The maintenance requirement of cows Energy balance experiments with rations of hay and of hay and concentrates

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Summary

Energy, carbon and nitrogen balances were measured for five dry, non-pregnant cows fed at the maintenance level with ten rations of hay or hay and concentrates. The digestibility of the dry matter of the rations varied from 50.9 to 80.1. The maintenance requirement for metabolisable energy increased with a lower digestibility of the ration and also slightly with a higher proportion of digestible energy of protein origin in the digested ration. This was so for rations with and without concentrates.

The first kind of increase was of the size found in our earlier work with hay and given by Breirem (1944), Blaxter (1962) and Armstrong (1964).

A tendency toward the second kind of increase was found in our earlier experiments and in those of Armstrong (1964).

Replacement in the regression computations of maintenance requirement for metabolisable energy at 500 kg body weight on rations or composition of rations, of the ten ration variables by 2–5 variables such as digestibility of energy, crude protein content etc. of the ten rations, resulted in an approx. 30 % higher residual sum of squares. A residual sum of squares more close to the residual sum obtained when the rations were used as ten separate variables might be got, if the contents of digested cellulose, digested hemicelluloses and digested other carbohydrates could have been used instead of digested crude fibre and digested N-free extractives.

In the present experiments there was no significant change of maintenance requirement of the same animal in the course of time, nor were there significant carry-over effects. Comments are given on the influence of changes of the fill of the gastrointestinal tract on the maintenance requirement, and on the question whether it is allowed to accept a slightly higher residual error for predicted maintenance requirements by omitting the determination of digestibility.

1. Introduction

At many laboratories experiments to determine the maintenance requirement for metabolisable or net energy of cows and sheep have been performed. Usually either only hay or only mixed rations were the objects of the investigations. In this study the requirement on rations of hay is compared with the requirement on mixed rations of the same hay and concentrates.

2. Experimental

2.1. Hays

In 1962 early and late cut hay was harvested from two fields and in 1963 from

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Table 1. Details on hay making

Kind of hay	*Field*	*Cut*	*Drying method*	*Rain*		*Brought indoors*	*Barndried*
				while not on tripods	*while on tripods*		
Early hay 1962 I	1	1.VI	on tripods 6.VI	hardly any	much	25.VII	no
Late hay 1962 I	1	7.VII	on tripods 10.VII	hardly any	much	25.VII	no
Early hay 1962 II	6	4.VI	on tripods 7.VI	hardly any	much	25.VII	no
Late hay 1962 II	6	9.VII	often turned	hardly any		23.VII	no
Early hay 1963	14	1.VI	often turned	hardly any		5.VI	yes
Late hay 1963	14	2.VII	often turned	hardly any		5.VII	yes

one field. Each field produced both an early and a late cut hay, the herbage being cut from alternative strips. Table 1 gives details on methods of hay making and weather.

2.2. Animals

Initially four dry, non-pregnant Friesian cows were used. After seven experiments animal Dora was replaced by animal Griet as the separation of urine and faeces with Dora was rather difficult. All animals were trained to the experimental routine before the experiments began. Their age during experiment R 58 was about 5 years. Animal 4 refused its feed in the preliminary period of experiment R 54, but recovered after a few days.

2.3. Plan of experiments (Table 2)

During the first four experiments (R 51–R 54) the hays 1962 II were fed to the four animals at the maintenance level, either alone or with cornmeal and groundnutmeal. In the latter case the amount of hay was reduced to 50 % and such quantities of cornmeal and groundnutmeal were given so that the estimated quantities of digestible crude protein and digestible organic matter of the mixed ration were equal to those of the ration of hay alone.
During the next experiment (R 55) only 50 % of the rations of R 54 was fed.
The experiments R 56 and R 57 consisted of a reversal trial with the early and late cut hay 1962 I, the hays were fed at the maintenance level.
In the experiments R 58–60 again hay 1962 I was used, this time either alone or with cornmeal and groundnutmeal in the same way as during R 51–54 with hay 1962 II.
The experiments R 61–62 were meant to be a reversal difference trial with feeding levels at 1 × maintenance and 1½ × maintenance with the early and late cut hay 1963. During a period of some days prior to the experiment the late cut hay was not eaten in a sufficient amount at the high level, therefore this level was reduced to the ½ × maintenance level. During the experiments R 63, 64, 65, 68 either the hays 1962 I or 1963 were fed at the maintenance level to study the variation in maintenance requirement with respect to time. During earlier experiments with hay rations higher requirements were sometimes found at the end of the stall-period and lower at its begining when the animals had been outdoors for some weeks (VAN Es et al., 1964). This effect may have been due to a deficiency or lack of exercise. Therefore copper, cobalt and vitamins A and D_3 were added to the ration of two

Table 2. Date of the experiments, and rations and body weights of the cows

Experiment (No. and month)	Food	Cow 1 (Kee A)		Cow 2 (Dora)		Cow 3 (Corrie 14)		Cow 4 (Anna 3)	
		food	(body weight)	food	(body weight)	food	(body weight)	food	(body weight)
R 51 II–1963	hay 1962 II	5440 g E[1]		2630 g E[1]		7990 g L[2]		4390 g L[2]	
	cornmeal	—	(454 kg)	1390 g	(438 kg)	—	(429 kg)	2170 g	(504 kg)
	groundnutmeal	—		540 g		—		80 g	
R 52 III–1963	hay 1962 II	8090 g L		4000 g L		5130 g E		2760 g E	
	cornmeal	—	(494 kg)	1955 g	(463 kg)	—	(426 kg)	1456 g	(482 kg)
	groundnutmeal	—		60 g		—		60 g	
R 53 IV–1963	hay 1962 II	4352 g L		8500 g L		2545 g E		5800 g E	
	cornmeal	2205 g	(464 kg)	—	(507 kg)	1400 g	(403 kg)	—	(490 kg)
	groundnutmeal	66 g		—		558 g		—	
R 54 V–1963	hay 1962 II	2392 g E		6000 g E		4004 g L		8500 g L	
	cornmeal	1316 g	(435 kg)	—	(468 kg)	2029 g	(421 kg)	—	(496 kg)
	groundnutmeal	525 g		—		61 g		—	
R 55 VI–1963	hay 1962 II	1196 g E		3000 g E		2002 g L		4250 g L	
	cornmeal	658 g	(408 kg)	—	(435 kg)	1014 g	(395 kg)	—	(462 kg)
	groundnutmeal	262 g		—		30 g		—	
R 56 X–1963	hay 1962 I	8000 g L	(508 kg)	6200 g E	(515 kg)	6000 g E	(464 kg)	8800 g L	(526 kg)
R 57 XI–1963	hay 1962 I	5100 g E	(468 kg)	7200 g L	(537 kg)	6901 g L	(486 kg)	5600 g E	(486 kg)
				Cow 2a (Griet 37)					
R 58 I–1964	hay 1962 I	6400 g L		3030 g L		4500 g E		2420 g E	
	cornmeal	—	(488 kg)	1840 g	(501 kg)	—	(456 kg)	1600 g	(468 kg)
	groundnutmeal	—		—		—		220 g	
R 59 II–1964	hay 1962 I	2880 g L		6720 g L		2100 g E		5700 g E	
	cornmeal	1750 g	(458 kg)	—	(515 kg)	1390 g	(446 kg)	—	(488 kg)
	groundnutmeal	—		—		190 g		—	
R 60 III–1964	hay 1962 I	5000 g E		2800 g E		5800 g L		3000 g L	
	cornmeal	—	(459 kg)	1850 g	(498 kg)	—	(475 kg)	1800 g	(481 kg)
	groundnutmeal	—		250 g		—		—	
R 61 V–1964	hay 1963	8500 g L	(506 kg)	5500 g E	(507 kg)	3700 g L	(439 kg)	9000 g E	(524 kg)
R 62 VI–1964	hay 1963	4200 g L	(456 kg)	9000 g E	(546 kg)	7500 g L	(477 kg)	5700 g E	(511 kg)
R 63 VII–1964	hay 1962 I	7000 g L	(471 kg)	5100 g E	(526 kg)	5700 g L	(459 kg)	5200 g E	(501 kg)
R 64 VII–1964	hay 1963	7000 g L	(474 kg)	5900 g E	(530 kg)	6300 g L	(469 kg)	5700 g E	(494 kg)
R 65 IX–1964	hay 1963	—		6300 g E	(542 kg)	6300 g L	(470 kg)	—	
R 68 XI–1964	hay 1963	—		6000 g E	(534 kg)	6300 g L	(467 kg)	—	

[1] E = early cut hay.
[2] L = late cut hay.

Table 3. Composition of the feed intake on a dry matter basis

Hay	*Concentr.*	*% CP*	*(CV)*	*% CFAT*	*(CV)*	*% CF*	*(CV)*	*% NFE*	*(CV)*	*% MM*	*(CV)*	*% C*	*(CV)*	*cal./g*	*(CV)*	*Number of experiments*
E 1962 II	no	21.70	1.4	3.45	2.8	22.13	0.9	41.42	0.5	11.26	2.0	44.86	0.8	4404	0.3	5 (R 51–55)
E 1962 II	yes	22.29	1.8	3.54	2.8	14.42	2.6	51.52	1.1	8.19	4.8	45.06	0.5	4456	0.5	5 (R 51–55)
L 1962 II	no	10.61	1.4	1.51	1.9	37.04	1.9	42.80	0.9	7.99	10.0	45.50	1.1	4394	1.0	5 (R 51–55)
L 1962 II	yes	11.17	0.8	2.47	1.0	25.56	1.0	53.80	0.8	6.96	7.8	45.22	0.7	4390	0.7	5 (R 51–55)
E 1962 I	no	15.12	0.8	3.16	2.4	23.88	0.6	47.39	0.6	10.40	2.1	44.32	0.5	4309	0.7	7 (R 56–60)
E 1962 I	yes	15.57	0.7	3.52	3.1	15.53	1.0	57.99	0.4	7.35	2.3	44.86	0.1	4375	0.1	3 (R 58–60)
L 1962 I	no	9.21	0.6	1.75	2.4	35.00	0.5	44.84	0.6	9.15	4.0	44.38	0.5	4277	0.7	7 (R 56–60)
L 1962 I	yes	9.71	0.9	2.75	4.4	23.06	0.2	57.45	0.4	6.99	1.5	44.73	0.3	4329	0.3	3 (R 58–60)
E 1963	no	17.84	0.2	3.46	0.4	27.19	0.3	40.77	0.3	10.70	2.5	44.46	0.3	4355	0.3	4 (R 61–62)
L 1963	no	11.63	0.3	2.24	0.4	32.84	0.3	43.60	0.3	9.65	2.9	44.43	0.3	4300	0.3	4 (R 61–62)

CV = coefficient of variation
CP = crude protein
MM = mineral matter
DM = dry matter
GE = gross energy
HEXP = heat expenditure
W = body weight
CFAT = crude fat
CF = crude fibre
C = carbon
OM = organic matter
DE = digestible energy
NFE = N-free extractives
cal./g = calorific value
DMI = dry matter intake
ME = metabolisable energy
N-, C- and ENBAL = N-, C- and energy balance
$M_{m,500}$ = maintenance requirement of ME if W = 500 kg

Table 4. Apparent digestibility of the rations

Hay	*Concentr.*	*DM* [1]	*(CV)*	*OM*	*(CV)*	*CP*	*(CV)*	*CFAT*	*(CV)*	*CF*	*(CV)*	*NFE*	*(CV)*	*C*	*(CV)*	*kcal.*	*(CV)*	*Number of experiments*
E 1962 II	no	73.7	1.6	76.7	1.5	71.8	1.7	57.1	3.6	80.1	1.8	79.1	1.3	74.0	1.8	72.9	1.7	4 (R 51–54)
E 1962 II	yes	80.1	1.8	83.0	1.6	75.7	1.9	72.1	4.1	80.1	2.7	87.6	1.6	80.8	1.7	80.1	1.7	4 (R 51–54)
L 1962 II	no	50.9	1.9	53.1	1.7	44.1	1.5	23.2	46.7	58.8	1.8	51.5	1.8	49.7	1.5	48.9	1.7	3 (R 51–53)
L 1962 II	yes	62.4	1.7	64.9	1.8	50.5	4.4	63.5	3.2	58.0	2.3	71.3	1.8	61.8	2.0	61.2	2.0	4 (R 51–54)
E 1962 I	no	77.1	1.8	79.9	1.9	67.4	2.2	60.6	0.4	83.4	2.3	83.5	1.7	77.0	2.0	75.8	2.0	4 (R 56–57)
		75.7	1.5	78.4	1.4	65.0	2.2	60.4	3.4	82.3	1.9	82.0	1.3	75.4	1.5	74.1	1.6	3 (R 58–60)
E 1962 I	yes	81.3	1.7	83.5	1.5	70.4	4.4	76.1	3.5	79.4	1.7	88.5	0.9	81.2	1.6	80.3	1.7	3 (R 58–60)
L 1962 I	no	62.0	1.7	64.2	1.6	49.2	3.6	41.4	6.7	67.6	2.1	65.5	1.6	60.6	1.7	59.5	1.8	4 (R 56–57)
		61.9	1.1	64.1	1.1	48.8	1.6	48.2	2.3	66.8	1.5	65.7	1.6	60.6	0.8	59.5	0.7	3 (R 58–60)
L 1962 I	yes	71.4	1.8	73.8	1.9	52.5	5.6	71.2	2.7	67.1	3.7	80.1	0.9	70.8	2.2	70.0	2.3	3 (R 58–60)
E 1693	no	69.9	2.0	71.8	2.2	69.0	1.0	52.2	3.1	73.8	3.5	73.3	2.3	68.5	2.4	67.4	2.3	4 (R 61–62)
L 1963	no	59.2	1.5	60.7	1.4	58.0	1.6	42.5	9.4	59.3	2.6	63.5	0.7	57.5	1.5	56.6	1.7	4 (R 61–62)

[1] Abbreviations: see Table 3.

(No. 1 and No. 4) of the animals. The same two animals also were allowed free exercise in a paved yard outdoors (R 63, R 64). The maintenance requirement of the animals 2 and 3 which remained indoors was determined once more in R 65 after the animals had been given small quantities of copper, cobalt and vitamins A and D_3 in addition to their ration. Their maintenance requirement finally was determined in R 68 after their having been at pasture for two months.
All animals were given daily 30 g NaCl.

2.4. Methods

The preliminary and experimental periods of the experiments R 51–55 lasted 12 and 14 days, respectively, those of R 56–62 19 and 16 days, respectively. In the experimental periods 2 24-hour respiration trials were performed three times with each animal. The preliminary and experimental periods of R 63–65 lasted 15 and 6 days, respectively, those of R 68 17 and 5 days. Only 2 24-hour respiration trials were performed in these four experiments.
Technical and analytical methods as described earlier (VAN Es, 1961, 1966) have been used. In the experiments R 63, 64, 65 and 68 only dry matter intake, faecal dry matter and respiratory gasexchange were measured. From these data metabolisable energy, heat expenditure and average energy balance were computed with the aid of data obtained from the earlier completed balances in which the animals had been fed the same hays.
Factors and constants recommended by the 3rd Symposium on Energy Metabolism of the European Association of Animal Production, Troon, 1964, have been used.

3. Results

3.1. Composition, digestibility and metabolisability of the rations

Ration late hay 1962 II was not eaten completely, feed residues amounted to 5–15 % of the amount given. With all other rations no feed residues or only very small quantities were left. Table 3 gives the composition of the food taken in by the animals and also the coefficients of variation of the component percentages of the three to seven times that the same rations were fed to the animals. The coefficients of variation are low, although slightly higher than those found within an experiment. In the latter case only variation due to analysis and sampling is involved. In the present experiments there was another source of variation due to the fact that neither the concentrates nor the hay used for all experiments came from thoroughly mixed lots. Before the rations were weighed, usually for one, sometimes for two experiments, from the only roughly mixed big lots minor quantities of sufficient size were taken and mixed thoroughly.
There was a considerable difference in composition between the early and the late cut hays, the former having higher crude protein, crude fat and ash contents and lower crude fibre contents. The four rations with concentrates contained 0.5 % more crude protein, 0.1–1.0 % more crude fat, 8–12 % less crude fibre, 10–13 % more N-free extractives and 1–3 % less ash than the corresponding four rations without concentrates.
The average apparent digestibilities of the rations are given in Table 4.
They are averages of results obtained with three or four different animals, their coef-

Table 5. Composition of the apparently digested organic matter

Hay	Concentr.	CP [1]	(CV)	CFAT	(CV)	CF	(CV)	NFE	(CV)	C	(CV)	cal./g	(CV)	Number of experiments
E 1962 II	no	22.9	1.6	2.9	4.5	26.1	1.1	48.2	0.5	48.8	1.0	4718	0.2	5 (R 51–55)
E 1962 II	yes	22.2	2.1	3.4	6.5	15.1	3.3	59.3	0.5	47.8	0.2	4684	0.2	5 (R 51–55)
L 1962 II	no	9.6	2.5	0.8	34.4	44.6	1.5	44.9	1.7	46.4	1.3	4391	0.7	5 (R 51–55)
L 1962 II	yes	9.4	4.5	2.6	3.4	24.7	2.2	63.2	1.3	46.4	0.6	4452	0.5	5 (R 51–55)
E 1962 I	no	14.1	0.7	2.7	3.6	27.9	1.0	55.3	0.4	47.6	0.5	4553	0.8	7 (R 56–60)
E 1962 I	yes	14.2	3.7	3.5	5.1	15.9	1.0	66.4	1.1	47.1	0.2	4543	0.2	3 (R 58–60)
L 1962 I	no	7.8	2.7	1.3	10.9	40.4	0.9	50.5	0.9	46.2	0.3	4369	0.4	7 (R 56–60)
L 1962 I	yes	7.4	4.4	2.9	3.9	22.6	1.9	67.1	0.7	46.2	0.4	4414	0.6	3 (R 58–60)
E 1963	no	19.2	1.3	2.8	2.5	31.3	1.7	46.6	0.9	47.5	0.2	4585	0.2	4 (R 61–62)
L 1963	no	12.3	1.1	1.7	8.5	35.5	1.4	50.5	1.0	46.6	0.2	4440	0.3	4 (R 61–62)

[1] Abbreviations: see Table 3.

Table 6. Digestible energy, energy in methane and urine, metabolisable energy, all as a percentage of energy intake

Hay	Concentr.	100 DE [1] / GE	(CV)	100 CH_4-energy / GE	(CV)	100 urine-energy / GE	(CV)	100 ME / GE	(CV)	100 ME / DE	(CV)	% protein energy in DE [2]	Number of experiments
E 1962 II	no	72.9	1.7	7.7	6.2	7.2	2.6	57.9	1.9	79.5	1.0	27.6	4 (R 51–54)
E 1962 II	yes	80.1	1.7	8.5	5.3	7.2	7.0	64.3	1.8	80.3	1.3	26.6	4 (R 51–54)
L 1962 II	no	48.9	1.7	6.6	1.9	3.1	10.1	39.2	2.2	80.1	0.8	12.3	3 (R 51–53)
L 1962 II	yes	61.2	2.0	7.8	7.6	3.1	10.3	50.2	1.7	82.1	1.4	11.9	4 (R 51–54)
E 1962 I	no	75.8	2.0	8.8	2.9	6.2	16.3	60.7	0.6	80.1	1.5	17.6	4 (R 56–57)
		74.1	1.6	8.9	2.4	5.7	3.0	59.5	1.8	80.3	0.4	17.7	3 (R 58–60)
E 1962 I	yes	80.3	1.7	9.0	1.7	5.5	5.5	65.8	1.4	81.9	0.3	17.7	3 (R 58–60)
L 1962 I	no	59.5	1.8	8.0	2.0	3.3	4.0	48.2	1.8	81.1	0.4	10.0	4 (R 56–57)
		59.5	0.7	8.0	2.6	3.3	7.2	48.2	0.5	81.0	0.7	10.1	3 (R 58–60)
L 1962 I	yes	70.0	2.3	8.6	1.0	3.6	6.1	57.8	2.3	82.6	0.3	9.6	3 (R 58–60)
E 1963	no	67.4	2.3	7.5	4.3	6.5	4.3	53.4	2.0	79.2	0.5	23.8	4 (R 61–62)
L 1963	no	56.6	1.7	7.0	2.4	4.9	11.5	44.7	0.8	78.9	1.2	15.8	4 (R 61–62)

[1] Abbreviations: see Table 3.

[2] Equal to $\{$(grams digested crude protein) $\times 5.7 \times 100\}$ / (digested energy).

ficient of variation therefore also includes variation due to between-animal variation in digestibility. These coefficients of variation nevertheless are low. All components of the early cut hays were better digested than those of the corresponding late cut hays. The replacement of half of the hay by concentrates led to higher digestibilities of all components except crude fibre, the increase in digestibility of dry and organic matter, N-free extractives, C and energy was greater for the late than for the early hays as might be expected. This replacement hardly changed the contents of crude protein, C and energy of the digested organic matter (Table 5), however, it decreased its content of crude fibre and it increased its content of N-free extractives.
The digestibility of dry and organic matter, and of energy tended to be one or two units higher during the experiments with ½ × maintenance rations (R 55, R 61 cow 3, R 62 cow 1). The digestibilities of all components of the late hay ration of cow 4 in R 54 were very low. This animal refused its feed in the preliminary period of this experiment but recovered after some days. In the further computations the results obtained with this animal in this experiment usually have been omitted. The digestibilities of the dry matter in the experiments R 63, 64, 65 and 68 did not differ significantly from those of corresponding rations in earlier experiments.

The average energy losses due to methane and urine and also the contents of metabolisable energy as a percentage of energy intake of the rations are given in Table 6. Replacement of half of the hay of the ration by concentrates tended to increase the percentage of gross energy lost as methane. It also increased the ratio 100 ME/DE by about one unit. Higher urinary energy losses occurred with the early cut hays than with the late cut hays, a fact found earlier (BROUWER et al., 1964).

3.2. Regression of digestible and metabolisable energy on digested components of the rations

The multiple regression of digestible energy (y_1, kcal.) or metabolisable energy (y_2, kcal.) on digested crude protein (x_1, g), digested crude fat (x_2, g), digested crude fibre (x_3, g) and digested N-free extractives (x_4, g) was computed with and without a constant. This has been done with all 205 maintenance experiments so far performed at this laboratory (R 1–62), of which 136 were rations of hay and 69 rations of hay and concentrates:

Regression equation		RSD [1]	$\frac{100\ \text{RSD}}{\bar{y}}$	n	ration
$y_1 = 6.23x_1 + 5.71x_2 + 4.03x_3 + 4.56x_4$	—476	140	0.8	136	hay
$y_1 = 5.93x_1 + 7.50x_2 + 3.97x_3 + 4.36x_4$		147	0.8	136	hay
$y_1 = 5.74x_1 + 9.32x_2 + 4.49x_3 + 3.87x_4$	+381	88	0.5	69	hay + conc.
$y_1 = 5.70x_1 + 11.70x_2 + 4.48x_3 + 3.94x_4$		109	0.6	69	hay + conc.
$y_1 = 5.81x_1 + 9.33x_2 + 4.12x_3 + 4.13x_4$	+118	145	0.8	205	all rations
$y_2 = 4.45x_1 + 5.91x_2 + 3.21x_3 + 3.73x_4$	—457	215	1.6	136	hay
$y_2 = 3.76x_1 + 10.53x_2 + 2.96x_3 + 3.79x_4$	—406	124	0.9	69	hay + conc.
$y_2 = 4.27x_1 + 6.97x_2 + 3.16x_3 + 3.72x_4$	—341	192	1.4	205	all rations

[1] RSD = residual standard deviation; n = number of experiments.

All regression coefficients were statistically significant. The standard deviations of these coefficients of the y_1-equations were less than 0.1 for the hay rations, less than 0.2 for x_1, 1.1 for x_2 and 0.1 for x_3 and x_4 for the mixed rations. These coefficients of the y_1-equations are close to the calorific values of protein, fat and carbohydrates. Similar results were obtained by SCHIEMANN et al. (1963) with concentrates. It is clear that digestible and metabolisable energy may be computed with high precision from the digestible components x_1 — x_4 of the ration.

3.3. The N-, C- and energy balances

The main data on the balances of all experiments are given in Table 7. A limited number of the complete balance sheets (VAN Es, 1966) may be obtained at request.
Except for those of the experiments with rations fed at ½ or 1½ times the maintenance level and of cow 4 in R 54, none of the balances differed considerably from zero (N-balance: +11 to —9 g; C-balance: +184 to —130 g; energy balance: +2122 to —1698 kcal.).
As in earlier experiments there was a difference of 1–2 % of the energy intake between the energy balance computed from C- and N-balance and the energy balance computed from metabolisable energy and heat expenditure.

3.4. The maintenance requirement of metabolisable energy

To obtain comparable data on the requirement of metabolisable energy for maintenance, the measured intakes of metabolisable energy should be corrected to zero energy balance and converted to figures applying to animals with equal body weight.
Some information on factors for correction to zero energy balance might be obtained from the experiments with ½ and 1½ times maintenance rations together with the experiments with maintenance rations which immediately preceded or followed them (R 54 and 55 with animals 1–3, R 61 and 62 with animals 1, 2a, 3 and 4; experiments R 54 and 55 with animal 4 were excluded because of the abnormally low digestibility and high heat expenditure of this animal in R 54; in the preliminary period of this experiment the animal had refused food for some days). Thus the number of available difference trials was five below and two above energy equilibrium. In the case that one of the two experiments of a difference trial had a positive and the other a negative energy balance it was assumed that the efficiency of the utilisation of metabolisable energy for lipogenesis was roughly 0.8 times the efficiency for maintenance; thus the balance having the smallest absolute value was either multiplied or divided by 0.8. Correction for differences in body weight in both parts of a difference trial was done by using the 0.75 power. The efficiencies for maintenance of the rations early hay 1962 II without and with concentrates, late hay 1962 II with concentrates and (twice) late hay 1963 were 71, 63, 63, 56 and 66 %, respectively, those for lipogenesis of the ration early hay 1963 (twice) were 51 and 54 %. Without a correction for differences in body weight lower values by 5–7 units and in one case by 3 units were obtained.
As mentioned above in the experiments with rations fed at the maintenance level, most energy balances were small, therefore correction of intake of metabolisable energy to zero energy balance with slightly incorrect efficiency-values would hardly invalidate the results. It was concluded that an efficiency of the utilization of metabolisable energy of 50 % in the case of positive balances and one 66.7 % in the

Table 7. Balances and other data

Hay	Conc.	Exp.	An.	DMI [1] (g)	CP (% in DM)	CF (% in DM)	GE (kcal.)	DE (kcal.)	DE/GE (%)	ME (kcal.)	ME/GE (%)	HEXP (kcal.)	N-BAL (g)	C-BAL (g)	ENBAL [2] (kcal.)	W (kg)	$M_{m,500}$ (kcal.)
E 62 II	—	R 51	1	4940	21.30	22.46	21,791	15,738	72.22	12,432	57.05	12,333	—2	31	245	454	12,838
		R 52	3	4680	22.09	22.13	20,648	14,862	71.97	11,973	57.98	11,767	10	37	312	426	12,797
		R 53	4	5186	21.56	22.12	22,787	16,563	72.68	13,037	57.21	13,134	4	4	—30	490	13,281
		R 54	2	5394	21.84	22.04	23,822	17,779	74.63	14,173	59.49	12,595	11	182	1895	468	10,910
		R 55	2	2710	21.72	21.92	11,904	9,086	76.32	7,085	59.51	9,495	—2	—169	—2250	435	
E 62 II	+	R 51	2	4115	22.04	14.73	18,362	14,891	81.09	11,839	64.47	11,400	3	54	550	438	11,858
		R 52	4	4361	21.74	14.70	19,473	15,473	79.45	12,285	63.09	12,137	2	29	253	482	12,107
		R 53	3	4057	22.75	14.65	18,177	14,252	78.40	11,605	63.84	10,853	7	74	822	403	11,708
		R 54	1	3806	22.49	14.03	16,961	13,783	81.26	11,167	65.83	11,226	10	11	18	435	12,355
		R 55	1	1918	22.43	14.00	8,486	6,903	81.34	5,361	63.17	8,730	—8	—261	—3287	408	
L 62 II	—	R 51	3	6438	10.54	37.46	28,510	13,729	48.15	10,989	38.54	12,033	—7	—46	—790	429	13,655
		R 52	1	6117	10.86	36.78	27,079	13,225	48.83	10,505	38.79	12,314	—7	—130	—1698	494	13,170
		R 53	2	7025	10.54	37.98	31,030	15,441	49.76	12,466	40.17	12,678	1	13	—24	507	12,373
		R 54	4	5896	10.51	36.90	25,830	11,536	44.66	8,988	34.79	13,440	—9	—364	—4461	496	(15,774)
		R 55	4	3799	10.64	36.09	16,414	7,812	47.59	6,117	37.27	11,039	—12	—368	—4716	462	
L 62 II	+	R 51	4	5829	11.28	25.31	25,732	16,137	62.71	12,974	50.41	13,113	—4	2	—47	504	12,966
		R 52	2	5349	11.19	25.85	23,660	14,459	61.11	11,985	50.65	11,356	7	67	718	463	11,175
		R 53	1	5917	11.03	25.83	25,982	15,503	59.66	12,729	48.99	12,051	3	69	760	464	11,854
		R 54	3	5441	11.14	25.43	23,797	14,591	61.31	12,102	50.85	11,146	—0	110	1160	421	11,127
		R 55	3	2737	11.21	25.39	11,912	7,760	65.14	6,188	51.95	8,309	—11	—153	—1987	395	
E 62 I	—	R 56	2	5334	15.05	23.85	22,968	17,916	78.00	14,047	61.15	12,305	4	162	1866	515	10,088
		R 56	3	5164	15.05	23.85	22,231	16,610	74.71	13,458	60.53	11,476	3	184	2122	464	9,743
		R 57	1	4414	15.05	23.77	19,193	14,523	75.67	11,659	60.74	11,195	1	58	591	468	11,009
		R 57	4	4836	15.06	23.79	21,036	15,716	74.71	12,681	60.28	12,166	1	64	655	486	11,615
		R 58	3	3976	15.08	23.82	17,050	12,852	75.38	10,347	60.68	10,080	5	47	413	456	10,202
		R 59	4	5119	15.25	23.89	22,020	16,067	72.96	12,919	58.66	11,972	7	108	1128	488	10,858
		R 60	1	4522	15.33	24.20	19,324	14,308	74.04	11,435	59.17	11,407	5	33	208	459	11,747
		R 63 [3]	2a	4565					77.2	12,158	61.9	12,160			146	524	11,455
		R 63 [3]	4	4657					73.0	11,727	58.5	12,414			—539	500	12,536

E 62 I	+	R 58	4	3720	15.49	15.37	16,304	12,870	78.93	10,566	64.81	10,275	3	43	408	468	10,245
		R 59	3	3293	15.53	15.55	14,405	11,588	80.44	9,487	65.86	9,184	1	44	426	446	9,408
		R 60	2a	4397	15.70	15.67	19,219	15,686	81.61	12,808	66.64	11,097	4	175	1931	498	8,971
L 62 I	—	R 56	1	6998	9.22	35.02	30,091	17,810	59.18	14,427	47.94	13,175	2	127	1410	508	11,469
		R 56	4	7629	9.24	35.12	32,898	19,296	58.65	15,716	47.77	14,465	2	125	1399	526	12,435
		R 57	2	6299	9.19	35.21	27,074	16,003	59.10	12,907	47.67	12,314	1	60	668	537	10,967
		R 57	3	6089	9.15	35.07	26,069	15,920	61.07	12,915	49.54	11,701	1	119	1344	486	10,446
		R 58	1	5699	9.33	34.99	24,342	14,453	59.37	11,796	48.45	11,573	4	55	444	488	11,107
		R 59	2a	6076	9.18	34.86	25,780	15,259	59.19	12,373	47.99	12,357	0	30	194	515	11,721
		R 60	3	5272	9.22	34.74	22,352	13,417	60.02	10,790	48.27	10,532	—0	48	431	475	10,317
		R 63 [3]	1	6368					58.0	12,775	46.4	12,352			578	475	12,074
		R 63 [3]	3	5188					61.0	10,940	48.8	10,367			728	458	10,129
L 62 I	+	R 58	2a	4294	9.74	23.04	18,665	13,395	71.76	11,069	59.30	11,034	—7	29	218	501	10,616
		R 59	1	4152	9.62	23.12	17,939	12,445	69.37	10,315	57.50	10,419	—0	10	12	458	10,991
		R 60	4	4317	9.78	23.02	18,655	12,827	68.75	10,570	56.65	11,542	0	—55	—829	481	12,163
E 63	—	R 61	2a	4968	17.82	27.13	21,597	14,966	69.29	11,825	54.75	12,106	1	6	—105	507	11,859
		R 61	4	7957	17.89	27.32	34,812	22,779	65.43	18,136	52.09	15,576	9	241	2754	524	
		R 62	2a	8100	17.86	27.19	35,291	23,803	67.44	18,873	53.47	15,930	7	274	3157	546	
		R 62	4	5143	17.82	27.14	22,362	15,124	67.63	11,915	53.28	12,627	—2	—33	—556	511	12,544
		R 64 [3]	2a	5207					70.1	12,523	55.3	13,012			—324	530	12,452
		R 64 [3]	4	5021					66.5	11,452	52.5	11,564			53	494	11,449
		R 65 [3]	2a	5560					68.9	13,145	54.4	12,487			823	542	10,824
		R 68 [3]	2a	5295					67.5	12,262	53.3	12,012			415	534	10,882
L 63	—	R 61	1	7683	11.68	32.96	33,165	18,414	55.52	14,660	44.20	14,115	0	88	818	506	12,907
		R 61	3	3376	11.60	32.74	14,476	8,328	57.53	6,505	44.93	8,996	—11	—187	—2378	439	
		R 62	1	3827	11.61	32.78	16,427	9,419	57.34	7,366	44.83	9,996	—10	—199	—2528	456	
		R 62	3	6806	11.65	32.89	29,317	16,471	56.18	13,152	44.86	12,075	3	116	1254	477	11,027
		R 64 [3]	1	6279					55.6	11,984	44.3	12,248			—35	474	12,528
		R 64 [3]	3	5654					57.4	11,136	45.8	10,644			721	469	10,171
		R 65 [3]	3	5631					57.0	11,012	45.4	10,999			242	470	11,028
		R 68 [3]	3	5615					58.3	11,231	46.5	10,895			565	467	10,631

[1] Abbreviations: see Table 3.
[2] Average of energy balances computed from N- and C-balances and from ME and HEXP.
[3] For computation see section 2.4 (*Methods*).

case of negative balances could be used. Similar values were used in earlier work (VAN ES, 1961; BROUWER et al., 1964, p. 57).
As all body weights of the animals were close to 500 kg correction to a weight of 500 kg with the power 0.75 would hardly produce additional error variance.
In the last column of Table 7 the maintenance requirements $M_{m,500}$ computed as explained above are given. They vary from 8971 to 13,655. This variation might be due to the kind of ration fed, differences between the animals, period (time, season), influences due to the ration used in the previous experiment, and error. With the aid of multiple regression the variance was computed for each of these influences, which for brevity were named ration, animal, period, carry-over and random variation. The model used was:

$$M_{m,500} = \overline{M}_{m,500} \times 1 + a_1A_1 + \ldots + a_{k-1}A_{k-1} + (-a_1 - \ldots - a_{k-1})A_k$$
$$+ b_1B_1 + \ldots + b_{l-1}B_{l-1} + (-b_1 - \ldots - b_{l-1})B_l$$
$$+ c_1C_1 + \ldots + c_{m-1}C_{m-1} + (-c_1 - \ldots - c_{m-1})C_m + d_1D_1 + d_2D_2 + e$$

with $\sum_k^1 a_i = 0$, $\sum_l^1 b_i = 0$ and $\sum_m^1 c_i = 0$, thus e.g. for ration k a_k is not used, but $-a_1 - a_2 \ldots - a_{k-1}$. In this equation $\overline{M}_{m,500}$, $a_1, \ldots, a_{k-1}$, $b_1, \ldots, b_{l-1}$, $c_1, \ldots, c_{m-1}$, d_1, d_2 are the regression coefficients, the A's denote the rations, the B's the animals and the C's the experiments, finally D_1 and D_2 are the differences in energy digestibility, and in the protein energy percentage of the digestible energy, respectively, between one experiment and that preceding it. In the 51 experiments with maintenance

Table 8. Multiple regression of $M_{m,500}$ computed in nine ways on mean, five animals and ten rations

Correction [1]		*Residual sum of squares × 0.001*			*n-m*	*R* [2]	*RSD*	*Mean*
of balance	*weight of*	*after mean m = 1*	*after mean + cows m = 5*	*after mean + cows + rations m = 14*				
50/67	0.6	47,166	37,312	6474	25	0.863	509	11,484
% DE	0.6	45,306	36,033	7063	25	0.844	532	11,413
% CF	0.6	48,746	39,236	7021	25	0.856	530	11,445
50/67	0.75	47,579	38,600	7002	25	0.853	529	11,555
% DE	0.75	46,281	38,234	7572	25	0.836	550	11,484
% CF	0.75	49,895	41,465	7638	25	0.847	553	11,517
50/67	1.0	50,727	42,375	8355	25	0.835	578	11,676
% DE	1.0	50,366	43,563	8884	25	0.824	596	11,605
% CF	1.0	54,318	46,878	9139	25	0.832	605	11,638

F (cows) = 10–5 ** F (rations) = 12–10 **

[1] See text.
R = multiple correlation coefficient.
RSD = residual standard deviation.
n = number of experiments.
m = number of independent variables.
F = variance ratio; * = 5 % point, ** = 1 % point of distribution of F, NS = non-significant.

rations (all except R 54 with animal 4) neither carry-over, nor period variation were significant, in contrast to animal and ration variation which were significant. In the following computations therefore attention was only paid to animal and ration variation. The twelve results of the experiments R 63, 64, 65 and 68 were excluded as these experiments were of a shorter length and were only performed to study period variation. There remained 39 results obtained with five animals and ten rations. To see whether the assumption that the influence of the choice of the factors used in correcting intake of metabolisable energy for energy balance and body weight differences was small, was in fact correct, nine differently computed sets of values $M_{m,500}$ were regressed on general mean, animals and rations (Table 8). The correction for energy balance in these sets was calculated either assuming 50 % and 67 % efficiencies of the utilization of ME for gain and loss, respectively, or assuming efficiencies of 0.75 × % DE — 4 (derived from BLAXTER, 1962, p. 247) and 0.3 × % DE + 50.9 (derived from ARMSTRONG, 1964, p. 410), respectively, or efficiencies of — 0.7 × % CF + 65.6 (analysis of BREIREM, 1944) and — 0.5 × % CF + 80 (derived from BROUWER et al., 1964, p. 63), respectively.

The correction for body weight was calculated using the powers 0.6, 0.75 and 1.0. Table 8 shows that the choice of the correction factors hardly influenced the results of the regression computation. The regression coefficients with the corrections 50/67 % and 0.75 were:

Mean 11,555 ± 96 kcal.
Cows 328, —671, —46, —428, 817 (± approx. 200) kcal.
Rations E 62 II 890; L 62 II 1768; E+ 62 II 442; L+ 62 II 215
E 62 I —912; L 62 I —331; E+ 62 I —2128; L+ 62 I —665
E 63 259; L 63 462 (± approx. 250) kcal.

The regressioncoefficients for the other sets differed at the most by approx. 100 kcal. for mean and cows and by approx. 200 kcal. for rations. Their standard deviations were of the same size as those of the above mentioned set.

The influence of the composition of the ration on the maintenance requirement in the regression computations was studied by replacing the ten rations by their contents of 2–5 components. Five combinations of components were used:

a. % DE of GE, % protein kcal. of DE and presence or absence of concentrates,
b. equal to *a* minus concentrates,
c. % crude fibre, % crude protein, both in dry matter taken in, presence or absence of concentrates,
d. equal to *c* minus concentrates,
e. % digestible crude protein, % digestible crude fat, % digestible crude fibre, % digestible N-free extractives and % crude fibre of the dry matter intake.

Prior to the regression computation from each of these percentages of an experiment its average value in all experiments was subtracted. The average values were: % DE of GE 67.81; % protein kcal. of DE 16.89; % crude fibre 25.88; % crude protein 14.30; % digestible crude protein 9.08; % digestible crude fat 1.62; % digestible crude fibre 18.17; and % digestible N-free extract 36.42. Table 9 shows the results of these computations. The residual sums of squares, especially those of method *d*, are higher than those of the earlier method. It is clear that in this respect none

Table 9. Multiple regression of $M_{m,500}$ computed in various ways on mean, five animals and 2–5 ration characteristics

Correction [1] of balance	Correction [1] of weight	Ration characteristic [1]	Residual sum of squares × 0.001	n-m	R	RSD	Regression coefficients of ration-characteristics				
50/67	0.75	a	11,494	31	0.758	609	—124 ± 15;	150 ± 21;	447 ± 231		
„	„	b	12,879	32	0.729	634	—110 ± 14;	137 ± 21			
„	„	c	11,905	31	0.750	620	294 ± 37;	341 ± 44;	2015 ± 374		
„	„	d	23,070	32	0.515	849	129 ± 29;	176 ± 44			
„	„	e	11,137	29	0.766	620	—28 ± 134;	—240 ± 937;	—204 ± 90;	—210 ± 89;	—99 ± 226
„	„	f	11,210	30	0.764	611	24 ± 63;	15 ± 722;	—238 ± 46;	—176 ± 47	
50/67	0.6	a	10,402	31	0.779	579	—123 ± 15;	141 ± 20;	335 ± 220		
„	„	b	11,181	32	0.763	591	—113 ± 13;	131 ± 20			
„	„	c	10,761	31	0.772	589	291 ± 35;	327 ± 42;	1898 ± 355		
„	„	d	20,661	32	0.562	804	136 ± 27;	172 ± 42			
„	„	e	10,131	29	0.785	591	—4 ± 128;	—196 ± 893;	—201 ± 86;	—187 ± 85;	—54 ± 215
„	„	f	10,153	30	0.785	582	24 ± 60;	—56 ± 687;	—220 ± 44;	—169 ± 44	
% DE	0.75	a	14,813	31	0.680	691	—108 ± 17;	155 ± 24;	432 ± 263		
„	„	b	16,107	32	0.652	709	—95 ± 16;	142 ± 23			
„	„	c	14,959	31	0.677	695	260 ± 41;	336 ± 50;	1790 ± 419		
„	„	d	23,763	32	0.487	862	113 ± 29;	190 ± 45			
„	„	e	13,870	29	0.700	692	—84 ± 150;	—367 ± 1045;	—141 ± 101;	—250 ± 100;	—231 ± 252
% CF	„	a	13,502	31	0.729	660	—124 ± 17;	164 ± 23;	605 ± 251		
„	„	b	16,040	32	0.679	708	—106 ± 16;	146 ± 23			
„	„	c	14,814	31	0.703	691	290 ± 41;	358 ± 49;	2118 ± 417		
„	„	d	27,151	32	0.456	921	117 ± 31;	184 ± 48			
„	„	e	12,630	29	0.747	660	—98 ± 143;	—323 ± 997;	—192 ± 96;	—267 ± 95;	—219 ± 240

[1] See text, and footnotes under Table 8. *n-m* = degrees of freedom.

of the five combinations of component-contents could replace the rations completely The combinations *a*, *b*, *c* and *e* could replace them to a considerable extent. With the corrections 50/67 % and 0.75 the residual sum of squares after mean and cows was 38,600,000, after mean, cows and rations was 7,002,000 and after mean, cows and contents of ration *a*, *b*, *c* or *e* was about 12,000,000. Figures of similar size were obtained with the other corrections.

It is interesting to compare the results obtained above with the results from earlier maintenance experiments with rations of hay. In these experiments there was significant period variation, especially if the maintenance requirements of net energy of the same animals in all experiments were supposed to be equal. If these maintenance requirements were supposed to be equal in up to five successive experiments, lasting at the most half a year period variation was less marked. As there were a larger number of animals and many different rations used, it was not possible to treat the results of the earlier experiments in the same manner as those of the present experiments. Therefore both sets were treated in a simpler way. The correction for energy balance was calculated using the efficiencies of utilization of the metabolisable energy for gain and for loss having values of 50 and 67 %, respectively. The correction for body weight was done using the power 0.75. Furthermore it was assumed that the maintenance requirements of net energy for an animal, corrected to a body weight of 500 kg, remained equal for at the most six successive experiments. The resulting maintenance requirements $M_{m,500}$ were treated with multiple regression, with mean, cows, periods, % DE of GE, and % protein kcal. of DE as independent variables (Table 10).

The regression coefficients of the latter two variables were:
R 16–41 —96 ± 38 and 51 ± 60 kcal. (8 early and late hays)
R 42–50 —74 ± 64 and 44 ± 51 kcal. (6 hays, neither early nor late)
R 51–68 —76 ± 25 and 79 ± 41 kcal. (6 early and late hays and mixed rations).

As far as these variables are concerned there is little difference between the three series of experiments. All three had significant animal variation. The first and second series also had significant period variation, even though the results of the same cow which had been used during ten experiments (e.g. six successive ones in autumn and winter and four successive ones in early summer) have been used as if derived from two cows, i.e. six experiments with one and four experiments with the other animal.

Similar results were obtained using another simpler method. To avoid the influence of variation due to cows and to period, instead of one common mean, variable means were used, i.e. each cow had in two experiments its own mean (regression with variable level). The regression coefficients of the variables % DE of GE (*a*) and % protein kcal. of DE (*b*) were:

R 16–41 —76 ± 15 and 27 ± 25 kcal. ($\bar{a}$ = 64.0; $\bar{b}$ = 18.8; RSD 552)
R 42–50 —21 ± 39 and 21 ± 26 kcal. ($\bar{a}$ = 60.2; $\bar{b}$ = 13.7; RSD 488)
R 51–62 —95 ± 15 and 95 ± 25 kcal. ($\bar{a}$ = 67.8; $\bar{b}$ = 16.6; RSD 539)
R 16–62 —79 ± 10 and 50 ± 15 kcal. ($\bar{a}$ = 64.3; $\bar{b}$ = 16.8; RSD 540)

Without % protein kcal. of DE as an independent variable the regression coefficients of % DE of GE were:
R 16–41 —62 ± 9 (RSD 553)
R 42–50 —25 ± 33 (RSD 484)
R 51–62 —50 ± 10 (RSD 648)
R 16–62 —55 ± 7 (RSD 569)

Table 10. Multiple regression of $M_{m,500}$ on mean (M), animals [1] (a), periods (p), % DE of GE (d_1) and % protein kcal. of DE (d_2); earlier and present experiments

Experiments	*Residual sums of squares (× 0.001)*					*n*	*Mean*	*RSD*
	after M	*after M, a*	*after M, a, p*	*after M, a, p, d_1*	*after M, a, p, d_1, d_2*			
R 16–41	73,500	39,651	13,235	4,624	4,460	54	11,741	472
m	1	10	32	33	34			
significance		a **	p **	d_1 **	d_2 NS			
R 51–68	56,367	19,360	15,220	11,812	10,121	51	11,355	678
m	1	13	27	28	29			
significance		a **	p NS	d_1 **	d_2 nearly *			
	after M	*after M, d_2*	*after M, d_2, d_1*	*after M, d_2, d_1, a*	*after M, d_2, d_1, a, p*			
R 42–50	50,930	49,088	46,753	5,305	1,649	33	13,071	342
m	1	2	3	11	19			
significance		d_2 **	d_1 **	a **	p nearly **			

[1] If the same animal had been used in many experiments (= periods), it was considered to be a new animal after the first part of these experiments, actually there were only nine different animals in R 16–41, six in R 42–50 and five in R 51–68.
See also the footnotes under Table 8.

If metabolisability (a) and 6.25 times g urinary N, corrected to a body weight of 500 kg (b), were used as independent variables the coefficients were:
R 16–62 —95 ± 11 and 1.42 ± 0.21 kcal. ($\bar{a}$ = 51.2; $\bar{b}$ = 466; RSD 531), with only a as the independent variable the regression coefficient was —72 ± 8 with RSD 555.
With a = digestibility of dry matter and b = percentage of digestible protein in the dry matter in the food, the coefficients were:
R 16–62 —104 ± 15 and 109 ± 31 kcal. ($\bar{a}$ = 66.5; $\bar{b}$ = 8.5; RSD 540), with only a the regression coefficient was —58 ± 7 and the RSD 571.
With a = % crude fibre of dry matter in the food and b = % digestible crude protein of dry matter in the food, the coefficients were:
R 16–62 101 ± 16 and 35 ± 24 kcal. (RSD 566), the RSD was 563 if only crude fibre was used.
Finally with five variables (percentages digestible crude protein, digestible crude fat, digestible crude fibre and digestible N-free extractives of food dry matter, and percentage of crude fibre in dry matter of food) the coefficients were:
R 16–62 21 ± 52, 661 ± 303, —170 ± 54, —94 ± 32 and 132 ± 72 kcal. (RSD 522).
Again it is not very important which components are used to indicate the properties of each ration.

4. Discussion

4.1. Maintenance requirement and small differences of body weight

Differences in body weight of an animal may result from changes in fill of the gastrointestinal tract and from changes in the amount of tissue present which are due to nutrition being below or above the requirement for maintenance and milk. The second kind of changes involves changes in maintenance requirement, corrections for such changes are usually made in proportion to powers of the body weight which may vary from 0.6 to 1.0. Whether the first change involves changes in maintenance requirement, is not accurately known. BLAXTER (1964, personal communication) assumes that these changes are very small and may be neglected. In our opinion these changes are greater, as to move and to carry a heavier content of the gastrointestinal tract will require additional energy. We therefore prefer to correct also for these changes in body weight using the same power as is used for correcting for the change in the amount of tissue. In practice this has the advantage that measured or estimated body weights may be used in the computation of the requirements, it is thus not necessary to correct for by estimating the content of the gastrointestinal tract.
In the analysis of the results of difference trials, e.g. trials with the same ration fed at two or more feeding levels, most investigators correct for changes in body weight, some with the power 1.0, others with the power 0.75. If the separate experiments in such trials are of a short duration, the changes in body weight from one experiment to another will mainly be due to changes in content of gastrointestinal tract. Blaxter, using experiments of such duration, therefore, does not correct for body weight changes. As our opinion differs from his on this point we prefer not to neglect these differences in body weight.

4.2. Period variation of maintenance requirement

Period variation of maintenance requirement, i.e. variation in the requirements for net energy with the same animal per 500 kg body weight with time, may be due to various causes. Excitement may increase the requirement, e.g. when untrained animals are brought into a respiration chamber which is built in such a way that one animal cannot see or smell other animals. Animals which have been partly accustomed to the experimental routine of experiments using respiration chambers often have up to 10 % higher mainentance requirements, even after two or three weeks of training. About one quarter of the experiments R 16–41 were performed with such poorly trained animals; this may explain some of the period variation found in these trials.
Prolonged feeding of rations which are deficient in one or more vitamins, minerals, or trace-elements will probably also result in less efficient utilization of metabolisable energy, resulting in higher requirements. This may have been the case during the experiments R 42–50 in which only hay of moderate quality was fed. After about five months a considerable increase in maintenance requirement was observed with all the cows. This effect lasted until the end of the series of experiments. The same animals again had lower requirements in other experiments which were performed after they had been out at pasture for some weeks. No significant period variation was observed in the present experiments during which rations of excellent and moderate hay and also rations of hay and concentrates were fed. In this series, moreover, the percentage of experiments performed using poorly trained animals was small. In a later series of experiments initiated in September 1964 no period variation has yet been observed (July 1965). In this series mixed rations with additions of vitamins, minerals and trace-elements in the manner generally used in practice were fed, moreover the animals were allowed some exercise in a paved yard for 6 hours per day during a week in the preliminary period of each experiment.

4.3. The residual standard deviation

The residual standard deviations (RSD) of the regression computations of section 3.4., vary from 500 to 600 kcal., i.e. from 4–6 % of the average maintenance requirement of the metabolisable energy for a cow of 500 kg. A large part of this deviation is due to analytical and physiological errors. The intake of metabolisable energy usually has a standard deviation of 1–1.5 % of the gross energy, i.e. 200–300 kcal. (see Table 6; also BROUWER et al., 1964, p. 63). One 24-hour determination of the heat expenditure has a coefficient of variation of 3–5 %, which results in a coefficient of variation of 1.5–2.5 % for the average heat expenditure during 4 days, i.e. 180–300 kcal. The energy balance thus has an error of about 300–400 kcal. The correction of the intake of metabolisable energy to zero energy balance may introduce considerable additional error if the energy balance differs much from zero, and if the factors to be used for this correction are not known accurately. Finally the correction of intake of metabolisable energy for maintenance to a common body weight leads to an additional error as the measured body weight is not free from error. RSD's of the size found in the computations of section 3.4. might therefore be expected. Considering the animal itself only part of the total variation is important, e.g. small changes in its ability to digest the same food with time alter its daily supply of digested energy. Similar changes in its ability to convert digested energy into net energy alter its daily supply of net energy, and finally its maintenance requirement may change due to excitement, illness etc. A considerable part of the total variation consists of measurement errors, made while determining composition, digestibility, heat expenditure, body weight and correction factors.

It is clear from the regressions on digestible dry matter etc. and on crude fibre near the end of section 3.4., that the maintenance requirement for metabolisable energy per 500 kg body weight may be predicted from ration composition with the same error as from contents of digested quantities. However, the prediction of the amount of metabolisable energy present in a ration from content of crude fibre or lignin of the hay, and from type of concentrates used, gives less accurate figures than the determination of its content of metabolisable energy in a digestion experiment. The standard deviation of the metabolisability in an experiment is about 1–1.5 units. The residual standard deviation of regression equations used to predict metabolisability from content of lignin or crude fibre of hay is about 2 or 3. The determination of metabolisable energy thus has an error of 200–250 kcal., its prediction by regression gives an error of 400–500 kcal. The determination of ME and the prediction of the maintenance requirement for ME per 500 kg body weight from crude fibre content gave a total RSD of about 570 kcal. Prediction of ME and of maintenance requirement probably gives a total RSD of about $\sqrt{(570^2 - 225^2 + 450^2)} = 760$ kcal. Because both figures are high, the difference between them is relatively small. However, to the animal itself the difference is relatively much greater. If the amount of metabolisable energy of a ration has been measured, the animal may be fed with an error of 200–250 kcal. metabolisable energy, if the amount of metabolisable energy of the ration is predicted, it may be fed with an error of 400–500 kcal. Small changes in the animal's ability to convert metabolisable energy into net energy and small changes in its maintenance requirement are the only other reasons why a known quantity of a ration does not always give exactly the same production above maintenance. The additional error produced in predicting the content of metabolisable energy thus for the animal is relatively much greater.

When the net energy content of a food can be computed by regression on e.g. its crude fibre content with 10–20 % greater RSD than by regression on % digestible dry matter, it is tempting to accept the lower accuracy of the former method in view of the amount of work saved if only crude fibre has to be determined. From similar considerations ARMSTRONG et al. (1964) suggested that for advisory purposes simple chemical analysis should be preferred, despite the slightly less precise estimate obtained when compared with methods based on digestibility determinations. In our opinion, however, one should be careful in accepting slightly higher RSD's since in energy balance experiments the RSD's usually consist for a large part of errors of measurement, which overshadow the physiological errors.

4.4. Variation of the maintenance requirement of metabolisable energy due to the composition of the ration

Replacement of the ten rations as ten variables in the regression computations by the contents of some components of the rations as variables resulted in a 30–35 % increase of residual variance. Obviously it was not possible to describe all the properties of the rations in this manner. Better results might be obtained if instead of the components digested crude fibre and digested N-free extractives better defined components could be used, such as the groups digested cellulose, digested branched and non-branched hemicelluloses, and digested other carbohydrates.

In general the maintenance requirement for metabolisable energy ($M_{m,500}$) decreased with increasing digestibility both in the present and in the earlier series of experiments. Decreases of similar size were found by ARMSTRONG (1964), with artificially dried grasses, and by BREIREM (1944) in a computation of experiments performed by various investigators before 1940. The size of the variation, however, is small if compared with the ration variation in lipogenesis. In our experiments R 16–62 an increase in the metabolisability of one unit decreased $M_{m,500}$ by 72 kcal., i.e. 0.6 % of $M_{m,500}$. According to Blaxter's equation $E = 0.94\ m - 8$ (BLAXTER, 1962, p. 247), the efficiency E of the utilisation of metabolisable energy for lipogenesis changes by 0.94 per unit metabolisability (m), i.e. with about 2 % of the average E. From the figures of ARMSTRONG (1964), on the efficiency of the utilisation of metabolisable energy for maintenance (E_m) and for lipogenesis (E_f) of twelve artificially dried grasses, we computed the following regression equations (x_1 = digestibility of energy, x_2 = percentage of proteincalories in digested energy):

$$E_m = (0.32 \pm 0.09)\ (x_1 - 73.26) + 73.21 \quad \text{(RSD 2.1)}$$

$$E_m = (0.56 \pm 0.14)\ (x_1 - 73.26) - (0.41 \pm 0.21)\ (x_2 - 17.21) + 73.21 \quad \text{(RSD 2.2)}$$

$$E_f = (0.56 \pm 0.15)\ (x_1 - 73.26) + 48.03 \quad \text{(RSD 3.6)}$$

$$E_f = (0.21 \pm 0.24)\ (x_1 - 73.26) + (0.63 \pm 0.36)\ (x_2 - 17.21) + 48.03 \quad \text{(RSD 3.6)}$$

If x_1 is increased by one unit, the E_m -figures change only with 0.32 or 0.4 % of the average E_m, the E_f -figures with 0.56 or 1.2 % of average E_f. As stated above the variation due to ration is much higher for lipogenesis than for maintenance. The size of the variation of E_m as found by Blaxter (see ARMSTRONG, 1964) in his experiments with hay- and mixed rations differed hardly from the variation of E_m in Armstrong's experiments, again the variation of E_f was much higher.

In the present experiments the residual sum of squares hardly decreased when the absence or presence of concentrates in the ration was added as a variable in the regression computations. Blaxter and Breirem dealing also with mixed rations found the same results as Armstrong and ourselves. Obviously the absence or presence of concentrates as such plays no important role in maintenance requirement.

The influence of digestible calories originating from protein on $M_{m,500}$ is not completely clear. Theoretically it might be expected that a high proportion of digestible energy of protein origin would result in a higher excretion of urea which might require additional energy (BLAXTER, 1962, p. 248). Indeed, in the present series the maintenance requirement increased significantly with increasing level of digestible calories of protein origin, a similar effect occurred in Armstrong's experiments with artificially dried hays. In our earlier experiments with rations of hay there was only a tendency toward such an influence; when all our experiments are considered together the influence is significant.

The rule of increased requirement of ME for maintenance due to lower digestibility probably does not always hold true for rations containing silage. Preliminary results of some recent experiments showed a decrease of requirement if the silage of a mixed ration was replaced by hay having a lower digestibility than the silage; not all silages, however, behaved in this way.

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