# The Nutrition of the Young Ayrshire Calf

## 5. The Nutritive Value of Cow's Whole Milk

By K. L. BLAXTER (IN RECEIPT OF A SENIOR AWARD OF THE
AGRICULTURAL RESEARCH COUNCIL)
AND W. A. WOOD
*Hannah Dairy Research Institute, Kirkhill, Ayr*

The energy and nitrogen metabolism of calves, when given whole-milk diets, has been the subject of experiment for over 70 years. Soxhlet's (1878) work involved simultaneous study of mineral, N and energy balances and these experiments, together with those of Fingerling (1908), Blackwood, Morris & Wright (1936) and of Tomme & Taranenko (1939), appear to be the only ones that have not been complicated by the inclusion of roughage in the diet of the animals. No metabolism studies appear to have been made in which variation in nutritional plane has been employed. Several practical trials have, however, been carried out in which different quantities of whole milk have been given (Filmer, 1948, 1949) and in which higher planes of nutrition have been associated with greater growth, at least during the first 5 weeks of life.

In a previous paper (Blaxter & Wood, 1951 c) it was suggested that biological values of proteins, giving their true significance, could be determined by regression analysis of the results of nitrogen-balance experiments in which different quantities of the same diet had been given. The object of the present experiment was to repeat this type of determination using cow's whole milk. In view of the paucity of information on the calcium and phosphorus metabolism and the energy exchange of the young calf in relation to nutritional plane, additional observations on these aspects were made.

### EXPERIMENTAL

*Calves and their management*

Two bull calves, which had previously been given colostrum and whole milk, were used. They were housed in metabolism crates; urine and faeces collections were made as previously described (Blaxter & Wood, 1951 a). The calves were 5 days old at the commencement of the experiment. Whole milk was given to each calf as its sole diet for three 12-day periods; calf no. 13 received 2·6, 5·0 and 5·8 l. in consecutive periods and calf no. 14 received 4·2, 3·4 and 6·6 l. These quantities are step-wise changes of 0·8 l. and were chosen to cover a range of feeding from about maintenance level to two and a half times maintenance. The diets were allocated in such a way that each calf was given widely differing quantities. Two days were allowed between each change-over to allow an equilibrium to be attained. The whole milk used contained

on the average 3·0–3·1 % fat and was supplemented by a daily dose of 5 ml. of a mineral mixture containing those trace elements that are required by the rat when milk is the sole diet. Magnesium was also included in this mixture to prevent the hypomagnesaemic tetany of calves that results when whole-milk diets are given (Duncan, Huffman & Robinson, 1935). The composition of this mixture in g/l. was: $MgSO_4.4H_2O$ 0·5, $CuSO_4.5H_2O$ 0·5, $CoSO_4.7H_2O$ 0·1, $Fe_2(SO_4)_3.7H_2O$ 20·0, $MgCl_2.6H_2O$ 60·0. Five ml. cod-liver oil were given once a week.

Milk samples were taken at each feeding (9 a.m. and 8 p.m.) and were preserved with formaldehyde. Urine and faeces were collected daily.

*Analytical procedure*

All analyses for nitrogenous constituents were made at 2-day intervals with the exception of urinary N which was determined daily. Mineral analyses were made on pooled samples representing the last 10 days of each period. The animals were weighed every 2 days before the morning feed. Notes on general behaviour and appearance were made at each feeding and the pulse rate was also recorded at this time. The respiratory metabolism was determined using the apparatus and technique of Blaxter & Howells (1951).

The following determinations were made:

*Urine.* Total N (Kjeldahl); urea (Van Slyke & Cullen, 1910); ammonia (Van Slyke & Cullen, 1910); protein (Kjeldahl); amino-N (Albanese & Irby, 1944); purine bases (Krüger & Schmidt, 1905); uric acid (King, 1946); allantoin (Young & Conway, 1942); creatine and creatinine (Folin, 1914); calcium (McCrudden, 1911–12); phosphorus (Fiske & Subbarow, 1925).

*Faeces.* Dry matter; total N (Kjeldahl); ash; total fat.

*Milk.* Fat (Röse-Gottlieb); total N (Kjeldahl); total solids; ash; calcium (McCrudden, 1911–12); phosphorus (Fiske & Subbarow, 1925).

RESULTS

*General observations and body-weight gains*

Both calves were bright and in good condition at the commencement of the experiment. Calf no. 13, when receiving the lowest quantity of milk (2·6 l./day) became rather thin, but still remained alert and active. Towards the end of period 3 this calf became lethargic and scoured badly. Calf no. 14 was in excellent condition throughout the experiment. Calf no. 13 was more nervous and irritable than calf no. 14.

Table 1 summarizes the daily body-weight gains calculated by regression analysis of the individual weights, and these values plotted against milk intake are presented in Fig. 1. It will be noted that the relation between the rate of gain of body-weight and milk intake was linear, even at the highest level of feeding. Though the results are limited in that they apply to only two calves, they have been analysed statistically using methods of covariance analysis (Fisher, 1925). The method is shown in the second part of Table 1 and has been used throughout. It makes possible an estimate of the

Table 1. *Gain in body-weight of the calves and its statistical significance*

| Calf no. 13 | | Calf no. 14 | |
| --- | --- | --- | --- |
| Milk ingested (l./day) | Body-weight gain (g/day) | Milk ingested (l./day) | Body-weight gain (g/day) |
| 2·6 | −49 | 3·4 | 230 |
| 5·0 | 480 | 4·2 | 355 |
| 5·8 | 690 | 6·6 | 910 |

*Analysis of covariance of body-weight gain in g/day (y) on milk intake in l./day (x)*

| | Degrees of freedom | Sum of squares and products | | | Reduction in sum of squares due to regression | Sum of squares after reduction | Mean square |
| --- | --- | --- | --- | --- | --- | --- | --- |
| | | $x^2$ | $xy$ | $y^2$ | | | |
| Between calves | 1 | 0·107 | 49·87 | 23,313 | — | 6333 | 6333 |
| Within calves | 4 | 11·093 | 2470·13 | 552,037 | 550,020 | 2017 | 672 |
| Total | 5 | 11·200 | 2520·00 | — | 567,000 | 8350 | — |

Significance of regression: variance ratio (3 degrees of freedom) = 818·2, $P < 0.001$.
Significance of differences between calves: variance ratio (3 degrees of freedom) = 9·4, $P = 0.054$.
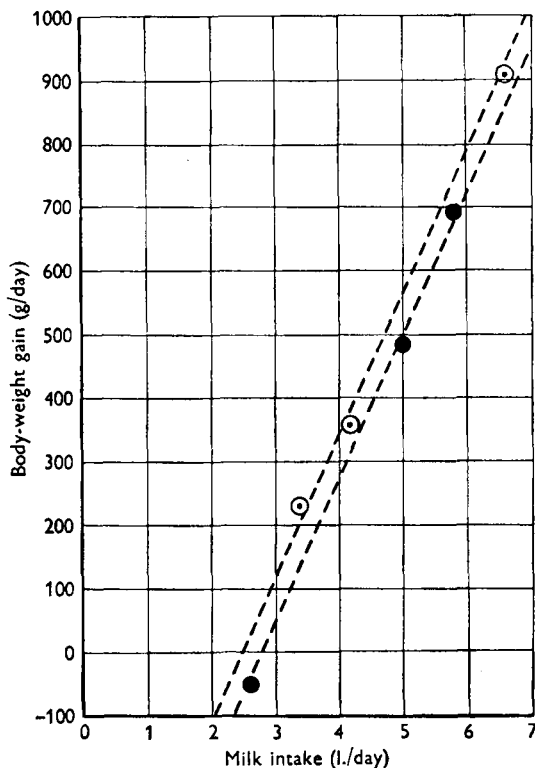


Fig. 1. Relation between milk intake and gain in body-weight of the calves.
⊙, calf no. 14; ●, calf no. 13.

significance of the regression of body-weight gain, N balance or other balances on milk intake as well as an assessment of differences between the two calves when given identical quantities of milk. To establish a difference in performance of two animals in such a short period as the first 6 weeks of life is difficult, since the length of period precludes replication on anything but a limited scale. Even so, statistical analysis of such limited data provides a reasonably valid estimate of the significance of any differences. The two equations relating body gain in g/day ($G$) to milk intake in l./day ($M$) were:

$$\text{calf no. 13} \quad G = 222 \cdot 7M - 621 \cdot 8,$$
$$\text{calf no. 14} \quad G = 222 \cdot 7M - 555 \cdot 7.$$

As shown in the analysis of variance, the pooled regression was highly significant statistically and the difference between calves, after allowing for differences in intake of milk, was only significant at $P = 0 \cdot 054$. From this it would appear that calf no. 14 was a more efficient animal than calf no. 13. These two equations permit the estimation of the milk required for maintenance of body-weight, that is the milk intake associated with no gain of body-weight. For calf no. 13 this was 2·8 l./day, and for calf no. 14, 2·5 l., with a mean of 2·65 ± 0·16, which may be taken as an estimate of the requirement of the calf for body-weight maintenance in terms of milk with a fat content of 3 %.

### The apparent digestibility of the milk

From analyses of faeces the coefficients of apparent digestibility of dry matter, N and fat were calculated as shown in Table 2. There were no statistically significant differences in the digestibility of any component due to either the effect of the amount of milk consumed, or to individual differences between the calves. Low apparent digestibility of dry matter, of N and, more particularly, of fat occurred when calf no. 13 scoured during period 3. The mean apparent digestibility of N, irrespective of calf or feeding level, was 93·8 %. This value is quite comparable to that of 93·3 % obtained by Blackwood et al. (1936), that of 94·3 % obtained by Tomme & Taranenko (1939) and that of 95·4 % obtained by Fingerling (1908). The mean apparent digestibility of the milk fat was 95·6 %. Fingerling obtained a value of 100 for the apparent digestibility coefficient of the ether extract of milk. This high value was no doubt due to the fact that his fat determinations were made on dried, unacidified faeces, so that soaps,

Table 2. *Apparent digestibility for the calves of dry matter, nitrogen and fat*

| Calf no. | Milk ingested (l./day) | Mean daily faecal excretion (g) | | | Coefficient of apparent digestibility (%) | | |
|---|---|---|---|---|---|---|---|
| | | Dry matter | N | Fat | Dry matter | N | Fat |
| 13 | 2·6 | 12·8 | 0·88 | 5·0 | 96·3 | 94·1 | 93·4 |
| 14 | 3·4 | 19·6 | 1·83 | 4·0 | 95·4 | 90·7 | 96·1 |
| 14 | 4·2 | 15·2 | 1·50 | 4·4 | 97·0 | 93·8 | 96·4 |
| 13 | 5·0 | 11·3 | 0·85 | 3·2 | 98·2 | 97·1 | 97·9 |
| 13 | 5·8 | 38·8 | 2·70 | 13·0 | 94·4 | 91·7 | 92·8 |
| 14 | 6·6 | 19·5 | 1·64 | 6·5 | 97·5 | 95·6 | 96·8 |

normally present in large quantities in calf faeces, would not be included in the total fat excretion. Tomme & Taranenko (1939) give a value of 95 % for the 'digestibility' of the total calories of cow's milk. The present results are thus in substantial agreement with previous results. Except for calf no. 13, during the period when it had diarrhoea, the faecal excretion of fat remained very constant despite the wide range of dietary intake (from 75 to 205 g fat daily). This suggests that most of the faecal fat is of body origin and does not represent unabsorbed dietary fat. Even during fasting, the calf excretes 4·2 g fat/day (Blaxter & Wood, 1951 b), a value close to the mean excretion of 4·6 g observed in these experiments when the one abnormal value was excluded.

*Nitrogen metabolism*

Table 3 summarizes the results from which the N balances may be calculated.

When the N balances were plotted against the dietary N apparently digested as shown in Fig. 2, it was seen that the calves differed in their N balances in much the

Table 3. *Nitrogen metabolism of the calves in relation to milk intake*

| Calf no. | Milk ingested (l./day) | N intake (g/day) | N apparently digested (g/day) | Urinary N (g/day) | N balance (g/day) |
|---|---|---|---|---|---|
| 13 | 2·6 | 14·96 | 14·08 | 13·54 | 0·54 |
| 14 | 3·4 | 19·78 | 17·95 | 9·53 | 8·41 |
| 14 | 4·2 | 24·16 | 22·66 | 8·74 | 13·92 |
| 13 | 5·0 | 29·09 | 28·24 | 12·58 | 15·66 |
| 13 | 5·8 | 32·36 | 29·66 | 13·63 | 16·03 |
| 14 | 6·6 | 37·03 | 35·39 | 10·31 | 25·07 |

same way as they did in their body-weight gains, calf no. 14 storing more N than calf no. 13 at comparable intakes. Employing the statistical method used in the analysis of weight gains, it was found that the difference in intercept was statistically significant ($P < 0·01$), so that there were two equations relating N balance ($NB$) in g/day to apparently digested N intake in g/day ($ADN$):

$$\text{calf no. 13} \quad NB = 0·972 ADN - 12·8,$$
$$\text{calf no. 14} \quad NB = 0·972 ADN - 9·2,$$
$$\text{mean} \quad NB = 0·972 ADN - 11·0.$$

The intercepts of the equations represent the loss of body N when the N intake is nil, and, as apparently digested nitrogen is the independent variable, they also represent the urinary N excretion under the same conditions. The mean value of the intercept, 11·0 g, is higher than was found with diets containing various levels of dried skim-milk protein where these intercepts increased with increasing level of dietary protein (Blaxter & Wood, 1951 c). Blaxter & Wood suggested that this intercept represents two fractions, one endogenous and one largely determined by the higher levels of deamination which occur on high-protein diets. The present result is in complete accordance with those results, for in cow's milk 29·7 % of the total calories are present as protein, whereas in the previous experiments the maximum was 20·5 %. Statistically, the regression of urinary N excretion on N intake was not

significant. This is a reflexion of the high biological value of whole-milk protein, for the additional amounts of protein given were all stored. The difference between the calves in their urinary N excretion, however, was statistically significant ($P < 0.01$). The implications of this difference will be discussed later.
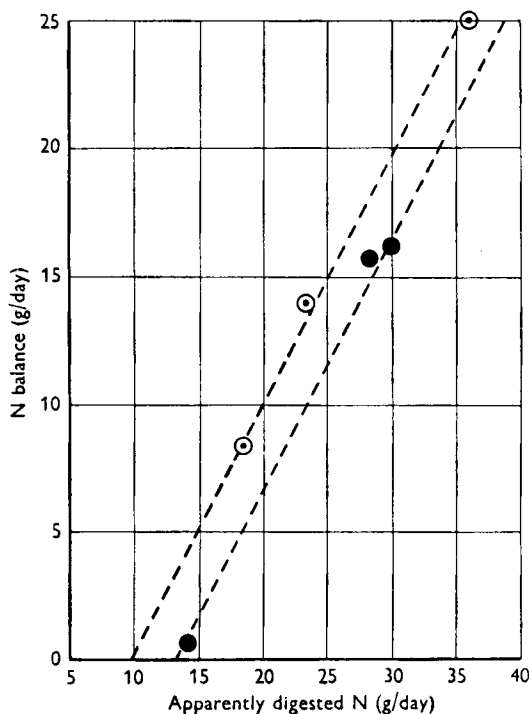


Fig. 2. Relation between N balance of the calves and N apparently digested.
⊙, calf no. 14; ●, calf no. 13.

In each period the distribution of the urinary N was determined. As may be inferred from the results for total urinary N excretion, only small changes occurred as the result of a change in nutritional plane. Creatinine N increased ($P = 0.07$) with increasing intake of milk. There were, however, large and statistically significant differences between the calves in their excretion of urea, ammonia and amino-acid N, as shown in Table 4. An increase in the excretion of these three metabolites accounted for over 90 % of the difference between the total N excretion of the calves. The small difference between the calves in their excretion of purine N and creatinine N was not statistically significant. It may be concluded therefore that the higher N excretion by calf no. 13 was the result of an increased protein metabolism, rather than of an increase in its endogenous metabolism, as indicated by purine and creatinine metabolism.

It will be noted that a heat-coagulable protein is a normal minor constituent of calf urine. Smith & Little (1924) reported pronounced proteinuria in newborn calves after they had been given colostrum, but found none after 3 days of age, regarding the fine clouding then present after the heat test as negative.

Biological values of the dietary N were calculated as in previous papers, using as an estimate of the endogenous N excretion a value calculated from basal-energy metabolism determinations made simultaneously (Blaxter & Wood, 1951*a*). These

Table 4. *Mean daily excretion by the calves of nitrogen in urinary nitrogenous metabolites (g)*

| Metabolite | Calf no. 13 | Calf no. 14 |
|---|---|---|
| Urea | 8·92 | 6·22 |
| Ammonia | 1·18 | 0·73 |
| Amino-acids | 0·34 | 0·23 |
| Total urea, ammonia and amino-N | 10·44 | 7·18 |
| Purine bases | 0·16 | 0·14 |
| Uric acid | 0·04 | 0·04 |
| Allantoin | 0·59 | 0·55 |
| Total purine | 0·79 | 0·73 |
| Creatine | 0·28 | 0·27 |
| Creatinine | 0·46 | 0·46 |
| Protein (heat coagulum) | 0·18 | 0·17 |

Table 5. *Biological value for the calves of the nitrogen of whole milk at different levels of intake*

| Calf no. | Milk intake (l./day) | Apparently digested N (g/day) | Biological value |
|---|---|---|---|
| 13 | 2·6 | 14·3 | 40·0 |
| 14 | 3·4 | 18·3 | 63·8 |
| 14 | 4·2 | 22·9 | 76·6 |
| 13 | 5·0 | 28·0 | 70·0 |
| 13 | 5·8 | 30·4 | 70·3 |
| 14 | 6·6 | 35·8 | 83·6 |

values are presented in Table 5. The biological value of the whole-milk N increased with increasing intake in both calves. The regression of biological value on milk intake was statistically significant ($P=0·03$), and this result confirms previous work on semi-synthetic diets which showed that the biological value of a protein in a growing animal varies with the total intake of food, provided the composition of the diet remains constant (Blaxter & Wood, 1951*c*).

*Respiratory exchange*

The respiratory exchange of each calf was determined at the end of each period after the calf had been starved for some 15 h. Table 6 presents the results of these determinations, as well as the mean pulse rates determined throughout the experiment. Statistical analysis by the method previously outlined showed that the regression of heat production per sq.m of body surface per h ($HP$) on milk ingested in l./day ($M$) was statistically significant ($P<0·01$). The difference between the calves was not significant ($P=0·12$). The regression equations for each calf were:

$$\text{calf no. 13} \quad HP=6·44M+40·1,$$
$$\text{calf no. 14} \quad HP=6·44M+33·4,$$
$$\text{mean} \quad HP=6·44M+36·8.$$

The respiratory quotient was not appreciably affected by the plane of nutrition. The minute volume of the respiration and respiratory rate increased at the higher levels. There was little effect on pulse rate, extremely high values being recorded during the first 2 weeks of the experiment regardless of feeding level. Whether this is an age effect or represents an effect of 'training' is not known.

Table 6. *Respiratory exchanges of the calves*

| Calf no. | 13 | 14 | 14 | 13 | 13 | 14 |
|---|---|---|---|---|---|---|
| Milk ingested (l./day) | 2·6 | 3·4 | 4·2 | 5·0 | 5·8 | 6·6 |
| Time after feeding (h) | 14·5 | 14·0 | 14·5 | 14·0 | 15·5 | 15·5 |
| Respiratory rate (respirations/min) | 26 | 21 | 28 | 43 | 39 | 25 |
| Pulse rate (beats/min)* | 88 | 78 | 112 | 95 | 97 | 106 |
| Minute volume of respiration (l.) | 5·8 | 5·0 | 7·2 | 10·9 | 12·4 | 9·2 |
| Oxygen consumption (l./h) | 13·0 | 14·1 | 16·5 | 18·0 | 22·2 | 21·7 |
| R.Q. | 0·82 | 0·80 | 0·84 | 0·80 | 0·75 | 0·78 |
| Heat production (Cal./h) | 63·1 | 67·6 | 80·2 | 86·3 | 105·1 | 103·9 |
| Heat production (Cal./sq.m/h)† | 56·4 | 53·6 | 66·3 | 70·7 | 79·6 | 74·8 |

\* Determined twice daily throughout each period.

† Surface area estimated by the formula: $S = 0.15\, W^{0.56}$, where $S$ = surface area in sq.m and $W$ = body-weight in kg.

The increase in the intake of milk was clearly associated with a marked increase in the heat production determined 15 h after the previous meal. The increases were large; at a milk intake equivalent to that required for body-weight maintenance the mean heat production per sq.m per h was 53·8 Cal.; when the milk intake was doubled the heat production was 70·9 Cal.; when it was increased three times it was 88·0 Cal. It appears unlikely that this increase was due to unabsorbed milk nutrients remaining in the rumen and abomasum of the calf and reaching the small intestine many hours after the last meal, as it would entail the assumption of a very high heat increment of feeding for what must be very small quantities of milk. The activity of each calf was minimal, so increased muscular activity does not afford an explanation.

Part of the increase may be explained by an increase in muscular tone at the higher nutritional levels, but in any case the results suggest that the heat production of the calf, determined under conditions comparable to those employed in the determination of the basal metabolism of man, is not a stable entity but is sensitive to changes in nutritional plane. That the effect is related to nutritional plane and not to age is shown by the results obtained with calf no. 14. It was 14 days older when given 3·4 l. milk than when given 4·2 l., and its heat production was higher in the earlier period when the nutritional plane was high. Such an instability of basal heat production in relation to nutritional plane has been observed in the rat by Hamilton (1937) and by Treichler & Mitchell (1941). It has also been observed in adult cows by Ritzman & Benedict (1938).

*Calcium and phosphorus metabolism*

Table 7 summarizes the results of the calcium and phosphorus determinations. Statistically, the regressions of Ca and P balance on milk intake were highly significant ($P < 0.01$). In neither case was the difference between calves significant. Where

$Ca=$ the calcium balance and $P=$ the phosphorus balance in g/day, and $M=$ milk ingested in l./day, the regression equations were:

$$Ca = 1.408M - 0.603,$$
$$P = 0.857M - 0.636.$$

There was no indication, even at the highest level of intake of milk, that the full capacity of the tissues to retain Ca or P had been reached.

Table 7. *Metabolism of calcium and phosphorus of the calves*

| | | Ca | | | | P | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Intake | Excretion | | | Intake | Excretion | | |
| Calf no. | Milk ingested (l./day) | Intake (g/day) | Urine (mg/day) | Faeces (g/day) | Balance (g/day) | Intake (g/day) | Urine (g/day) | Faeces (g/day) | Balance (g/day) |
| 13 | 2·6 | 3·87 | 23 | 1·03 | +2·82 | 2·55 | 0·80 | 0·24 | +1·51 |
| 14 | 3·4 | 5·17 | 37 | 0·96 | +4·18 | 3·50 | 0·86 | 0·26 | +2·38 |
| 14 | 4·2 | 6·26 | 50 | 0·47 | +5·74 | 4·11 | 0·94 | 0·19 | +2·98 |
| 13 | 5·0 | 7·60 | 38 | 0·63 | +6·93 | 5·15 | 0·94 | 0·32 | +3·88 |
| 13 | 5·8 | 8·70 | 40 | 2·16 | +6·50 | 5·80 | 1·27 | 0·75 | +3·78 |
| 14 | 6·6 | 9·90 | 110 | 0·71 | +9·08 | 6·60 | 1·07 | 0·24 | +5·29 |

The urinary excretion of Ca was low throughout the experiment, amounting to only 5 % of the faecal excretion of Ca. The value is higher than the highest value of 2 % found by Blackwood *et al.* (1936) and does not justify in experiments with calves the omission of the determination of urinary Ca as inferred by these workers.

As previously mentioned, calf no. 13, when given 5·8 l. of milk, scoured badly. The mean daily excretion of ash in the faeces was exceptionally high during this period, as was also the faecal excretion of Ca. The percentage of Ca in the total ash, when the animal scoured, was 27·0 %, which did not differ from the mean percentage of 28·6 found during normal periods. Similarly, the faecal excretion of P increased when calf no. 13 scoured, but the percentage of P in the ash was 9·3 compared with the general mean of 9·6. Thus, although the faecal excretion of ash increased three times during scouring, the proportions of Ca and P in the ash were not affected. This large faecal loss of Ca and P during the alimentary disturbance necessarily resulted in a low retention. The excretion of P in the urine of calf no. 13 increased during the scouring period despite the fact that there was a marked increase in the excretion of P in the faeces. The reason for this is not known; it was certainly not due to an excessive katabolism of body protein during this time. Excluding the results obtained in the scouring period, the increase in urinary P with increasing milk intake was statistically significant $(P < 0.01)$.

DISCUSSION

The effect of nutritional plane on the storage of N, Ca and P, on growth and on heat production, has already been discussed. The two calves, however, differed from one another in several ways. Calf no. 13 required more milk for maintenance of body-weight and for maintenance of N equilibrium than calf no. 14 and it also had a higher

basal metabolism. These results are interrelated: a high basal metabolism entails a greater katabolism of ingested food or body tissue to meet this demand for energy, and the higher urinary N largely made up of urea-, ammonia- and amino-N reflects the higher rate of deamination of ingested protein that occurred in order to furnish energy for this purpose. Armsby & Fries (1911) compared the utilization of feed energy by a pure-bred steer with that of a scrub steer and concluded that 'the energy requirement of the scrub steer for maintenance, computed to the same live-weight, averaged 18·7 % higher than that of the pure-bred. Accordingly the latter was able to use a relatively larger proportion of the total energy of his ration for the production of gain.' The difference in heat production of the present calves was 13·2 %, and judging from photographs of Armsby's animals the present calves did not differ in appearance as much as his. The calves in the present experiment were essentially dairy-type animals of the same breed born on neighbouring farms within 1 day of one another and were thought, on purchase, to be comparable in all respects. A further indication of the inherent differences between animals was shown by Wood & Yule (1914), who found that the average live-weight increases of individual oxen on the same diets and under the same conditions could vary between 1 and 3 lb./day. Wood & Hill (1914) later showed that the difference in live-weight increase between 'good doers' and 'bad doers' was inversely related to the skin temperature of the animals, and presumably therefore to their heat production. It is surprising that such large differences exist at such an early age, and these differences must be of considerable practical importance.

From the results presented it is clear that body-weight maintenance in the calf involves storage of minerals in bone and deposition of protein. From the equations presented it can be seen that 2·83 g N, 3·13 g Ca and 1·64 g P were stored daily in this way. The amount of tissue stored in terms of body-weight may be calculated roughly from the Ca, P and N balances. Since the Ca : P ratio in bone is 2·15 (Shohl, 1939), the positive balance of 3·13 g Ca was associated with storage of 1·46 g P. If all the N stored represented a storage of tissue comparable in composition with muscle, 2·83 g N would have been associated with 88 g muscle substance. This protein would have a ratio of N : P of 14·7 (Shohl, 1939) giving an estimate of P retention as muscle of 0·19 g and an estimate of total P retention of 1·65 g against the 1·64 g actually determined. The total gain of body-weight would thus be about 90 g. This gain is presumably balanced by a loss of body fat and possibly by slight dehydration of the tissues.

This general picture of maintenance in the young growing animal is in complete accordance with Waters's (1908, 1910) observations that the body form of cattle kept at constant body-weight did not remain infantile, but that an increase in skeletal proportions and a loss of subcutaneous and depot fat occurred. The results of the present experiment provide a quantitative estimate of these changes in terms of storage of Ca P and N.

## SUMMARY

1. Two young calves were given whole-milk diets at levels from 2·6 to 6·6 l./day and their metabolism of nitrogen, calcium, phosphorus and energy was studied.

2. The apparent digestibility of the dry matter, fat and total N of the milk was not affected by the amount given.

3. Both body-weight gain and N storage were linearly related to the intake of milk. Urinary N excretion did not change significantly on increasing the milk intake, and for each additional g of N apparently digested 0·97 g was stored. Biological values increased with increasing milk intake, even at the higher levels of ingestion.

4. The basal metabolism of the calves, 15 h after the last meal, increased from 53·8 Cal./sq.m body surface/24 h at maintenance to 79·5 Cal. at two and a half times the maintenance level.

5. Both Ca and P storages were linearly related to the amount of milk ingested, and at the highest level (about two and a half times the maintenance intake) 92 % of the milk Ca and 80 % of the milk P were retained in the tissues.

6. The two calves differed in their basal energy expenditure at a constant nutritional plane by 13·7 %. The animal with the higher basal metabolism did not grow as quickly or store as much body N as the other and its excretion of urinary N exceeded that of the other by approximately 40 %. This N loss was accounted for by an increased excretion of urea-, ammonia- and amino-N, suggesting a greater deamination of amino-acids in this animal.

7. In confirmation of earlier work it was found that body-weight maintenance did not entail cessation of growth. At body-weight maintenance 2·8 g N, 3·13 g Ca and 1·64 g P were stored daily.

## REFERENCES

Albanese, A. A. & Irby, V. (1944). *J. biol. Chem.* **153**, 583.
Armsby, H. P. & Fries, J. A. (1911). *Bull. U.S. Dep. Agric.* no. 128.
Blackwood, J. H., Morris, S. & Wright, N. C. (1936). *J. Dairy Res.* **7**, 228.
Blaxter, K. L. & Howells, A. (1951). *Brit. J. Nutrit.* **5**, 25.
Blaxter, K. L. & Wood, W. A. (1951*a*). *Brit. J. Nutrit.* **5**, 11.
Blaxter, K. L. & Wood, W. A. (1951*b*). *Brit. J. Nutrit.* **5**, 29.
Blaxter, K. L. & Wood, W. A. (1951*c*). *Brit. J. Nutrit.* **5**, 55.
Duncan, C. W., Huffman, C. F. & Robinson, C. S. (1935). *J. biol. Chem.* **108**, 35.
Filmer, J. F. (1948). *Rep. N.Z. Dep. Agric.* 1947–8.
Filmer, J. F. (1949). *Rep. N.Z. Dep. Agric.* 1948–9.
Fingerling, G. (1908). *Landw. VersSta.* **68**, 141.
Fisher, R. A. (1925). *Statistical Methods for Research Workers*, 1st ed. Edinburgh: Oliver and Boyd.
Fiske, C. H. & Subbarow, Y. (1925). *J. biol. Chem.* **66**, 375.
Folin, O. (1914). *J. biol. Chem.* **17**, 469.
Hamilton, T. S. (1937). Thesis, University of Illinois.
King, E. J. (1946). *Microanalysis in Medical Biochemistry*. London: J. and A. Churchill Ltd.
Krüger, M. & Schmidt, J. (1905). *Hoppe-Seyl. Z.* **45**, 1.
McCrudden, F. H. (1911–12). *J. biol. Chem.* **10**, 187.
Ritzman, E. G. & Benedict, F. G. (1938). *Publ. Carneg. Instn*, no. 494.
Shohl, A. T. (1939). *Mineral Metabolism*. New York: Reinhold Publishing Corporation.
Smith, T. & Little, R. B. (1924). *J. exp. Med.* **39**, 303.
Soxhlet, F. (1878). *Ber. VerSta., Wien*, no. 1.
Tomme, M. F. & Taranenko, G. A. (1939). *Byull. vsesoyuz. Akad. sel. khoz. Nauk. Im. Lenina*, no. 10 p. 36.

Treichler, R. & Mitchell, H. H. (1941). *J. Nutrit.* **22**, 333.
Van Slyke, D. D. & Cullen, G. E. (1910). *J. biol. Chem.* **24**, 117.
Waters, H. J. (1908). *Proc. Soc. Prom. agric. Sci.,* *N.Y.,* 29th Mtg, p. 71.
Waters, H. J. (1910). *Rep. Kans. St. Bd agric.* **113**, 59.
Wood, T. B. & Hill, A. V. (1914). *J. agric. Sci.* **6**, 252.
Wood, T. B. & Yule, G. U. (1914). *J. agric. Sci.* **6**, 233.
Young, E. G. & Conway, C. F. (1942). *J. biol. Chem.* **142**, 839.

# The Nutrition of the Young Ayrshire Calf

## 6. The Utilization of the Energy of Whole Milk

BY K. L. BLAXTER (IN RECEIPT OF A SENIOR AWARD OF THE
AGRICULTURAL RESEARCH COUNCIL)

*Hannah Dairy Research Institute, Kirkhill, Ayr*

Two series of experiments with calves to determine the net energy value of whole milk have been published, one in Austria (Soxhlet, 1878) and one in Russia (Tomme & Taranenko, 1939). Soxhlet determined carbon and nitrogen balances in three experiments at a high nutritional plane and, from the results he obtained Armsby, (1917) calculated the net availability of the metabolizable energy of whole milk. To accomplish this Armsby assumed that the maintenance requirement of the calf, per unit of surface area, was 10 % higher than that of the adult steer. He commented that the value he obtained was much lower than would be expected on the basis of the application of Rubner's factors of 69 % for protein, 87 % for fat and 94 % for carbohydrate to the proximate principles present in whole milk. Kellner's (1926) computation of the net energy value of whole milk was, however, considerably lower than Armsby's value, and so indeed was Hansson's (1926). These estimates were made by the application of factors, determined by Kellner on mature cattle, to the proximate principles digested by the calf.

Russian workers (Urmaliat, Reinbot & Elitchiev, 1937; Lebehdiev, 1937) realized these large discrepancies between estimates of the nutritive value of cow's milk, and in 1939 Tomme & Taranenko made six determinations of energy balance with young calves given 7–8 l. of whole milk as the sole diet. They calculated that the starch equivalent of whole milk containing 4 % fat was 21·7, a value higher than Kellner's value of 14·7 and lower than Armsby's value of 27·1. It is uncertain from Tomme & Taranenko's paper what method was used to calculate the maintenance requirement upon which the calculation of net energy ultimately depends. It would appear, however, that fasting heat production determined 12–18 h after the last meal was the basis. Blaxter & Wood (1951 *a*), however, have shown that the heat production of the calf determined at this time is markedly affected by the previous plane of nutrition. There is therefore some uncertainty regarding the nutritive value of the gross energy