months to age 1 year, fed 76 and 86 percent, respectively, of a liberal ration.

In view of the fact that b might be expected, as has been pointed out earlier, to be equal to approximately two-thirds, the estimated value, 0.6686, obviously agrees with expectation as closely as one could desire; in fact, the agreement is really closer than the most optimistic biologist ordinarily would expect.

To observe how well the equation fits the data, consider the relationship between maintenance requirement and body weight. The maintenance requirement of an animal, as that term has been defined here, is $0.0582\ w^{0.6686}$. If the data follow equation 5 reasonably well,

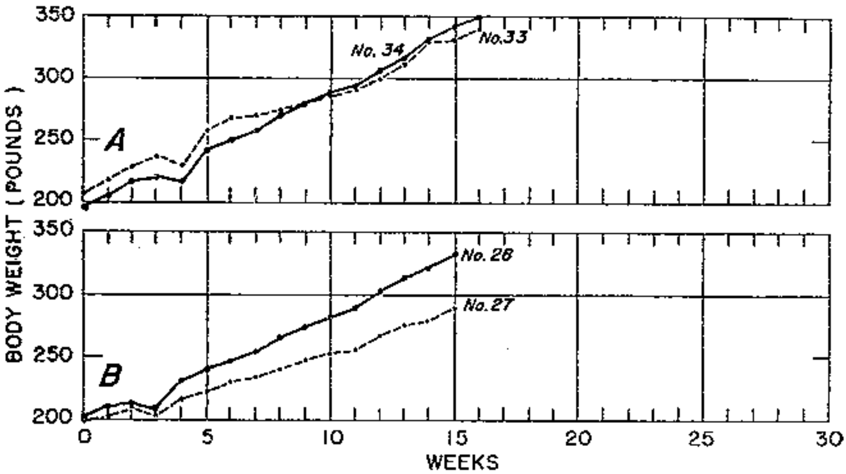

FIGURE 9.—Growth curves.

A, Pair Nos. 33 and 34 from age 3 months to age 6 months, fed 78 and 96 percent, respectively, of a liberal ration.
B, Pair Nos. 27 and 28 from age 3 months to age 6 months, fed 83 and 95 percent, respectively, of a liberal ration.

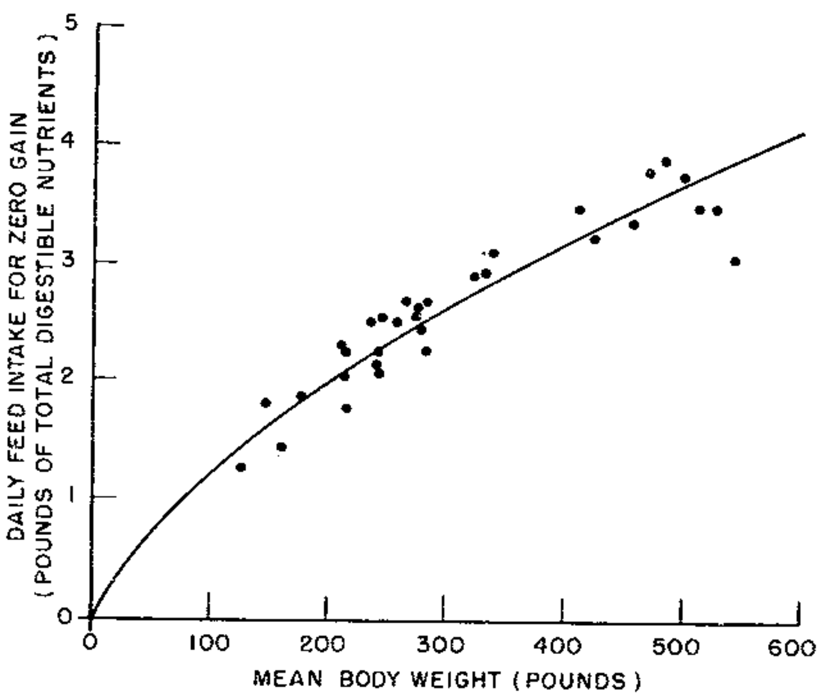

FIGURE 10.—Estimated maintenance requirements derived from equation 5.

the values of f in table 1 (mean daily energy consumption, TDN, pounds), divided by $e^{0.4854g}$, should lie close to the smooth curve obtained by plotting values of 0.0582 $w^{0.6080}$ against values of w. The agreement between these "observed" and "computed" maintenance requirements is shown in figure 10.

The relationship between f and g, when the values of f are adjusted for differences in maintenance requirements, is shown in figure 11. In that chart, values of $\frac{f}{aw^b}$ plotted against the corresponding values of g should lie close to the smooth curve obtained by plotting values of $e^{0.4854g}$ against the values of g.

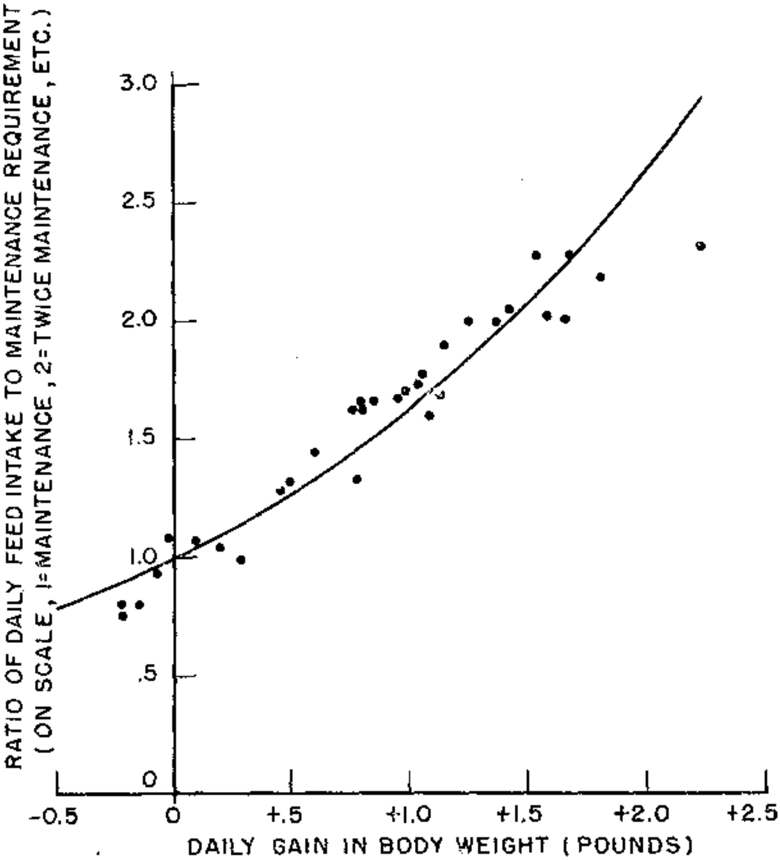

FIGURE 11.—Relationship between f and g from equation 5 when f is adjusted for maintenance requirement.

An examination of figure 10 shows that the equation describes the maintenance requirements fairly well except, perhaps, for the heaviest animal. Figure 11 shows that the observed point for this same animal (plotted as the largest value of g) is out of line on this chart also.

However, the most noteworthy feature of figure 11 is that the observed points actually seem to follow a linear trend more closely than they do a curvilinear trend such as is postulated by the equation. This suggests that, instead of using equation 5, a better fit might be obtained by using an equation of the form,

$$f=aw^b\ (1+kg) \qquad (6)$$

This change in the equation should not have any material effect on the numerical value of b. Therefore, it was assumed that $b=\frac{2}{3}$, and only a and k were computed from the data. Thus,

$$a=0.0553$$

$$k=0.805$$

Applying the same test as before, we divide the values of f by $1+0.805g$ and compare the results with the computed maintenance requirements given by $0.0553w^{2/3}$. The results are shown in figure 12. The "observed" points on this chart seem to follow the smooth curve more closely than was the case in figure 10.

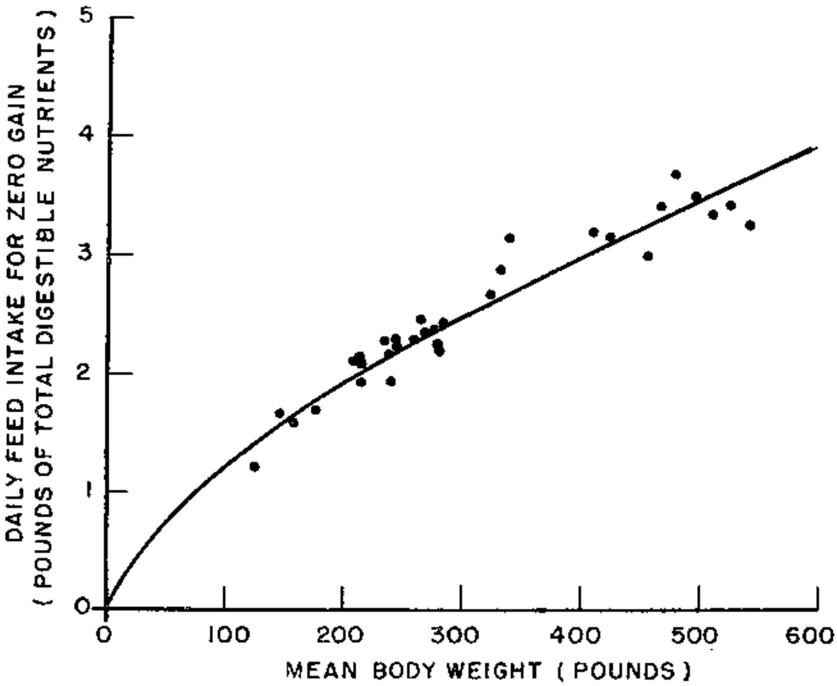

FIGURE 12.—Estimated maintenance requirements derived from equation 6.

The values of f divided by $0.0553w^{2/3}$ are compared with computed values of $1+0.805g$ in figure 13. The "observed" points, on this chart, also agree more closely with the trend imposed by the equation than was the case in figure 11.

Equation 6 is superior to equation 5 for use with data similar to that dealt with here.

DISCUSSION

The daily energy requirements, in terms of TDN (total digestible nutrients), determined by equation 6, of animals weighing 400, 600, and 800 pounds, making daily gains of 1.6, 1.4, and 1.2 pounds, respectively, are 6.9, 8.4, and 9.4 pounds respectively. Daily requirements of heifers and steers of these sizes making such gains are given as 7.0, 8.5, and 9.5 pounds, respectively, in the Report of the Committee on Animal Nutrition No. IV (1950) of the National Research Council (*9*). This close agreement suggests that the 32 individuals on which our study is based may be considered a reasonably fair sample of the beef cattle population.

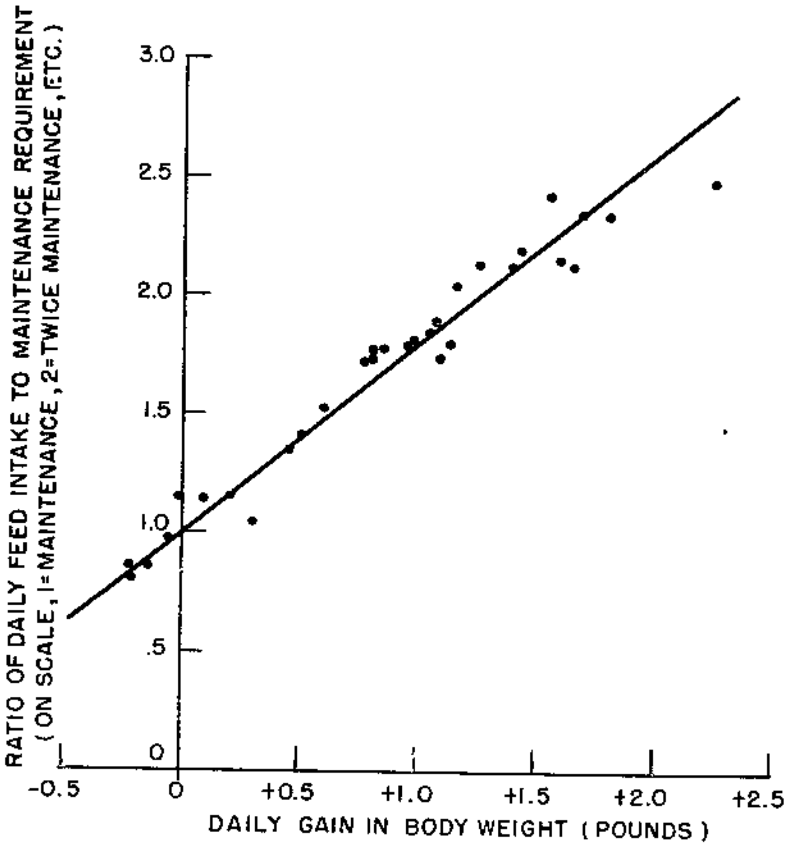

FIGURE 13.—Relationship between *f* and *g* from equation 6 when *f* is adjusted for maintenance requirement.

Daily energy requirements of cattle of weights varying from 200 to 800 pounds and making daily gains at various rates from 0 to 2 pounds, computed by means of equation 6, are presented in table 2.

Figures 12 and 13 can be used to estimate requirements not given in table 2. For example, suppose the information desired is the feed required by an animal that weighs 420 pounds to make 1¾ pounds of gain daily. We first find the daily gain of 1¾ in figure 13, then we follow the vertical line toward the top of the page to the point where the line intersects the curve. We then follow the horizontal line to the left where the column of figures shows that when the daily gain in body weight is 1¾ pounds, the ratio of daily energy intake to the maintenance requirement is 2.4. We then turn to figure 12 where we find that the maintenance requirement of a 420-pound animal is

TABLE 1.—*Energy consumption and weight changes of 16 pairs of identical twin calves*

Animal No.[1]	Age at start	Duration of experiment	Mean daily gain in body weight (*g*)	Mean daily energy consumption (TDN)	Mean of body weight at beginning and end of period of restricted feed (*w*)
	Months	*Days*	*Pounds*	*Pounds*	*Pounds*
37	4	124	−0.226	1.87	246
24	3	91	−.220	1.30	160
25	4	126	−.143	1.69	215
21	3	92	−.087	1.96	212
7	6	183	−.022	3.11	338
18	6	183	+.087	3.04	332
29	4	126	+.190	2.47	240
20	3	91	+.286	1.47	127
32	3	91	+.462	2.35	177
16	6	183	+.492	3.72	325
6	6	183	+.579	4.67	408
23	3	91	+.769	3.35	209
35	3	109	+.771	3.08	242
19	3	91	+.780	2.66	148
22	3	92	+.793	3.68	234
27	3	108	+.852	3.81	244
38	4	124	+.952	3.99	259
26	4	126	+.984	4.25	274
30	4	126	+1.032	4.42	285
1	6	196	+1.041	6.30	468
3	7	211	+1.081	5.63	456
33	3	108	+1.130	4.25	279
31	3	91	+1.164	4.01	213
28	3	108	+1.241	4.91	267
2	6	196	+1.378	7.38	495
34	3	108	+1.426	5.10	273
17	6	183	+1.519	8.25	479
4	7	211	+1.592	7.61	508
36	3	109	+1.651	5.06	282
15	6	183	+1.672	7.36	423
5	6	183	+1.803	8.42	525
8	6	183	+2.235	9.12	542

[1] Identical co-twins are numbered 1 and 2, 3 and 4, 5 and 6, etc. Pairs were numbered in the order in which they were obtained. Data on pairs 9 and 10, 11 and 12, and 13 and 14 were not included because these pairs were found to be fraternal rather than identical twins.

about 3.08 pounds of TDN per day. The daily feed requirement of the animal in question, then, is 2.4×3.08 or 7.4 pounds of TDN. In some cases, however, the desired information may be estimated even more quickly by interpolation between the figures given in table 2.

TABLE 2.—*Pounds of total digestible nutrients required daily by beef calves weighing 200 to 800 pounds to maintain weight, and to make regular daily gains*

[Determined by the equation $f=0.0553\ w^{2/3}\ (1+0.805\ g)$][1]

Weight of animal (pounds)	T. D. N. required to maintain weight	T. D. N. required to gain weight daily in the following amounts				
		½ pound	¾ pound	1 pound	1½ pounds	2 pounds
	(Pounds)	*(Pounds)*	*(Pounds)*	*(Pounds)*	*(Pounds)*	*(Pounds)*
200	1. 9	2. 6	3. 0	3. 4	4. 2	-------
300	2. 5	3. 5	4. 0	4. 5	5. 5	6. 5
400	3. 0	4. 2	4. 8	5. 4	6. 6	7. 8
500	3. 5	4. 9	5. 6	6. 3	7. 7	9. 1
600	3. 9	5. 5	6. 3	7. 1	8. 7	10. 3
700	4. 4	6. 1	7. 0	7. 9	9. 6	11. 4
800	4. 8	6. 7	7. 6	8. 6	10. 5	12. 4

[1] In this equation, f=energy requirement in pounds of T. D. N. w=body weight of animal in pounds, g=daily gain in pounds.

SUMMARY

Data are given on growth rates and levels of energy intake of 16 pairs of identical twin calves during periods when one member of each pair received a reduced energy allowance as low, in some cases, as 80 percent of a ration sufficient to maintain body weight, and its co-twin received a more liberal energy allowance. From these data, equations have been derived for the determination of energy requirements for growth and for maintenance (defined as the energy requirement of an animal that is neither gaining nor losing weight). The energy requirement of a growing animal was found to be:

$$\text{Energy requirement in pounds' T. D. N.}=0.0553\times\text{pounds' bodyweight}^{2/3}(1+0.805\times\text{pounds' daily gain})$$

This equation also can be used to determine maintenance requirements (growth=0) of young cattle.

Figures 12 and 13 can be used to estimate the energy requirements of animals weighing from 200 to 800 pounds for maintenance or for growth at any reasonable rate. Energy requirements for maintenance, and for growth at various rates, are shown in table 2.

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