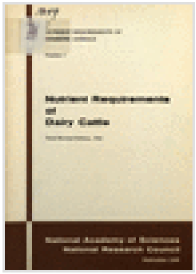

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NUTRIENT REQUIREMENTS OF
DOMESTIC ANIMALS

Number 3

Nutrient Requirements of Dairy Cattle

Third Revised Edition, 1966

A Report of the

SUBCOMMITTEE ON DAIRY CATTLE NUTRITION
COMMITTEE ON ANIMAL NUTRITION
AGRICULTURAL BOARD
NATIONAL ACADEMY OF SCIENCES
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FOREWORD

This report on the *Nutrient Requirements of Dairy Cattle* has been prepared by the Subcommittee on Dairy Cattle Nutrition of the Committee on Animal Nutrition, National Academy of Sciences—National Research Council. The original report was published in August 1945. The first revision was published in 1950 and the second revision in 1958.

This third revision differs from earlier ones in that the metric system is used throughout. The table on feed composition (Table 4) follows the new nomenclature, adopted by the Committee on Animal Nutrition, U.S.A., and the National Committee on Animal Nutrition, Canada, for feeds. Interpretation of the requirement data and names of feeds may be necessary for practical application. It is suggested that teachers and research workers should begin using the nomenclature employed in this report as an aid to making the transition to these more useful systems.

The purposes of this revision, as in previous reports, are (a) to make available a concise summary of the knowledge available regarding the nutrient requirements of dairy cattle, (b) to describe briefly the specific nutritional deficiency syndromes which have been seen in practice or produced experimentally, and (c) to present a feeding

WEIGHT UNIT CONVERSION FACTORS

		CONVERSION FACTOR				CONVERSION FACTOR	
Units given	Units wanted	Multiply units given by	Divide units given by	Units given	Units wanted	Multiply units given by	Divide units given by
lb	g	453.59	—	mg/kg	mg/lb	—	2.2046
lb	kg	—	2.2046	μg/kg	μg/lb	—	2.2046
oz	gm	28.4	—	kcal/kg	kcal/lb	—	2.2046
kg	lb	2.2046	—	kcal/lb	kcal/kg	2.2046	—
kg	g	1,000.	—	μg/g	ppm	0.	0.
kg	mg	1,000,000.	—	mg/kg	ppm	0.	0.
g	mg	1,000.	—	mg/kg	%	—	1,000.
g	μg	1,000,000.	—	mg/g	%	—	10.
ppm	mg/lb	0.45359	—	g/kg	%	—	10.
mg/g	mg/lb	453.59	—				

standard which will serve as a guide to successful, efficient and economical feeding of dairy cattle.

The Committee on Animal Nutrition requested the Subcommittee on Dairy Cattle Nutrition to prepare this revision using the metric system. Later reports on Nutrient Requirements will all be presented in the metric system. The conversion factors given on the preceding page may be useful to those who use this report.

The present values for nutrients required for growth, maintenance, reproduction, and lactation are generally similar to those published in the earlier report (3), except where new information has shown the need for modifications. In making these changes, data published since the last revision have been evaluated and earlier information has been re-examined. There remains a critical need for more complete quantitative data on the requirements for certain nutrients.

The present report includes new data published since the last revision and the tables are revised accordingly. There remain many deficiencies in quantitative data on requirements of various nutrients. As new data are published the report will be revised and brought up to date.

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DETERMINATION OF NUTRIENT REQUIREMENTS

The daily nutrient requirements for growth and maintenance of dairy cattle are presented in Table 1 and for milk production in Table 2. The percentage composition of complete rations which will meet the requirements are shown in Table 3. These levels of nutrients are adequate to prevent detectable signs of deficiencies and they will allow acceptable rates of growth, reproduction, and milk production with feeds of at least average composition and digestibility (1–4). The amounts of nutrients required per day differ somewhat among individual animals, depending upon rates of growth, levels of production, and activity. Variation among dairy cattle in ability to digest feed appears to be relatively small, but larger differences exist in feed capacity, appetite, growth rates, and level of milk production (2, 4).

The average composition of common feeds is shown in Table 4. In using these tables one should recognize that average values can only serve as guides to adequate nutrition, and not as accurate descriptions of the needs of any particular animal or the specific value of any feed.

WATER

Dairy cattle will suffer more quickly from a lack of water than from a shortage of any other nutrient. Water should be provided free choice so that the animals can drink as much as they desire. It has been found that non-lactating cows will drink 45 to 55 kg of water per day when they are consuming dry feeds. Cows producing 40 kg of milk per day may drink up to 110 kg of water when fed dry feeds (5). When pasturage or other feeds high in moisture are fed, cattle will drink much less water. High ambient temperatures and excessive intakes of salt increase the water requirement. Indian breeds of cattle (*Bos indicus*) generally require somewhat less water than European breeds (*Bos taurus*), especially at higher environmental temperatures (6).

ENERGY

The energy requirements in Tables 1, 2, and 3 are expressed as total digestible nutrients (TDN), digestible energy (DE), and metabolizable energy (ME). The use of TDN is retained as in the earlier reports (3) because many of the available data both for the energy requirements of animals and for the values of feeds are reported as TDN. Recent research has provided some data for digestible energy and metabolizable energy; thus these values are also included. Information is inadequate to express requirements in net energy terms, but further research may make this possible (24). Both TDN and digestible energy (DE) have been criticized as measures of the useful energy value of roughage and concentrates (30). Net energy (NE) values of feeds vary

TABLE 1. DAILY NUTRIENT REQUIREMENTS OF DAIRY CATTLE

		Daily Nutrients per Animal[1]										
			Protein		Energy							
Body Weight	Daily Gain	Feed[2]	Total	Digestible	TDN	DE[3]	ME[3]	Ca	P	Carotene	Vitamin A	Vitamin D[4]
kg	gm	kg	gm	gm	kg	Mcal	Mcal	gm	gm	mg	1,000 IU	IU
GROWTH OF HEIFERS FOR HERD REPLACEMENT												
25	300	0.4	90	80	0.50	2.2	1.8	2.0	1.5	2.5	1.0	165
35	450	0.7	155	140	0.75	3.3	2.7	2.8	2.1	3.7	1.5	230
50	500	1.0	200	180	1.00	4.4	3.6	4.0	3.0	5.3	2.1	330
75	550	2.0	340	240	1.50	6.6	5.4	8.0	6.0	7.9	3.2	500
100	650	2.8	430	280	1.90	8.4	6.9	9.6	8.4	10.6	4.2	660
150	700	4.0	480	320	2.55	11.2	9.2	12	11	15.9	6.4	1,000
200	700	5.2	520	380	3.15	13.9	11.4	13	12	21.2	8.5	1,300
250	650	6.2	630	400	3.55	15.6	12.8	14	13	26.4	10.6	
300	600	7.2	660	410	4.10	18.0	14.8	15	14	31.8	12.7	
350	600	8.0	675	415	4.50	19.8	16.2	16	15	37.0	14.8	
400	600	8.8	700	420	4.60	20.2	16.7	16	15	42.4	17.0	
450	500	9.2	725	435	4.70	20.7	17.0	16	15	47.7	19.1	
500	400	9.6	750	450	4.80	21.1	17.3	16	15	53.0	21.2	
550	300	9.8	765	460	4.90	21.6	17.7	16	15	58.0	23.2	
600	200	10.0	780	470	5.00	22.0	18.0	16	15	63.5	25.4	
GROWTH OF VEAL CALVES FOR SLAUGHTER												
35	500	0.7	155	140	0.80	3.5	2.9	2.8	2.1	3.7	1.5	230
50	700	1.2	270	240	1.40	6.2	5.1	4.8	3.6	5.3	2.1	330
75	900	2.0	400	360	2.30	10.1	8.3	8.0	6.0	7.9	3.2	500
100	1,100	2.8	600	450	3.00	13.2	10.8	9.5	8.4	10.6	4.2	660
150	1,200	3.2	640	480	3.20	14.1	11.6	12.0	11.4	15.9	6.4	1,000
MAINTENANCE OF MATURE COWS												
350		5.2	375	225	2.80	12.3	10.1	10	10	37	14.8	
400		5.8	417	250	2.95	13.0	10.7	11	11	42	16.8	
450		6.2	450	270	3.20	14.1	11.6	12	12	48	19.2	
500		7.0	500	300	3.45	15.2	12.5	14	14	53	21.2	
550		7.8	533	330	3.80	16.7	13.7	15	15	58	23.2	
600		8.0	567	340	3.95	17.4	14.3	16	16	64	25.6	

650		8.6	608	365	4.20	18.5	15.2	17	17	69	27.6
700		9.2	650	390	4.40	19.4	15.9	18	18	74	29.6
750		9.8	692	415	4.65	20.5	16.8	20	20	80	32.0
800		10.4	733	440	4.90	21.6	17.7	22	22	85	34.0
REPRODUCTION (ADD TO MAINTENANCE DURING LAST 2 TO 3 MONTHS OF GESTATION)											
400		4.0	400	240	2.4	10.6	8.7	10	8	22	8.8
550		5.0	460	275	3.0	13.2	10.8	13	11	30	12.0
700		6.0	550	330	3.6	15.8	13.0	16	14	38	15.2
GROWTH OF DAIRY BULLS											
25 to											
150	Use tables for growing heifers										
200	1,000	5.8	610	425	3.5	15.4	12.6	14	13	21.2	8.5
250	1,000	6.7	620	435	4.0	17.6	14.4	15	14	26.4	10.6
300	1,000	8.0	685	480	4.8	21.1	17.3	17	15	31.8	12.7
400	900	9.6	800	555	5.8	25.5	20.9	17	16	42.4	17.0
500	800	10.4	890	580	6.2	27.2	22.3	18	17	53.0	21.2
600	700	11.2	950	615	6.5	28.6	23.4	18	17	63	25.2
700	600	12.0	1,050	650	7.0	30.8	25.2	19	18	74	29.6
800	500	13.3	1,100	690	7.5	33.0	27.1	21	20	85	34.0
900		13.6	1,150	710	8.0	35.2	28.9	22	20	95	38.0
1,000		14.5	1,200	740	8.5	37.4	30.7	23	22	106	42.4
MAINTENANCE OF MATURE BREEDING BULLS											
500		7.8	675	450	4.4	19.4	15.9	11	11	53	21.2
600		8.8	735	490	5.0	22.0	18.0	12	12	64	25.6
700		10.0	810	540	5.7	25.1	20.5	15	15	74	29.6
800		11.0	885	590	6.4	28.2	23.1	17	17	85	34.0
900		12.2	960	640	7.0	30.8	25.2	20	20	95	38.0
1,000		13.5	1,035	690	7.8	34.3	28.1	22	22	106	42.4
1,100		14.5	1,110	740	8.4	37.0	30.3	24	24	117	46.8
1,200		15.5	1,200	800	9.0	39.6	32.5	25	25	127	50.8

[1] Thiamine, riboflavin, niacin, pyridoxine, pantothenic acid, folic acid, vitamin B_{12}, and vitamin K are synthesized by bacteria in the rumen, and it appears that adequate amounts of these vitamins are furnished by a combination of rumen synthesis and natural feedstuffs. Manganese, magnesium, iron, copper, and cobalt are essential, and the amounts needed are discussed in the text.

[2] Based on air-dry feed containing 90% dry matter. These figures are only rough estimations since the amount depends on the composition of the ration.

[3] ME (metabolizable energy) has been estimated on the basis that 1 gm of TDN has 4.4 kcal of DE (digestible energy) (4.4 Mcal per kg) and that 82% of the DE is available as ME. The ME values can be converted to DE by multiplying them by 122.

[4] While vitamin D is known to be required, quantitative data are not available for growing animals above 200 kg in body weight and for maintenance and reproduction. Animals exposed to direct sunlight or fed sun-cured forages do not need supplemental vitamin D.

TABLE 2. DAILY NUTRIENTS REQUIRED PER KG OF MILK[1]
(To be Added to Requirements for Growth or Maintenance)

Fat Content of Milk	Protein	Digestible Protein	TDN	DE	ME	Ca	P
%	gm	gm	gm	Mcal	Mcal	gm	gm
FOR COWS PRODUCING MORE THAN 35 KG OF MILK DAILY							
3.0	78	50	360	1.59	1.30	2.8	2.0
3.5	83	53	390	1.72	1.41	2.8	2.0
4.0	88	56	420	1.85	1.52	2.8	2.0
4.5	93	59	450	1.98	1.62	2.8	2.0
5.0	98	62	480	2.12	1.74	2.8	2.0
5.5	103	66	510	2.25	1.84	2.8	2.0
6.0	108	70	540	2.38	1.95	2.8	2.0
FOR COWS PRODUCING 20 TO 35 KG OF MILK DAILY							
3.0	70	45	320	1.41	1.16	2.4	1.8
3.5	74	48	345	1.52	1.25	2.4	1.8
4.0	78	51	370	1.63	1.34	2.4	1.8
4.5	82	54	395	1.74	1.43	2.4	1.8
5.0	86	56	420	1.85	1.52	2.4	1.8
5.5	90	58	445	1.96	1.61	2.4	1.8
6.0	94	60	470	2.07	1.70	2.4	1.8
FOR COWS PRODUCING LESS THAN 20 KG OF MILK DAILY							
3.0	62	40	280	1.23	1.01	2.2	1.6
3.5	66	43	305	1.34	1.10	2.2	1.6
4.0	70	46	330	1.46	1.20	2.2	1.6
4.5	74	48	355	1.57	1.29	2.2	1.6
5.0	78	50	380	1.68	1.38	2.2	1.6
5.5	82	53	405	1.79	1.47	2.2	1.6
6.0	86	56	430	1.90	1.56	2.2	1.6

[1] See the footnotes to Table 1. When calculating the intakes for lactating heifers that are still growing, the figures for growth rather than maintenance should be used. When adequate amounts of carotene, vitamin A, and vitamin D are fed for growth and reproduction, extra amounts will not stimulate milk production. For pasture levels of vitamin A activity of the milk, cows should be fed 300 mg of carotene or 36 mg (120,000 IU) of true vitamin A daily.

greatly, depending upon whether they are utilized for maintenance or growth and probably also for milk production (7, 11). Much more research is needed to define requirements more precisely and to describe the value of feeds. In making conversions, it has been assumed that 1.0 kg of TDN has 4,400 kcal (4.4 megcal) of DE and 3,740 kcal of ME (3.74 megcal). The data presented are the best now available, but they will be modified as rapidly as new information justifies a change.

When dairy heifers are allowed maximal energy intakes during growth, their lifespan milk-producing ability may be impaired. For this reason as well as for economic considerations it is recommended that only limited amounts of milk be fed to calves the first month or two, followed by liberal use of concentrates and forages for heifers only during the first 6 to 9 months. This permits rapid growth, early sexual maturity, and lactation by two years of age. The growth rates shown for calves (Table 1) grown as dairy replacements are only about one third to one half the maximal potential rate possible with ad libitum feeding, which is used for veal calves, yet these rates allow early calving and acceptable mature weights at minimal cost (4, 17, 23, 29, 33, 35, 38). After 300 to 400 kg body weight the energy intake of dairy heifers

TABLE 3. NUTRIENT CONTENT OF RATIONS FOR DAIRY CATTLE
(Based on Air-Dry Feed Containing 90% Dry Matter)

	Daily Feed		Percentage or Amount per Kg of Feed								
				Energy							
Body Weight	Total	% of Weight	Digestible Protein	TDN	DE	ME	Ca	P	Carotene	Vitamin A	Vitamin D
kg	kg	%	%	%	Mcal/kg	Mcal/kg	%	%	mg/kg	1000 IU/kg	IU/kg
GROWTH OF HEIFERS											
25	0.4	1.6	20.0	125	5.5	4.5	0.50	0.38	6.5	2.5	410
35	0.7	2.0	20.0	107	4.7	3.9	0.40	0.30	5.3	2.0	330
50	1.0	2.0	18.0	100	4.4	3.6	0.40	0.30	5.3	2.0	330
75	2.0	2.7	12.0	75	3.3	2.7	0.40	0.30	4.0	1.6	250
100	2.8	2.8	10.0	68	3.0	2.5	0.34	0.30	3.8	1.5	250
150	4.0	2.7	8.0	64	2.8	2.3	0.30	0.28	4.0	1.6	250
200	5.2	2.6	7.3	61	2.7	2.2	0.25	0.23	4.0	1.6	250
250	6.2	2.6	6.5	58	2.5	2.1	0.22	0.21	4.3	1.7	
300	7.2	2.4	5.7	57	2.5	2.1	0.21	0.19	4.4	1.8	
350	8.0	2.3	5.2	56	2.5	2.0	0.20	0.19	4.6	1.8	
400	8.8	2.2	4.8	52	2.3	1.9	0.18	0.17	4.8	1.9	
450	9.0	2.0	4.8	51	2.3	1.9	0.18	0.17	5.3	2.0	
500	9.6	1.9	4.7	50	2.2	1.8	0.17	0.16	5.5	2.1	
550	9.8	1.8	4.7	50	2.2	1.8	0.16	0.15	5.9	2.4	
600	10.0	1.7	4.7	50	2.2	1.8	0.16	0.15	6.4	2.5	
GROWTH OF VEAL CALVES FOR SLAUGHTER											
35	0.7	2.0	20.0	115	5.0	4.1	0.40	0.30	5.3	2.1	330
50	1.2	2.4	20.0	115	5.0	4.1	0.40	0.30	4.4	1.8	275
75	2.0	2.7	18.0	115	5.0	4.1	0.40	0.30	4.0	1.6	250
100	2.8	2.8	16.0	110	4.7	3.9	0.34	0.30	3.8	1.5	250
150	3.2	2.1	15.0	100	4.4	3.6	0.38	0.36	5.0	1.9	310
MAINTENANCE OF MATURE COWS											
350	5.2	1.5	4.3	54	2.4	1.9	0.19	0.19	7.1	2.7	
400	5.8	1.5	4.3	51	2.2	1.9	0.19	0.19	7.2	2.9	
450	6.2	1.4	4.3	52	2.3	1.9	0.19	0.19	7.7	3.0	
500	7.0	1.4	4.3	49	2.2	1.9	0.20	0.20	7.6	3.0	
550	7.8	1.4	4.2	49	2.2	1.8	0.20	0.20	7.5	3.0	
600	8.0	1.3	4.2	49	2.2	1.8	0.20	0.20	8.0	3.2	
650	8.6	1.3	4.2	49	2.2	1.8	0.20	0.20	8.0	3.2	
700	9.2	1.3	4.2	48	2.1	1.8	0.20	0.20	8.0	3.2	
750	9.8	1.3	4.2	47	2.1	1.7	0.20	0.20	8.1	3.3	
800	10.4	1.3	4.2	47	2.1	1.7	0.21	0.21	8.1	3.3	
REPRODUCTION (ADD TO MAINTENANCE)											
400	4.0		6.0	60	2.6	2.2	0.25	0.20	5.5	2.1	
550	5.0		5.5	60	2.6	2.2	0.26	0.22	6.0	2.4	
700	6.0		5.5	60	2.6	2.2	0.27	0.23	6.3	2.5	
GROWTH OF DAIRY BULLS											
25 to 150	Use table for heifers										
200	5.8	2.9	7.3	60	2.7	2.2	0.25	0.23	3.7	1.5	
250	6.7	2.7	6.5	60	2.6	2.2	0.22	0.21	3.9	1.6	
300	8.0	2.7	6.0	60	2.6	2.2	0.21	0.19	4.0	1.6	
400	9.6	2.4	5.8	60	2.6	2.2	0.18	0.17	4.4	1.8	

TABLE 3. Continued

Body Weight	Daily Feed: Total	Daily Feed: % of Weight	Digestible Protein	Energy: TDN	Energy: DE	Energy: ME	Ca	P	Carotene	Vitamin A	Vitamin D
kg	kg	%	%	%	Mcal/kg	Mcal/kg	%	%	mg/kg	1000 IU/kg	IU/kg
GROWTH OF DAIRY BULLS (Continued)											
500	10.4	2.1	5.6	60	2.6	2.1	0.17	0.16	5.1	2.0	
600	11.2	1.9	5.5	58	2.6	2.1	0.16	0.15	5.6	2.2	
700	12.0	1.7	5.4	58	2.6	2.1	0.16	0.15	6.2	2.5	
800	13.0	1.6	5.3	58	2.6	2.1	0.16	0.15	6.5	2.6	
900	13.6	1.5	5.2	58	2.6	2.1	0.16	0.15	7.0	2.8	
1,000	14.5	1.4	5.1	58	2.6	2.1	0.16	0.15	7.3	2.9	
MAINTENANCE OF MATURE BREEDING BULLS											
500	7.8	1.6	5.8	56	2.5	2.0	0.14	0.14	6.8	2.7	
600	8.8	1.5	5.6	57	2.5	2.0	0.14	0.14	7.3	2.9	
700	10.0	1.4	5.4	57	2.5	2.1	0.15	0.15	7.4	3.0	
800	11.0	1.4	5.4	58	2.6	2.1	0.15	0.15	7.7	3.1	
900	12.2	1.4	5.2	58	2.5	2.1	0.16	0.16	7.8	3.1	
1,000	13.5	1.4	5.1	58	2.5	2.1	0.16	0.16	7.9	3.1	
1,100	14.5	1.3	5.1	58	2.5	2.1	0.16	0.16	8.1	3.2	
1,200	15.5	1.3	5.1	58	2.5	2.1	0.16	0.16	8.2	3.3	

should be somewhat restricted to avoid excessive fattening. This can usually be accomplished by feeding only good-quality hay, silage, or pasture; lower-quality forage should be supplemented with a limited amount of concentrates. The present energy intakes for growth are about 10 per cent lower after 350 kg body weight than the previous values, because research has shown that allowing dairy heifers to become fat is not only wasteful of feed but is harmful to future milk-producing ability and productive life span (23, 33, 41).

Requirements for normal growth of veal calves and dairy bulls are also shown in Table 1. During the first few months following birth there is relatively little difference in growth rates between heifers and bulls, but at about 250 kg body weight bulls consume more feed per day to support a faster rate of growth and greater activity. Young dairy bulls should be liberally fed to stimulate early sexual maturity and semen production (12, 21, 43). After bulls are properly developed, energy intakes should be controlled to avoid over-fatness and lowered libido, but should be adequate to allow maintenance of good physical condition (13, 21).

The energy required for maintenance of cows varies widely depending upon their activity. Variation among cows of similar size and breed in maintenance requirements even under controlled activity is as much as 8 to 10 per cent (44). The maintenance values in Table 1 provide minimal energy to cover usual activity of cows fed in confinement, but not for grazing. Grazing cows may require 25 to 100 per cent more energy for maintenance than those confined (26, 34, 46), depending upon the amount of activity involved.

With respect to reproduction, Becker *et al.* (10) found that the average changes in body weight of Jersey cows due to combined weights of the fetus, fluids, fetal membranes, and increased size of the uterus amounted to 20 kg at 210 days of gestation, 34 kg at 240 days, 50 kg at 270 days, and 55 kg at term. These results agree with earlier publications, which also showed that weight increases are

60 to 100 per cent greater in the larger breeds of dairy cattle than in Jerseys, but similar data are not available for other breeds. Much of the growth of the products of reproduction occurs while cows are still lactating. Liberal feeding during the last 2 or 3 months of gestation insures proper fetal development and adequate body condition of the cow for maximal milk production after parturition.

The energy requirements for high levels of milk production are greater than was previously recognized (3, 16, 22, 27, 28, 34). Only recently has it become possible to obtain well-controlled data over full lactations on cows having milk yields of 8,000 to 10,000 kg yearly, but published data are still inadequate to provide satisfactory accuracy in defining energy requirements for high levels of milk production. The present energy standard (Table 2) is about 10 per cent higher than the earlier levels for average production and 25 per cent more for highest milk yields. Better cows will consume even more feed than the tables suggest. Although the energy requirements above maintenance may increase per unit of milk produced as the daily yield becomes higher, the *gross efficiency* continues to increase with higher production because a smaller proportion of the total energy is used for maintenance.

Research and experiences have demonstrated the advisability of feeding an adequate amount of concentrates during the last 2 to 4 weeks of gestation and in early lactation. With adequate intake of concentrates and high-quality forage, high-yielding cows will reach full feed and maximal milk yields as early as 2 to 4 weeks after calving, and excessive body weight losses will be prevented. Good cows are unable to consume enough feed the first few weeks of lactation to prevent some loss of body energy (20), calcium, phosphorous, and perhaps protein. The losses are minimized by feeding as much of a properly balanced ration as the cow can safely handle the first 6 to 8 weeks after calving. Thereafter milk yields should be the guide to the allowance of energy. Adequate feeding immediately after calving also helps to prevent ketosis. The values in Tables 1 and 2 provide a more useful guide to adequate feeding of high-producing cows than former standards, but future changes may be required. Over-feeding of concentrates and excessive weight gain, especially in late lactation, should be avoided, yet allowances should be made for changes in weight of the reproductive organs and fetus (10).

The utilization of energy by dairy cattle depends to a large extent upon rumen function and the microbial fermentation that occurs in the rumen.

The rumino-reticulum of the newborn calf is small and nonfunctional. Ingestion of non-liquid feed, however, promotes rapid change; the size of this organ increases, fermentation begins, rumen papillae develop and absorptive ability increases markedly (15, 25, 36, 40, 42, 47). The short-chain fatty acids (primarily acetic, propionic, and butyric), one group of the many products of rumen fermentation, not only affect functional development of the rumen but also significantly influence the general metabolism and represent a substantial part of the sources of energy available to the animal. For synthesis of body fat, the energy from acetic acid is used much less efficiently than that from propionic and butyric acids. A lower than normal acetate–propionate ratio in the rumen ingesta has been shown to result in less-efficient synthesis of milk fat (16, 37, 39). Consumption of finely ground hay (9, 32) a low-roughage ration, (39), a large amount of flaked corn (8, 31), and heated high-starch feeds (19, 37) markedly reduce milk-fat percentage, probably by decreasing the acetate–propionate ratio in the rumen. A discussion of this syndrome and a review of relevant literature has been presented by Van Soest (45). Feeding sodium bicarbonate will largely correct the depressed fat test (18). Underfeeding of energy reduces the protein and solids-not-fat of milk without necessarily lowering the percentage of milk fat.

PROTEIN

The protein requirements of dairy cattle are expressed as digestible protein. Values in Tables 1, 2, and 3 also include crude protein as an aid in relating feed composition to requirements of animals. The intakes are adequate to support the rates of growth shown, provided supplies of energy and other required nutrients are adequate (49–51, 53, 54, 56). Inadequate protein intake or a ration with a very wide protein-to-energy ratio, where protein meets minimum requirements but energy is very high, quickly depresses efficiency of ration utilization, growth rates, and milk yields. For maintenance the values previously used are still considered to be adequate (3, 22, 52). Thus 0.3 kg of digestible protein daily for a 500-kg cow was used as a base, and values for other body weights were calculated at the same rate per unit of weight to the 3/4 power. For milk production the present standard furnishes 135 to 145 per cent the amount of protein in the milk (22, 48, 52). A deficiency of protein will depress milk yields and may lower milk-protein content if the shortage is severe (58). Since protein is not toxic, large excesses can be fed without danger. Slight increases in protein content of the milk have been reported when protein intake is very high. Further research is needed to measure the protein requirements and the efficiency of utilization of protein by high-producing dairy cows.

UREA AND NONPROTEIN NITROGEN

Urea and certain ammonium salts can be used to replace up to 35 per cent of the protein of the concentrate ration of dairy cattle after rumen function has become established. Young calves receiving milk or milk replacers, and not yet consuming appreciable quantities of dry concentrate feeds or forages and not ruminating, do not utilize urea effectively, but older cattle perform as well with some urea in the ration as with high-quality true proteins (55, 57, 59). Urea should be well mixed with other feeds to avoid possible toxicity from excessive intakes.

MINERAL ELEMENTS

The mineral elements required by dairy cattle are calcium, phosphorus, magnesium, potassium, sodium, chloride, sulfur, iodine, iron, copper, cobalt, manganese, zinc, and selenium. These mineral elements are needed for bone formation, as constituents of the proteins and lipids that make up the muscles, organs, blood cells, and other soft tissues and in many enzyme systems of the body. They are concerned in the maintenance of osmotic relationships and acid-base equilibria, and exert characteristic effects on the irritability of muscles and nerves.

Calcium

It has been known for years that calcium is a critical nutrient in the ration of dairy cattle, and yet adequate quantitative data on requirements are not available for all phases of growth and the reproductive lifespan. There are large differences in the estimated requirements for growth and milk secretion depending upon the experimental techniques employed (82).

Dairy calves 8 to 16 weeks of age gained faster on 7 gm of calcium per day (0.17 per cent of the ration) than on 5 gm (0.13 per cent) and equal to calves receiving increasing calcium levels up to 20 gm per day (0.50 per cent). Spontaneous leg fractures occurred in some calves fed 3.2 gm per day (0.14 per cent of the ration). The ash content of the tenth rib increased with each increment of dietary calcium, but serum calcium was normal at all levels tested (85). Based on these studies it seems clear that a ration containing 0.17 per cent of calcium is adequate for growth of calves to 4 months of age (100 kg to 150 kg body weight). At this level, however, bones will not exhibit maximum density. The requirements (Tables 1 and 3) have been set somewhat higher than that figure to ensure adequacy on feeds that may have lower calcium availability than those used in the experiments.

Requirements for growth of dairy heifers and bulls are less accurately defined than for the younger calves. Slaughter studies showed that calves retained an average of 5.4 gm of calcium per day from birth to 1 year of age (69). Other feeding studies (65, 83) have shown that gains were as fast from 6 to 18 months of age with daily calcium intakes of 4.5 gm to 7 gm (0.12 to 0.14 per cent) as with larger intakes, but these levels were inadequate for gestation. Converse (65) concluded that calcium as 0.14 per cent of the daily ration was adequate for growth of dairy heifers and that 0.16 per cent was sufficient for gestation.

Reports of various workers who have conducted mineral-balance studies show that calves retained 62 to 92 per cent of the calcium in a milk diet (3, 62, 66, 67, 75). Absorption and retention are appreciably less efficient on rations consisting of forages and concentrate mixtures than on milk. The calcium requirement for maintenance has been estimated to be 5.2 to 10.6 gm per 454 kg of body weight (64, 84). It has been shown, using radiocalcium, that cattle between the ages of 6 months and maturity excreted an average of 1.54 gm of fecal endogenous calcium daily per 100 kg body weight and the true absorption varied from 30 to 40 per cent, averaging approximately 35 per cent (64). The amount of endogenous calcium per unit of body size increased as cows became older. Cows 12 to 16 years of age excreted slightly more than 2.0 gm per 100 kg body weight, and true absorption was only 22 per cent.

Balance studies have shown that cows are generally in negative calcium balance in early lactation. The deficit is made up in later lactation and the dry period (69, 70, 72, 73). Long-time feeding studies clearly show that dairy cows can produce milk and maintain good mineralization of the bones on far lower intakes of calcium than would appear possible on the basis of short time-balance studies, using radiocalcium to estimate maintenance requirements and efficiency of utilization (65, 66, 70, 71, 83). It is possible also that cattle grown on low-calcium rations utilize calcium more efficiently than animals receiving a more liberal supply such as the cattle used for the radiocalcium tests but there is no direct evidence on this question. Many cattle, especially those fed legume forage, consume two to three times more calcium than necessary with no apparent harmful effects. Until the calcium requirements have been defined more accurately, it seems advisable to allow more calcium for later stages of growth and for maintenance and milk production than suggested in previous standards; thus the values in Tables 1, 2, and 3 reflect this increase.

Parturient paresis (milk fever) in cows is not due to a calcium deficiency in the ration, but to a disturbance in metabolism manifested by a marked drop in blood-serum calcium. Feeding a low-calcium high-phosphorus ration (Ca:P ratio, 1:3.3) during the last month of the dry period reduces the incidence of the syndrome (63) and massive doses of vitamin D prepartum also prevents most of the cases (169).

Phosphorus

Wise *et al.* (87) have reported that dairy calves 90 to 125 kg in body weight required air-dry rations containing 0.22 per cent phosphorus. They recommended that 0.3 per cent be considered the safe allowance for practice. The calves fed diets with 0.22 per cent phosphorus consumed an average of 5.8 gm of phosphorus, and those on 0.3 per cent consumed 7.9 gm daily. Bone ash was higher on the 0.3 per cent than on the 0.22 per cent phosphorus diet, but there were no other differences, and higher levels of phosphorus intake did not improve performance. The values shown in Tables 1, 2, and 3 provide ample phosphorus to meet the requirements for growth and maintenance as indicated by various reports (60, 62, 67, 68, 72, 74, 75, 77).

Lofgreen *et al.* (79) found that the true digestibility of phosphorus by calves fed casein labeled with P^{32} was 92 per cent. The endogenous fecal phosphorus was 4.2 mg per kg of body weight. Kleiber *et al.* (76) reported the true digestibility of phosphorus by lactating dairy cows to be 50 to 64 per cent and the endogenous phosphorus 10 to 14 gm per day. Lofgreen and Kleiber (78) have also reported that 91 to 94 per cent of the phosphorus in alfalfa hay was absorbed by ruminants. Milk contains approximately 1.0 gm of phosphorus per kg. Assuming a true digestibility of 50 per cent, the feed should supply 2.0 gm per kg of milk, but with a 90 per cent true digestibility 1.1 gm of feed phosphorus per kg of milk above maintenance would suffice. There is no fully satisfactory explanation for the wide differences reported in utilization of phosphorus. It seems desirable to re-examine requirements for both calcium and phosphorus of high-yielding dairy cows under current feeding systems.

The ratio of calcium to phosphorus is far less critical for ruminants than it is for laboratory animals (80, 86). Within Ca:P ratios of 1:1 to 7:1, growth rate and feed utilization were entirely satisfactory and metabolic fecal calcium did not change. With narrower or wider ratios, performance was impaired. Metabolic fecal phosphorus increased as absorbed phosphorus increased, and decreased as absorbed calcium increased.

Salt (NaCl)

Babcock (88) reported that the salt in natural feeds would supply the 20 to 25 gm needed for maintenance of a cow, but that an additional 18 gm of salt were needed for each 10 kg of milk produced. Smith and Aines (89) found that 15 gm of supplemental salt per day were insufficient for milking cows, but that 30 gm daily were ample for the production of 20 kg of milk. Sodium is more likely to be deficient than chlorine. Cows consume more loose salt than block salt, but the lower intakes of block salt were adequate to meet the needs for lactation (90).

Magnesium

Several investigators have found that whole milk supplemented with iron, copper, manganese, and vitamin D is an inadequate ration for calves, and that tetany, associated with low serum magnesium, and death results (93). The magnesium requirement of calves fed only whole milk appears to be 30 to 50 mg per kg of body weight, whereas when a small amount of alfalfa hay or cereal grains supplement the whole milk, a level of only 10 to 12 mg is satisfactory (91, 92, 94, 95). Blaxter *et al.* (92) reported that, for optimum magnesium retention on semipurified diets, about 20 mg of magnesium per kg of body weight appeared to be needed by calves; weight gains were small, however.

Iodine

The lack of iodine is recognized as the principal cause of goiter in newborn calves (97). The goiter areas are found primarily around the Great Lakes and westward to the Pacific coast. In these regions, iodine supplements have been shown to be necessary. The use of iodized salt containing 0.015 per cent iodine incorporated at a 1 per cent level of the grain ration has proved effective. When iodized salt is stabilized to retard loss of iodine, a product containing 0.0076 per cent iodine (0.01 per cent potassium iodide) will probably provide the needed iodine supplementation. The use of stabilized iodine is recommended as a supplement to the ration of pregnant cows on farms where goiter has been known to occur among newborn calves (96).

Cobalt

Cobalt deficiency among ruminants was first identified by research workers in Australia in 1935 (100–102, 104). In the United States, this deficiency was first reported in Florida in 1937 (98, 103), but it has since been recognized among cattle in many areas of North America (99).

The minimum cobalt requirement of cattle has not been accurately defined. It has been shown, however, that supplements that furnish 0.1 to 1.0 mg of the element per day to cattle will cure a deficiency or prevent trouble on cobalt-low forage. Mixing 60 to 100 gm of cobalt sulfate or 40–50 gm of cobalt carbonate with 100 kg of salt makes an effective supplement to feeds in most areas.

Iron

Iron and copper are necessary for hemoglobin formation. Calves born with normal hemoglobin levels and fed milk, grain, and hay show a decline in hemoglobin until 30 to 70 days of age, then a gradual increase. Iron supplementation or iron dextran injections prevented the early postnatal decline in hemoglobin (105–107). The iron requirement of older cattle appears to be supplied ordinarily by that present in common feeds, except on low-iron soils.

Copper and molybdenum

Neal *et al.* (114) in 1931 were the first to suggest that a deficiency of copper occurs in ruminants. Copper deficiency may be due to a low copper content of the forage (less than 5 ppm on the dry basis) or it may be complicated with molybdenum excess or phosphorus deficiency (109, 110, 112). Reviews covering the role of copper in nutrition have been published by Marston (101) and by McElroy and Glass (113). The copper requirement of cattle is not known, but the addition of 1 per cent of copper sulfate to salt is usually recommended in copper-deficient areas, except on some residual muck soils and on high-molybdenum mineral soils where more copper is needed. On certain high-molybdenum muck soils the following mineral mixture has proven effective in preventing copper deficiency caused by excess molybdenum (108): steamed bone meal 50.0 kg, salt 46.7 kg, pulverized copper sulfate 2.5 kg, copper oxide 0.8 kg, cobalt carbonate 60 gm. Feeding or injecting excess copper may result in oxidized flavor in milk (111).

Manganese

According to Bentley and Phillips (115), rations with less than 10 ppm of manganese were inadequate for growth in young Holstein heifers, while 20 ppm of manganese was considered a satisfactory level for dairy cattle. This means that practical rations usually are adequate in this element since most feeds contain more than this (116).

Zinc

Zinc deficiency has been produced experimentally in dairy calves by feeding purified diets containing only 3.6 ppm of zinc (119, 120). When the feed contained 8.6 ppm of zinc, no deficiency was produced during a 9-month experimental period (118). Most feeds contain more than that amount of zinc. One instance has been reported (117) of parakeratosis in cattle grazing forage with a zinc content of 18 to 42 ppm on a dry basis.

Sulfur

Block and Stekol (121) reported that radioactive sulfur as sodium sulfate administered orally to a dairy cow appeared in the cystine and methionine of the milk proteins during the next 12 days. Although it has been shown with certain rations of natural feeds that adding inorganic sulfur is not beneficial (122), it may be desirable to supply additional inorganic sulfur when nonprotein nitrogen is fed along with low-sulfur feeds. Excess sulfur may enhance molybdenum toxicity and modify copper utilization (123).

Selenium

Supplements of selenium have been shown to prevent death loss of calves and to increase growth rate of young dairy cattle in New Zealand (124). The element aids, along with vitamin E, in preventing muscle dystrophy in growing animals.

Fluorine

Fluorine is of interest in nutrition of dairy cattle because of its toxic effects (125–127). An intake of 1.4 mg of fluorine per kg of body weight produced marginal toxicity. Larger intakes cause extensive metabolic changes and even death of cattle. Phosphorus supplements should contain not more than 0.18 per cent fluorine to avoid toxic effects.

VITAMINS

Ruminants are especially equipped to provide many of their nutrients via the microflora of the rumen (129–131, 135, 189). Protein, and members of the vitamin B group are readily synthesized in the rumen of dairy cattle. Hence an exogenous dietary source of the B vitamins is not needed after normal rumen function develops (132, 192).

Under normal conditions, natural feeds furnish most vitamins or their precursors in adequate amounts (128, 134). Vitamins A and D assume practical importance in dairy cattle nutrition only under special conditions. Colostrum contains, in addition to other essential factors, about ten times the vitamin A and two to three times the vitamin D potency of normal milk, and hence is nature's method of providing these nutrients for the calf, which is deficient at birth. Ration, age, and other factors (157, 168) cause nutrient variability in colostrum. Rations fed to pregnant dairy cows should therefore include feeds that contain ample carotene (vitamin A) and vitamin D.

Carotene and vitamin A

Carotene occurs in the forages consumed by cattle and is the precursor of physiologically active vitamin A. With poor forage or limited intakes, supplemental vitamin A should be fed. The carotene requirement is approximately four or five times that of vitamin A itself, but the conversion rate varies with level of intake (136, 146). Poorer conversion of carotene to vitamin A by the Guernsey breed increases its carotene requirement, but the vitamin A requirement is similar to that of other breeds. The minimum maintenance requirement of cattle for carotene is approximately 3.5 mg per 100 kg of body weight (145–147, 149). At least 50 to 75 per cent more is needed for normal growth and maintenance of adequate plasma and liver levels (148, 150, 151, 153, 154, 158). Calves require 10.6 mg of carotene per 100 kg of body weight to prevent elevated cerebro-spinal-fluid pressure (144). The requirement has been reported to vary from 10 to 20 mg per 100 kg of body weight for successful reproduction and lactation for extended periods (138, 151, 152, 155, 156). If sufficient vitamin A activity is provided for reproduction, there will be enough for lactation, but the intake must be increased several times to provide desirable levels in the milk (141, 156). There are no controlled studies to support the view that feeding true vitamin A will improve a ration that contains ample carotene from forages to meet the full requirements of dairy cattle, but some field observations suggest the existence of unidentified factors in certain forages that inhibit carotene utilization. Although some reports have indicated that nitrates may have an effect on the vitamin A status of animals under some conditions, this does not appear to be a problem of practical concern (140, 159, 160).

The vitamin A requirements of cattle can be met by carotene in feeds or vitamin A supplements, or combinations of the two. While international standards have defined 1.0 mg of β-carotene equal to 1,667 IU of vitamin A on the basis of rat growth, cattle convert carotene to vitamin A less efficiently than the rat does. Therefore, in this report 1.0 mg of carotene is considered to be equal to 400 IU of vitamin A with practical rations for dairy cattle.

The vitamin A values of milk vary with the amount of carotene or vitamin A in the ration of the dairy cow. During the pasture season, milk may contain as much as 2,500 IU of vitamin A equivalent per liter, whereas during the winter feeding period or late fall pasture period it may fall to one half or one third of that value (139). Consumption of 300 mg of carotene daily produced butter of a vitamin A potency approximating the maximum pasture level (147). When the ration contained adequate vitamin A for normal reproduction, the feeding of extra vitamin A did not result in increased milk yield, but the vitamin A content of the milk was enhanced (3, 141).

Vitamin D

Under usual conditions, sun-cured hay or exposure to sunlight supplies sufficient vitamin D for dairy cattle (171, 172, 176). A study of the literature leads to the recommendation of 660 IU of vitamin D per 100 kg of live weight for normal growth of dairy calves (161, 164). Corn silage that provided approximately 220 IU of vitamin D per 100 kg body weight effectively cured rickets in growing calves (164). Direct cut corn silage may be deficient in vitamin D. Roughages cured with limited exposure to sunlight furnished adequate vitamin D to prevent rickets in growing calves (171, 176). In northern states where long barn-feeding periods are common, incipient rickets occur in calves born in the fall or winter, as evidenced by the "surcingle effect" in some calves. Feeding of vitamin D at two to three times the minimum requirement may be beneficial in these cases, especially during the period of rapid skeletal growth.

Wallis (177, 178) has shown that vitamin D is essential for maintenance, reproduction, and lactation of mature dairy cows not exposed to sunlight. Feeding high levels of vitamin D (20,000,000 IU per cow per day), starting 5 days before expected calving date and continuing through the first day postpartum, with a maximum feeding period of 7 days, to cows susceptible to milk fever markedly reduced the incidence of the disease (166, 167, 169, 170). Maximum effect was attained after 3 days feeding and declined sharply 1 day after vitamin D feeding was discontinued. Feeding massive doses over periods of more than 1 week lead to soft-tissue calcification (175), and injection of massive doses of vitamin D causes calcification in shorter periods (173). More recent Ohio studies (169) showed that continuous feeding of 70,000 IU per kg of grain mixture (320,000 IU/day) reduced the incidence of milk fever from 78 per cent to 22 per cent in Jersey cows having previous history of the trouble.

Vitamin E

The critical importance of vitamin E for dairy cattle was demonstrated by Gullickson and Calverley (182). Blaxter *et al.* (180) presented evidence that indicates that the dietary constituents of the ration affect the vitamin E requirements of cattle. The requirement of calves is less than 40 mg of α-tocopherol per calf per day. Harris (184), in summarizing the vitamin E requirements, concluded that the requirement was proportional to the body-surface area. The tocopherol content of milk increased when milk cows went to pasture (181). Milk low in tocopherol content is more susceptible to development of oxidized flavors (185). Wheat-germ oil, the richest natural source of vitamin E, did not improve the breeding efficiency of bulls (187). Under normal conditions, natural feeds supply adequate amounts of vitamin E for adult dairy cattle. However, Safford *et al.* (133) reported muscle dystrophy in calves on western Montana ranges that could be controlled by selenium injections as well as by vitamin E.

Other vitamins

Many vitamins of the vitamin B complex are synthesized by microorganisms in the functional rumen of cattle (129, 135, 190). It appears that under most conditions adequate amounts of the B vitamins are furnished to dairy cattle by a combination of natural feeds and the action of the microflora of the rumen. Young dairy calves have a dietary requirement for thiamine, riboflavin, niacin, pyridoxine, choline, biotin, pantothenic acid, and vitamin B_{12} before the rumen starts to function (191, 195–199, 202, 203). Deficiencies of these vitamins in the young dairy calf cannot be demonstrated, however, except under very restricted dietary conditions. Hopper and Johnson (197) produced niacin deficiency in dairy calves by feeding a diet deficient in both niacin and tryptophan. Normally colostrum provides the B complex vitamins during the early days of life. These vitamins are also generally present in adequate amounts in natural rations to meet the requirements of young calves. Nevertheless, it is possible that supplementary vitamins may be needed when whole or skim milk is replaced in the diet of the calf at an early age by dry mixtures of cereals and by-product feeds. The frequency of such occurrences even under these conditions, however, is extremely low.

ANTIBIOTICS

Antibiotics are not nutrients; they are classified as additives. They are widely used in feeds for dairy calves. It has been demonstrated that young calves respond favorably to the oral administration of some of the antibiotics, particularly chlortetracycline and oxytetracycline. The increased body weight resulting from feeding antibiotics to young calves is usually accompanied by increased appetite, greater vigor, smoother hair coat, and improved feed efficiency (204, 206, 208). The greatest response to antibiotic feeding is during the first few months after birth. If antibiotic feeding is continued beyond 4 months, further improvement seldom occurs, but the initial advantage may be maintained for some time. Removal of the antibiotic from the ration causes a prompt cessation of the accelerated rate of growth, and the weight advantage of the supplemented animals gradually disappears.

In many instances, antibiotic feeding has resulted in lower incidence of diarrhea, but, even in the absence of a reduction in diarrhea, growth stimulation has been demonstrated. Thus, the stimulation of growth resulting from antibiotics cannot be attributed primarily to control of diarrhea. Calves exposed to adverse conditions of sanitation, housing, and disease show the greatest positive response when fed antibiotics.

There are indications that improved appetite, and thus greater feed consumption, is a major factor in the response to antibiotics. Improved skeletal development accompanies the increased weight gains; at least as far as calcium is concerned, the accelerated bone growth involves a greater intake of calcium rather than a higher percentage retention (205). Antibiotic feeding does not appreciably alter the apparent digestibility of feed nutrients in the young calf. Under most circumstances, levels of 40 mg per kg of milk replacer on a dry basis, or equivalent amount of whole milk, and 20 mg per kg of starter appear to be adequate for promoting near maximal responses, although, in some experiments, higher levels have been required to induce the same result. Responses have been observed when antibio ics were fed in the starter to 16-week-old calves; thus, initial deposition of the antibiotic in the rumen also stimulates growth, but this accelerated growth rate is of relatively short duration.

Some studies report that antibiotic feeding increases milk production of dairy cows slightly, whereas a number of others report no effect on milk production. Whether low-level feeding of antibiotics has any significant effect on the general health of dairy cows is questionable.

SYMPTOMS OF NUTRITIONAL DEFICIENCIES

ENERGY

An insufficient supply of energy results in retarded growth and delay in the onset of puberty in young animals and in a decline in milk yield and loss of body weight in mature dairy cattle (12, 23, 33, 34, 38). Severe and prolonged energy deficiency depresses reproductive function, but deficiencies of other nutrients have far more specific effects.

PROTEIN

A lack of protein will greatly depress the rate of growth and maturation of dairy cattle; milk yields decline and gestation may be interrupted if the deficiency is severe. Animals lose body protein and condition, and appetite for low-protein feeds declines. A severe deficiency (60 per cent of requirement or less) lowers the solids-not-fat content of milk as well as the yield (58). A large excess of protein increases milk-protein content slightly without influencing milk yield. The amino-acid makeup of the dietary protein is not important because of bacterial synthesis of the acids needed for body metabolism from simple nitrogen compounds.

CALCIUM

In young calves a calcium-deficient diet results in failure of normal bone growth and a slowing of general growth and development. The bones are low in calcium and phosphorus content and there may be spontaneous fractures. Blood-calcium values usually remain normal even in severe deficiency (85).

The feeding of rations low in calcium to mature cows over a long period of time may bring about a depletion of calcium and phosphorus in the bones, resulting in fragile, easily fractured bones and in reduced milk yields (61), but there is not a reduction in the calcium concentration in the milk. No other clinical manifestations are apparent (65).

PHOSPHORUS

The first evidence of phosphorus deficiency is a decline in blood-plasma inorganic phosphorus to subnormal levels. The normal values for cows are 4 to 6 mg per 100 ml and for calves under 1 year of age 6 to 8 mg per 100 ml. Plasma-phosphatase values increase. The mineral content of the bones is low and they become fragile. Appetite declines and growth rate is greatly retarded. Anorexia is the first clinical symptom of phosphorus deficiency, but it is of little diagnostic value because it is associated with other deficiencies in cattle. Depraved appetite—the chewing of substances not ordinarily classed as feed, such as bones, wood, and hair—often is observed (68, 81, 87). Cows, however, may suffer from extreme phosphorus deficiency without mani-

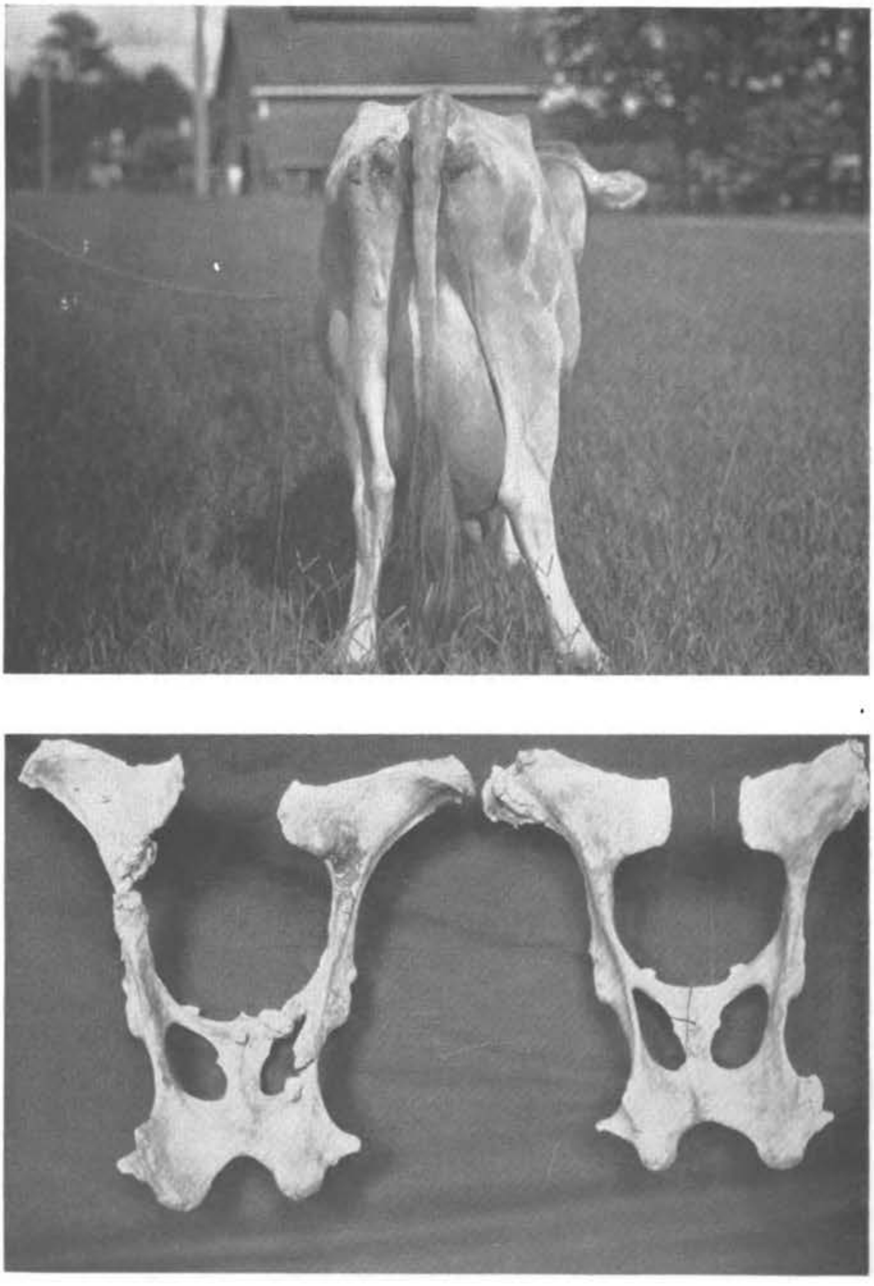


FIG. 1. Both hips of the cow shown above have been broken (knocked down) as a result of feeding a low-calcium ration. At lower left is shown the pelvis of a cow which suffered three breaks while the cow received a low-calcium ration. At lower right is the pelvis of the cow pictured above, showing the nature of the breaks involving both hip bones.

(*Becker* et al., *Florida Agr. Expt. Sta.*)

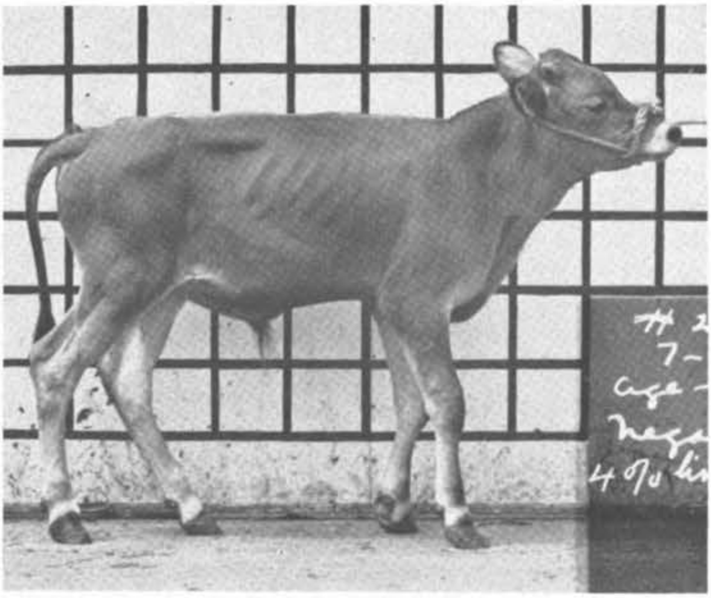


FIG. 2. (Above) Calf suffering from rickets.

Huffman, Mich. Agr. Expt. Sta.

(Below) Phosphorus deficient calf chewing wood, a manifestation of depraved appetite.

(Smith Cornell Agr. Expt. Sta.)

festing depraved appetite (74). The clinical symptoms of phosphorus and cobalt deficiencies are similar in this respect. These two deficiency diseases can be differentially diagnosed by differences in hemoglobin levels and plasma-phosphorus content. Usually, if the cows in a herd are manifesting anorexia or depraved appetite or both and the calves are normal, a phosphorus deficiency is indicated (74).

In chronic phosphorus deficiency, the animals sometimes become stiff in the joints (61). Upon postmortem, the articulating cartilages appear eroded. The bones of cows in phosphorus deficiency become fragile due to calcium and phosphorus withdrawal.

SALT (NaCl)

Salt deficiency is manifested by an intense craving for salt, a lack of appetite, a generally haggard appearance, lusterless eyes, and a rough hair coat. In milking cows there is a rapid loss of weight and a decline in milk production. In high-producing cows, collapse may be sudden and death may rapidly ensue (88, 89). In advanced stages of salt deficiency, the cows develop neuromuscular abnormalities such as continuous shivering and a wavering walk. Recovery is rapid following the administration of salt (89). Salt deficiency in calves (3) is reflected in an unthrifty condition and a harsh coat.

MAGNESIUM

A disease known as "grass tetany," manifested by low plasma-magnesium values, coma, and death, occurs on some pastures, although the magnesium content of the feed is in the normal range (91). Treatment with magnesium is usually effective in preventing and curing the trouble.

Among the early symptoms of experimentally produced magnesium deficiency in calves are anorexia, irritability, hyperemia, and greatly increased excitability. The calf becomes susceptible to convulsions (tetany), causing it to fall on its side with its legs alternately rigidly extended and contracted. There is frothing at the mouth and profuse salivation. These attacks may continue for several minutes or occur intermittently for a long time. Young calves seem to be able to withstand several convulsions, but older calves usually succumb to the first attack (92, 93). Extensive calcium deposits in the large blood vessels may occur.

IODINE

A deficiency of iodine is manifested by the production of dead or nonviable goitrous calves as a result of lack of iodine in the ration of the dam. There is a swelling of the thyroid gland of the calf, which is frequently referred to as "big neck." The trouble can be prevented by feeding iodized salt to the cow during the gestation period (97).

IRON

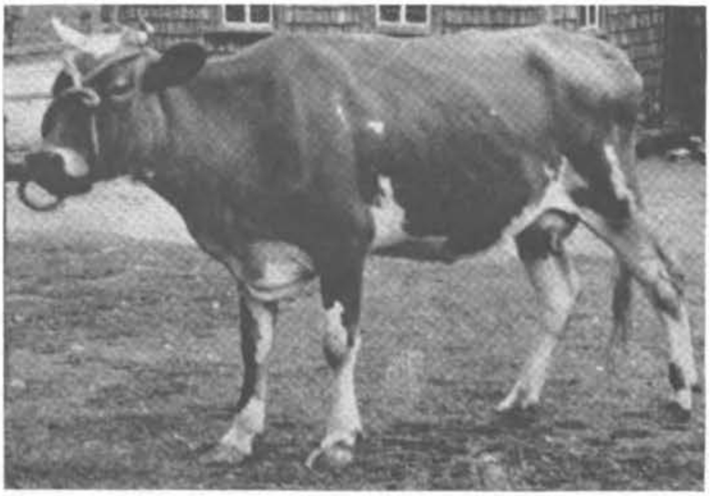
The principal symptom of iron deficiency in calves is anemia or low hemoglobin (106). Feeding iron salts or injecting iron dextran (105) will alleviate the anemia. Except on low-iron soils, natural rations of hay, silage, and concentrates supply ample iron to meet the requirements for growth, reproduction, and lactation without iron supplementation. The older studies of iron deficiency reported in the literature have been complicated by accompanying cobalt or copper deficiencies. The iron requirement is probably very low and in most instances can be met by the iron present in practical rations.

COBALT

When the ration contains insufficient cobalt, animals show a gradual loss of appetite, progressive emaciation, rough coat, listlessness, and eventually anemia. Depraved appetite is often observed. There is marked decrease in milk production and body weight in cows (101). However, these symptoms, other

FIG. 3. Milking cow suffering from cobalt deficiency (above) and the same cow after receiving cobalt (below).

(*Huffman* et al., *Mich. Agr. Expt. Sta.*)



than anemia in the final stages, are similar to phosphorus deficiency. Other than blood-plasma inorganic-phosphorus determinations, the best practical method of differentiating between these two deficiencies is as follows: If the calves under 1 year of age are healthy and the cows have poor appetites, feed a phosphorus supplement. If the calves are unthrifty and have poor appetites, but the cows have good appetites, feed a cobalt supplement. If appetite does not recover within a week, add a phosphorus supplement (74).

COPPER

According to Becker *et al.* (108), most cases of copper deficiency start with severe diarrhea, followed by rapid loss in weight, cessation of growth, abnormal appetite, rough, coarse, bleached, or graying hair coat, and anemia. A readily noticed characteristic of copper deficiency is a swelling of the ends of the leg bones, especially above the pasterns. The bones become very fragile, often resulting in multiple fractures of ribs, femur, or humerus.

Osteomalacia develops in mature cattle. Cows in a copper-depleted condition may fail to conceive or have difficulty at calving (retained placenta) or give birth to calves with congenital rickets. Affected animals may develop a pacing gait. "Falling disease" in cattle is due to a copper deficiency (109). "Swayback" results from damage to nervous tissues during embryonic development, which can be prevented by copper supplements (113).

The presence in forages of excess molybdenum results in diarrhea and bleaching of the hair coat, which can be cured or prevented by increasing the copper intake (110–112).

ZINC

Calves fed a diet containing 3.6 ppm of zinc developed severe parakeratosis (118–120). The tissue changes involved inflammation of the nose and mouth with submucosal hemorrhages, unthrifty appearance, rough hair coat, stiffness of the joints with soft edematous swelling of the feet in front of the fetlocks, breaks in the skin around the hoofs that later became deep fissures, dry scaly skin on the ears, thickening and cracking of skin around the nostrils, appearance of horny outgrowths of the mucosa on the lips and dental pads frequent gnashing of teeth, alopecia starting on the rear legs, red, scabby, and shrunken skin on the scrotum, and bowing of the rear legs.

Zinc content of the blood, pancreas, liver, and other organs, and of the bones and teeth was lower for deficient than for zinc-supplemented animals. Carbonic anhydrase activity of the blood also declined. Supplementing the deficient diet with 43 ppm Zn prevented these symptoms from developing and effected rapid cures of deficient animals. Zinc deficiency also has been reported in grazing cattle (117).

SELENIUM

Supplements of selenium have been shown to be effective in stimulating growth of unthrifty calves and in preventing muscular dystrophy affecting skeletal and cardiac muscle. Selenium supplements have produced growth responses in grazing cattle (124).

VITAMIN A

A vitamin A deficiency is easily detected by blood-plasma vitamin A analysis (136). The normal concentrations for the young calf are 10 μg or more of vitamin A per 100 ml of plasma. Concentrations of 7 to 8 μg of vitamin A per 100 ml will cause the calf to exhibit mild deficiency symptoms, while those of 5 μg of vitamin A or less will produce all the symptoms associated with the advanced stages of the disease. Depletion of liver reserves of the vitamin occur before plasma values fall to critical levels (142). The blood-plasma concentration of vitamin A in adult cattle during the long winter feeding period in the northern states declines from a pasture level of 60 or more to about 15 μg per 100 ml.

In the young calf, symptoms of the deficiency (mild to begin with but severe if they continue) usually start with watery eyes, a nasal discharge, sometimes a cough, and scours or diarrhea. Calves exhibit these symptoms for several days to several weeks and usually succumb to pneumonia.

The earliest sign of vitamin A deficiency in growing calves is elevated cerebro-spinal-fluid pressure (143, 144) and papilledema (152). An easily detected gross symptom of vitamin A deficiency is night blindness, readily observed when animals are driven about in a dim light (145). Lack of muscular coordination, staggering gait, and convulsive seizures may develop. Blindness in young growing cattle also occurs without the classical signs of the vitamin A deficiency syndrome as the result of stenosis of the optic foramen and chronic optic neuritis (152). In these cases blindness develops without keratitis. A lack of vitamin A causes the transformation of normal epithelial structures to stratified keratinized epithelium (epithelial metaplasia) but mature bulls are relatively resistant to these changes (137). The mucosa of the respiratory

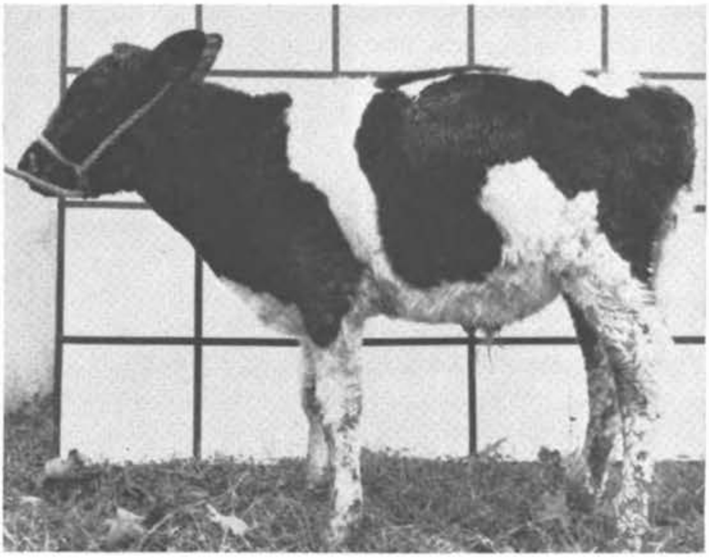
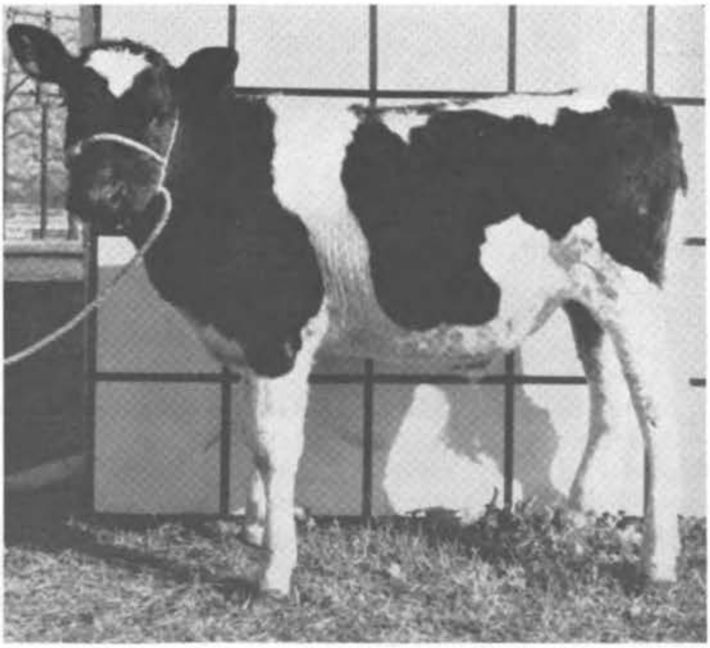


FIG. 4. (Above) Calf showing loss of hair on legs and severe scaliness, cracking and thickening of the skin as a result of zinc deficiency.
(Below) The same calf after receiving supplemental zinc.
(*Miller* et al., *Ga. Agr. Expt. Sta.*)



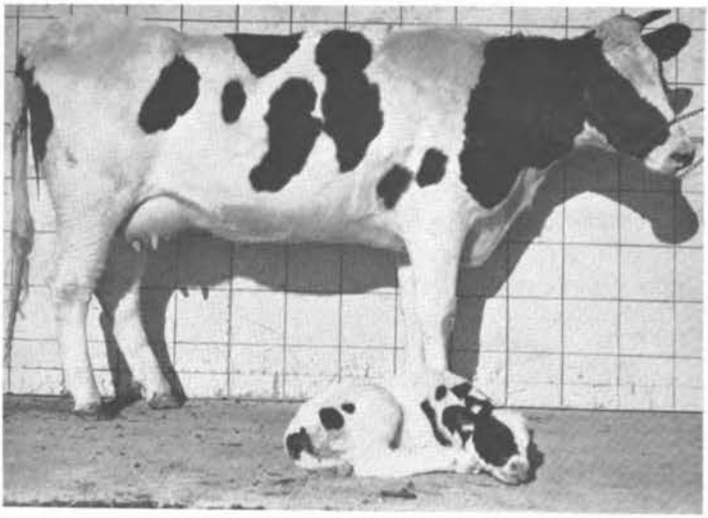


FIG. 5. (Above) The calf pictured with its dam was born weak and blind and failed to survive because the cow was fed a ration too low in vitamin A activity during gestation.
(*Huffman*, et al., *Mich. Agr. Expt. Sta.*)

(Below) Showing constriction of the optic nerves where they passed through the skull bones of a calf born blind from vitamin A deficiency.
(*Moore, Mich. Agr. Expt. Sta.*)

tract, buccal cavity, salivary glands, eyes, lacrimal glands, intestinal tract, urethra, kidney, and vagina are thus changed in the bovine deficient in vitamin A. Structures thus affected are very susceptible to infection, and as a result colds and pneumonia often occur. Diarrhea, loss of appetite, and emaciation are common features of the disease at this stage.

Subclinical vitamin A deficiency may be associated with the development of a roughened hair coat, general unthriftiness, emaciation, and dry pitriasis (bran-like scales of the skin), particularly about the neck and withers and along the back extending to the tail-head.

In the later stages, characteristic changes in the eye may take place; these are early excessive and exhaustive lacrimation, keratitis (corneal inflammation), a softening of the cornea, xerophthalmia (dry form of conjunctivitis), opacity and cloudiness of the cornea, and total blindness from infection. In the pregnant animal, vitamin A deficiency results in abortion or birth at term of dead, weak, or blind calves.

VITAMIN D

One of the first symptoms of low vitamin D rickets is a decrease in the blood-plasma concentration of calcium or inorganic phosphorus or both. These blood changes cause characteristic alterations in the bones, indicating a markedly retarded calcification of the cartilaginous matrix (174).

Clinical symptoms begin with thickening and swelling in regions of the metacarpal (pastern or ankle) or metatarsal bone or both. With the progress of the disease, the forelegs bend forward or sideways or both. The joints, particularly the knee and hock, become swollen and stiff, the pastern straight, and the back humped. In the more severe cases synovial fluid accumulates in the joints. Posterior paralysis may occur as the result of fractured vertebrae. The advanced stages of the disease are marked by stiffness of gait, dragging of the hind feet, irritability, tetany, labored and fast breathing, anorexia except for milk, weakness, and retardation of growth (161–163). On autopsy the gall bladder is frequently distended by accumulation of a viscous ropy orange-yellow bile. Enteritis occasionally occurs. Prolonged deficiency lowers retention of calcium, phosphorus, and nitrogen, and increases the metabolic rate (165).

VITAMIN E (α-tocopherol)

Supplements of α-tocopherol have been effective in overcoming muscular dystrophy in calves. Feeding of cod-liver oil appears to accelerate destruction of vitamin E and depletion of body reserves of the vitamin (180, 181). Heart failure and death may result from dystrophy of cardiac muscles and related tissue damage (182, 183). Supplements of selenium will not correct the defects of rations low in vitamin E (186). Low tocopherol content of the ration lowers the vitamin concentration in the milk and increases its susceptibility to development of oxidized flavors (185), but milk yield and fat content are not affected. Supplements of vitamin E have not improved reproductive performance of bulls (187).

THIAMINE

On a thiamine-deficient diet, nonruminating dairy calves become weak, lose coordination of the legs, and develop retraction of the head, convulsions, and in some cases severe scouring, anorexia, and dehydration. Thiamine injections alleviate the symptoms of polyneuritis (188, 191).

RIBOFLAVIN

Young calves require a dietary source of riboflavin (193–195) until rumen function develops. When the diet is deficient in riboflavin, the calf develops hyperemia of the buccal mucosa and lesions in the corner of the mouth, along the edges of the lips, and around the nose. There is loss of appetite, and growth is poor or ceases entirely. Severe scours develop, and excessive salivation and lacrimation are characteristic. A loss of hair occurs on various parts of the body but is most marked around the navel. Preliminary observations did not reveal vascularization of the cornea or opacity of the lens in any of the animals.

PANTOTHENIC ACID

Johnson *et al.* (198) have reported that the young dairy calf requires pantothenic acid. On a ration without pantothenic acid calves exhibited diarrhea, cessation of growth, and weakness of the legs with inability to stand.

VITAMIN B_{12}

Draper *et al.* (196), using a synthetic milk, produced a vitamin B_{12} deficiency in the dairy calf, manifested by no growth, poor appetite, and lack of coordination. Some demyelination occurred in the peripheral nerves. These symptoms were accompanied by biliary obstruction. Lassiter *et al.* (201) likewise produced a vitamin B_{12} deficiency in calves fed a synthetic milk low in B_{12}, and noted cessation of growth, poor condition, anorexia, and weakness. On postmortem, the liver had white spots on its surface. These workers obtained evidence that the requirement was greater than 10 μg but less than 40 μg per kg of dry-matter intake.

NICOTINIC ACID

The deficiency symptoms of nicotinic acid, or niacin, are loss of appetite, severe scouring, dehydration, and weakness followed by death on the second or third day on a deficient diet (197, 200).

BIOTIN

Studies by Wiese *et al.* (203) showed that the young calf requires a dietary source of biotin. On a biotin-deficient diet, calves develop paralysis of the hind quarters, which is curable by the administration of biotin. Pathological changes associated with a deficiency of biotin have not been reported.

VITAMIN B_6 (Pyridoxine)

On a diet without vitamin B_6 calves manifested poor gain in weight, listlessness, lack of appetite, and general lack of condition. Some of the calves showed epileptiform fits due to a nerve pathology (199) similar to the deficiency symptom observed in other species.

CHOLINE

Calves restricted to a "semisynthetic milk" low in choline developed deficiency symptoms within 7 days, including weakness, inability to stand, anorexia, and death. Some of the calves showed a mild fatty infiltration of the liver. The deficiency was observed only in very young calves, suggesting body synthesis of choline was adequate after the initial critical period was past (198).

COMPOSITION OF FEEDS

A table of feed composition for dairy cattle follows in this report (Table 4, page 27). A more comprehensive feed-composition table is available in National Academy of Sciences—National Research Council Publication 1232, entitled *Joint United States–Canadian Tables of Feed Composition*. Publication 1232 was especially prepared to accompany the series of reports on nutrient requirements of domestic animals, which includes this report. It contains data on proximate composition, energy values for gross energy (GE), apparent digestible energy (DE), metabolizable energy (ME), and TDN, mineral, vitamin, and amino-acid contents of feeds.

NRC NOMENCLATURE

In this publication and in Publication 1232, the NRC nomenclature of the feeds under which the analytical data are shown is based on a scheme proposed by Harris.* It is designed to give (to the extent that the information is available or applicable) a qualitative description of the product as to its: (1) origin or parent material, (2) species, variety, or kind, (3) the part actually eaten, (4) the process(es) and treatment(s) to which it has been subjected, (5) stage of maturity, (6) cutting or crop, (7) grade or quality designations, and (8) classification.

Feeds of the same origin or parent material (and the same species, variety, or kind, if designated) have been subgrouped into the following feed classes: (1) dry roughages, (2) pasture, range plants, and green soiling crops, (3) silages, (4) energy feeds, (5) protein supplements, (6) minerals, (7) vitamins, and (8) additives. Classes are coded as indicated above and are included in parentheses following the NRC names. Within each origin (and species, variety, or kind, if given) there may be feeds that belong to several different classes. These classes are grouped in ascending numerical order of their class code number. Within each class, feeds are grouped alphabetically by origin and species.

It may be noted in the NRC nomenclature that feeds that in the dry state contain more than 18 per cent crude fiber are classified as roughages. Products that contain 20 per cent or more of protein are classified as protein supplements. Products with less than 20 per cent protein are classified as energy feeds. The feeds have been classified in this way because each class has certain properties that are considered in balancing a ration. Fruits and nuts, and roots, have been classified as energy feeds because most of the by-product feeds from these subclasses furnish, primarily, energy to the animal. Examples are (1) apple and pomace, dehydrated, and (2) beet, sugar, and pulp, dehydrated.

The system of naming may be illustrated by examples, as follows:

* Harris, L. E. *J. Animal Sci. 22*:535 (1963).

(Example 1)

COMPONENTS

1. Origin . . . . Alfalfa
2. Variety . . . . Ranger
3. Part eaten . . . . hay
4. Process . . . . s-c
5. Maturity . . . . early blm
6. Cutting . . . . cut 1
7. Grade . . . . mn 17 prot mx 27 fbr
8. Classification . . . . (10)

(Example 2)

COMPONENTS

1. Origin . . . . Animal
3. Part eaten . . . . liver
4. Process . . . . dehy grnd
8. Classification . . . . (51)

The first example would be read: Alfalfa, Ranger, hay, sun-cured, early bloom, first cutting, minimum 17 per cent protein, maximum 27 per cent crude fiber. It is a dry roughage.

To reduce the names to minimum printing or punch-card space requirement a system of abbreviations has been devised covering many of the terms involved in the eight components of the name. (See table at top of opposite column.)

The NRC name is written out in linear form with the components of the name separated by commas and without other punctuation. Commas are not included within the eight components so that the reader may readily recognize the entire component.

It is probable that some feeds, particularly concentrate by-products, may not at first be recognized by their NRC names. For this reason, the common name by which these feeds are known has been included in parenthesis after the NRC name. Cross references (where necessary) have been included so the NRC name may be readily located.

For more information concerning the nomenclature, see NAS-NRC Publication 1232.

FEED-TERM ABBREVIATIONS

blm	bloom
by-prod	by-product
chop	chopped
cut	cutting
dehy	dehydrated
distil	distiller's
extn unspec	extraction unspecified
fbr	fiber
gm	gram
gr	grade
grnd	ground
IU	International Units
kcal	kilocalories
kg	kilogram
mech-extd	mechanically extracted, expeller extracted, hydraulic extracted, or old process
μg	microgram
mg	milligram
mil-rn	mill run
mn	minimum
mx	maximum
N	nitrogen
pt	part(s)
shed	shredded
sol	solubles
solv-extd	solvent extracted
s-c	sun-cured
TDN	total digestible nutrients
w	with
wo	without

COMPOSITION OF FEEDS FOR DAIRY CATTLE

Although the feed composition table for dairy cattle (Table 4) has been prepared with much care, it is realized that individual feed samples may vary widely from indicated averages because of influencing factors as crop variety, storage conditions, and climate and soil pertinent to the locality where the feed was produced. Therefore, the values given should be used with judgment, often in conjunction with more specific information on hand about the feed.

TABLE 4. COMPOSITION OF FEEDS FOR DAIRY CATTLE[1]
(For More Complete Information See NAS-NRC Pub. 1232)

Feeds	Dry Matter	Protein: Total	Protein: Digestible	TDN	Energy per Kg: Digestible[2]	Energy per Kg: Metabolizable[2]	Fat	Lignin	Cellulose	Crude Fiber	Calcium	Phosphorus	Carotene	Vitamin A Equivalent[3]
	%	%	%	%	kcal	kcal	%	%	%	%	%	%	mg/kg	IU/gm
Alfalfa, hay, s-c, pre-blm, (1)	89	19.1	13.6	54	2410	1976	2.4	9	24	23.4	1.89	0.27	446.0	743.5
Alfalfa, hay, s-c, early blm, (1)	90	16.6	11.4	52	2310	1894	2.0	9	25	26.8	1.12	0.21	114.0	190.0
Alfalfa, hay, s-c, mid-blm, (1)	89	15.2	10.8	51	2183	1790	1.8	10	27	27.5	1.20	0.20	30.0	50.0
Alfalfa, hay, s-c, full blm, (1)	88	14.0	10.1	50	2112	1732	1.6	11	30	29.8	1.13	0.18	33.3	55.5
Alfalfa, hay, s-c late blm, (1)	91	13.9	10.0	46	2141	1756	2.0	11	31	32.3	1.21	0.22	24.2	40.3
Alfalfa, aerial pt, ensiled, (3)	30	5.3	3.6	17	750	615	1.1	—	—	9.1	0.48	0.16	27.3	45.5
Alfalfa, aerial pt molasses added, ensiled, (3)	32	5.6	3.9	19	838	687	1.1	—	—	9.3	0.63	0.13	31.3	52.2
Alfalfa, aerial pt, wilted, ensiled, (3)	36	6.4	4.5	22	970	795	1.2	—	—	10.9	0.51	0.12	18.7	31.2
Alfalfa, aerial pt, dehy grnd, (7)	92	16.7	13.0	56	2469	2025	2.3	—	19	25.8	1.09	0.29	73.6	122.7
Alfalfa, leaves, dehy grnd, (7)	92	20.6	13.6	57	2513	2061	2.9	—	—	19.6	1.60	0.23	148.6	247.7
Animal, blood, dehy grnd, (5) (Blood meal)	90	79.9	56.7	60	2646	2170	1.6	—	—	0.8	0.28	0.22	—	—
Animal, blood, spray-dehy, (5) (Blood flour)	91	82.2	78.9	81	3571	2928	1.0	—	—	0.6	0.45	0.37	—	—
Animal, carcass residue, dehy grnd, (5) (Meat meal)	94	53.4	43.8	65	2866	2350	9.9	—	—	2.4	7.94	4.03	—	—
Animal, carcass residue w blood, dehy grnd, (5) (Meat meal tankage)	92	59.8	50.8	69	3042	2494	8.1	—	—	2.0	5.94	3.17	—	—
Animal, carcass residue w bone, dehy, grnd, (5) (Meat and bone meal tankage)	94	49.6	43.0	63	2778	2278	11.9	—	—	2.5	7.34	3.73	—	—
Animal, bone charcoal, spent, (6)	—	—	—	—	—	—	—	—	—	—	22.00	13.10	—	—
Animal, bone, steamed dehy grnd, (6)	95	12.1	—	—	—	—	3.2	—	—	1.7	30.00	13.90	—	—
Barley, s-c, hay, (1)	87	7.7	4.3	50	2205	1808	1.9	—	—	23.0	0.18	0.26	—	—
Barley, straw, (1)	88	3.6	0.6	43	1896	1555	1.6	—	—	37.3	0.30	0.08	—	—
Barley, grain, (4)	89	11.7	8.8	78	3439	2820	1.9	—	—	5.3	0.08	0.42	0.4	0.7
Barley, grain, Pacific Coast, (4)	90	8.7	6.9	79	3483	2856	—	—	—	—	0.06	0.33	—	—
Beans, field, seeds, (4)	90	22.9	20.2	79	3483	2856	—	—	—	—	0.15	0.57	—	—
Beet, sugar, tops, ensiled, (3)	26	3.1	1.9	12	529	434	0.5	—	—	3.2	0.60	0.05	9.3	15.5
Beet, sugar, molasses, (4)	77	8.4	4.4	61	2690	2206	0.2	—	—	0.0	0.16	0.03	—	—
Beet, sugar, pulp, dehy, (4)	91	8.9	4.1	69	3845	3153	0.6	—	—	19.4	0.68	0.10	0.2	0.3
Beet, sugar, pulp, wet, (4)	10	1.4	0.5	8	353	289	0.2	—	—	2.2	0.09	0.01	—	—
Beet, sugar, pulp w molasses, dehy, (4)	92	9.1	6.0	71	3131	2567	0.5	—	—	15.6	0.56	0.08	0.2	0.3
Bermudagrass, hay, s-c (1)	91	8.1	4.1	45	1984	1627	1.8	—	—	26.9	0.42	0.18	59.1	98.5

TABLE 4. Continued

Feeds	Dry Matter	Protein Total	Protein Digestible	TDN	Energy per Kg Digestible[2]	Energy per Kg Metabolizable[2]	Fat	Lignin	Cellulose	Crude Fiber	Calcium	Phosphorus	Carotene	Vitamin A Equivalent[3]
	%	%	%	%	kcal	kcal	%	%	%	%	%	%	mg/kg	IU/gm
Bermudagrass, coastal, hay, s-c, (1)	91	8.6	5.6	45	1984	1627	2.0	10	32	27.8	0.42	0.16	—	—
Blood flour, and meal, see Animal														
Bone black, and meal, see Animal														
Brewers dried grains, see Grains														
Bromegrass, hay, s-c, (1)	90	10.9	5.6	50	2205	1808	2.3	8	28	28.8	0.39	0.25	33.1	55.2
Buttermilk, see Cattle														
Canarygrass, reed, hay, s-c, (1)	91	8.0	4.0	42	1852	1519	2.0	—	—	31.2	0.31	0.23	82.2	137.0
Carrot, roots, (4)	12	1.2	0.6	11	485	398	—	—	—	1.1	0.05	0.04	72.0	120.0
Cattle, buttermilk, dehy, (5)	92	32.0	28.8	83	3660	3001	5.8	—	—	0.4	1.34	0.94	—	—
Cattle, milk, dehy, (5)	94	25.2	23.9	118	5203	4266	26.4	—	—	0.2	0.89	0.68	7.1	10.8
Cattle, milk, fresh, (5)	12	3.1	2.9	15	661	542	3.7	—	—	0.0	0.12	0.11	—	—
Cattle, milk, skim dehy, (5)	94	33.5	30.2	80	3527	2892	0.9	—	—	0.2	1.26	1.03	—	—
Cattle, whey, dehy, (5)	94	13.1	11.5	78	3439	2820	—	—	—	—	0.87	0.79	—	—
Citrus pulp, ensiled, (3)	20	1.4	0.3	20	882	723	1.8	—	—	3.2	—	—	—	—
Citrus pulp, shred dehy, (4)	90	6.6	2.7	75	3307	2712	4.6	—	—	13.0	1.96	0.12	0.2	0.3
Clover, alsike, hay, s-c, (1)	88	12.9	8.6	50	2205	1808	2.6	—	—	25.9	1.15	0.22	164.5	274.2
Clover, crimson, hay, s-c, (1)	87	14.7	9.8	45	1984	1627	2.0	—	—	28.0	1.22	0.18	—	—
Clover, ladino, hay, s-c, (1)	91	21.0	16.0	60	2646	2170	3.1	11	—	17.5	1.26	0.36	146.6	244.4
Clover, red, hay, s-c, (1)	88	13.1	7.9	52	2293	1880	2.6	13	23	26.5	1.42	0.19	33.1	55.2
Coconut, meat, mech-extd grnd, (5) (Coconut meal)	93	20.4	16.5	75	3307	2712	6.6	—	—	11.6	0.21	0.61	—	—
Coconut, meat, solv-extd grnd, (5) (Coconut meal)	92	21.3	17.3	68	2998	2458	1.8	—	—	15.4	0.17	0.61	—	—
Corn, see Maize														
Cotton bolls, s-c, (1)	92	8.5	2.3	42	1852	1519	2.4	—	—	30.8	0.61	0.09	—	—
Cotton seeds, (5)	93	23.0	17.2	91	4012	3290	22.8	—	—	16.7	0.14	0.68	—	—
Cotton seed hulls, (1)	90	3.9	0.2	37	1631	1337	1.4	24	54	42.8	0.14	0.09	—	—
Cotton seed, mech-extd grnd, (5) (Cottonseed meal)	93	41.4	33.5	73	3219	2640	5.8	—	—	10.7	0.18	1.15	—	—
Cotton seed, solv-extd grnd, (5) (Cottonseed meal)	91	41.6	33.7	64	2822	2314	1.6	—	—	—	0.15	1.10	—	—
Cotton seed w hulls, mech-extd grnd, (5) (Cottonseed, whole pressed)	90	25.1	18.1	63	2778	2278	8.4	—	—	23.3	0.17	0.64	—	—
Cowpea, hay, s-c, (1)	90	16.6	10.1	54	2381	1952	2.6	—	—	24.6	1.21	0.29	—	—
Defluorinated, phosphate, (6)	99	—	—	—	—	—	—	—	—	—	33.0	18.0	—	—

Dicalcium, phosphate, (6)	96	—	—	—	—	—	—	—	—	—	26.50	20.50	—	—
Fescue, meadow, hay, (1)	88	9.2	4.9	52	2293	1880	2.6	6	33	27.5	0.44	0.32	62.8	104.7
Fish, menhaden, cooked mech-extd dehy grnd, (5) (Fish, menhaden, meal)	92	61.3	49.7	68	2998	2458	7.7	—	—	0.7	5.49	2.81	—	—
Flax, seed, mech-extd grnd, (5) (Linseed meal)	91	35.3	31.1	74	3263	2676	5.2	—	—	8.5	0.44	0.89	0.3	0.5
Flax, seed screenings, extn unspec grnd, (5) (Flaxseed screenings meal)	91	24.5	13.7	55	2425	1988	7.2	—	—	11.8	0.37	0.43	—	—
Flax, seed, solv-extd grnd, (5) (Linseed meal)	91	35.1	30.5	71	3131	2567	1.7	—	—	8.9	0.40	0.83	—	—
Grains, brewers grains, dehy, (4) (Brewers dried grains)	92	25.9	19.2	60	2646	2170	6.2	—	—	14.5	0.27	0.50	—	—
Grass-legume, aerial pt, ensiled, (3)	29	3.4	1.7	13	573	470	1.0	—	—	9.1	0.23	0.08	66.6	111.0
Grass-legume, aerial pt molasses added, ensiled, (3)	30	3.4	2.0	15	661	542	1.0	—	—	9.3	0.28	0.08	69.0	115.0
Johnsongrass, see Sorghum														
Lespedeza, hay, s-c, pre-blm, (1)	92	16.4	11.8	50	2205	1808	3.1	—	—	21.8	1.12	0.25	133.6	222.7
Lespedeza, hay, s-c, early blm, (1)	93	14.3	9.8	49	2160	1771	3.9	18	29	25.1	1.14	0.23	—	—
Lespedeza, hay, s-c, mid-blm, (1)	93	13.0	8.6	47	2072	1699	—	—	29	—	1.11	0.24	—	—
Lespedeza, hay, s-c, full blm, (1)	93	12.5	5.6	45	1984	1627	2.9	—	27	28.8	0.97	0.21	—	—
Limestone, grnd, (6)	99	—	—	—	—	—	—	—	—	—	33.84	0.02	—	—
Linseed, see Flax														
Maize, aerial pt w ears w husks, s-c, (1) (Corn fodder)	82	7.3	3.9	52	2293	1880	2.0	—	—	21.2	0.41	0.21	—	—
Maize, aerial pt wo ears wo husks, s-c, mature, (1) (Corn stover, mature)	87	5.1	1.6	48	2116	1735	1.0	—	—	32.3	0.40	0.07	3.1	5.2
Maize, cobs, grnd, (1)	93	2.9	−0.8	46	2028	1663	0.4	—	—	34.3	—	—	—	—
Maize, aerial pt wo ears wo husks, ensiled, (3)	27	1.9	0.7	15	661	542	0.6	—	—	8.7	0.10	0.05	—	—
Maize, dent, aerial pt w ears w husks, ensiled, (3)	26	2.2	1.0	17	750	615	0.8	—	—	6.7	0.10	0.06	13.4	22.3
Maize, dent, aerial pt w ears w husks, ensiled, dough stage, (3)	29	2.3	1.2	19	884	725	0.8	—	—	6.3	—	—	9.7	16.2
Maize, dent, aerial pt w ears w husks, ensiled, milk stage, (3)	26	1.8	0.8	18	743	609	0.6	—	—	5.8	0.07	0.05	—	—
Maize, ears w husks, ensiled, (3)	45	1.7	0.9	35	1435	1177	0.8	—	—	2.3	—	—	—	—
Maize-soybean (mn 30) aerial pt, ensiled, (3)	28	3.2	2.0	20	882	723	1.0	—	—	7.0	0.20	0.08	51.4	85.7
Maize, cob w grain, grnd, (4)	86	7.4	5.3	73	3219	2640	—	—	—	—	0.04	0.22	—	—
Maize, dent yellow, grain, gr 2 US, (4)	89	8.9	6.8	81	3571	2928	3.9	—	—	2.3	0.02	0.31	1.8	3.0
Maize, distil grains, dehy, (4)	92	27.1	19.5	83	3660	3001	9.3	—	—	11.9	0.09	0.37	3.1	5.2
Maize, distil grains w sol, dehy, (4)	92	27.2	19.3	82	3616	2965	9.3	—	—	9.0	—	—	—	—
Maize, distil sol dehy, (4)	93	26.9	21.5	80	3527	2892	9.1	—	—	3.8	—	—	—	—
Maize, gluten, dehy, (4) (Corn gluten meal)	91	42.9	36.9	78	3439	2820	2.3	—	—	4.0	0.16	0.40	16.3	27.2

TABLE 4. Continued

Feeds	Dry Matter	Protein		TDN	Energy per Kg		Fat	Lignin	Cellulose	Crude Fiber	Calcium	Phosphorus	Carotene	Vitamin A Equivalent[3]
		Total	Digestible		Digestible[2]	Metabolizable[2]								
	%	%	%	%	kcal	kcal	%	%	%	%	%	%	mg/kg	IU/gm
Maize, gluten w bran, dehy, (4) (Corn gluten feed)	90	25.3	21.8	74	3263	2676	2.4	—	—	7.9	0.46	0.77	8.4	14.0
Maize, grits by-prod, mil-rn, (4) (Hominy feed)	90	11.1	7.4	84	3704	3037	6.1	—	—	5.0	0.02	0.58	—	—
Maize, sweet, cannery residue, ensiled, (4)	29	2.6	1.5	21	926	759	1.5	—	—	7.8	—	—	3.7	6.2
Mangel, roots, (4)	9	0.8	0.6	7	309	253	0.1	—	—	0.8	0.02	0.02	—	—
Meadow hay, see Native														
Milk, see Cattle														
Molasses, see Beet, and Sugarcane														
Monosodium, phosphate, (6)	—	—	—	—	—	—	—	—	—	—	—	22.40	—	—
Native, Intermountain, hay, s-c, (1) (Meadow hay)	93	8.5	5.1	54	2381	1952	2.8	—	—	28.0	0.53	0.16	—	—
Native, Midwest, hay, s-c, mid-blm, (1) (Prairie hay)	91	8.2	2.0	52	2293	1380	2.6	—	—	30.3	0.37	0.11	29.3	48.8
Native, Midwest, hay, s-c, late blm, (1) (Prairie hay)	91	6.9	2.9	51	2249	1844	2.9	—	—	30.0	0.46	0.07	22.3	37.2
Native, Midwest, hay, s-c, milk stage, (1) (Prairie hay)	90	6.0	2.1	50	2205	1808	2.4	—	—	29.3	0.47	0.07	7.9	13.2
Oat, hay, s-c, (1)	90	6.4	3.1	56	2469	2025	2.5	—	—	27.5	0.23	0.21	89.1	148.5
Oat, straw, (1)	90	4.0	1.3	47	2072	1699	1.9	—	—	36.9	0.30	0.90	—	—
Oat, aerial pt, ensiled, (3)	32	3.1	1.8	19	838	687	1.3	—	—	10.0	0.12	0.10	37.9	63.2
Oat, cereal by-product, (4) (Feeding oat meal)	91	16.1	13.7	91	4012	3290	—	—	—	—	0.07	0.46	—	—
Oat, grain, (4)	89	11.8	8.8	68	2998	2458	4.5	—	—	10.7	0.10	0.35	0.0	0.0
Oat, grain, Pacific Coast, (4)	91	9.2	7.0	70	3086	2531	5.3	—	—	11.0	0.10	0.35	—	—
Oat, groats, (4)	90	16.2	13.8	92	4056	3326	—	—	—	—	0.08	0.46	—	—
Orchardgrass, hay, s-c, (1)	88	11.2	6.7	50	2205	1808	3.3	7	22	29.9	0.40	0.33	29.5	49.2
Oyster, shells, grnd, (6)	99	1.0	—	—	—	—	—	—	—	—	38.05	0.07	—	—
Pea, field, aerial pt wo peas, ensiled, (3)	23	3.0	1.8	13	573	470	0.8	—	—	7.4	0.43	0.08	32.2	53.7
Peanut, kernel, mech-extd grnd, (5) (Peanut meal)	92	45.8	41.7	80	3527	2892	5.9	—	—	10.7	0.17	0.57	0.2	0.3
Peanut, kernel, solv-extd grnd, (5) (Peanut meal)	92	47.4	43.1	75	3307	2712	1.2	—	—	13.1	0.20	0.65	—	—
Potatoes, tubers, ensiled, (3)	25	2.5	1.2	19	838	687	0.2	—	—	2.1	—	—	—	—
Potatoes, tubers, dehy grnd, (4)	90	9.7	3.5	72	3175	2604	0.3	—	—	2.1	0.07	0.20	—	—
Potatoes, tubers, fresh, (4)	21	2.5	1.2	19	838	687	0.2	—	—	2.1	—	—	—	—

Prairie hay, see Native														
Rape, seed, (5)	90	20.4	17.3	117	5159	4230	43.6	—	—	6.6	—	—	—	—
Rice, bran w germ, (4)	91	13.5	8.8	61	2690	2206	15.1	—	—	10.9	0.06	1.82	—	—
Rice, white, polishings, (4)	90	11.8	7.7	80	3527	2892	13.2	—	—	3.3	0.04	1.42	—	—
Rye, straw, (1)	89	2.7	−1.4	40	1764	1446	1.3	—	—	42.4	0.25	0.09	—	—
Rye, distil grains, dehy, (4)	93	18.8	11.2	58	2557	2097	6.4	—	—	13.8	0.13	0.41	—	—
Rye, flour by-prod, mx 8.5 fbr, (4) (Rye middlings)	90	17.1	12.8	71	3131	2567	3.1	—	—	5.8	0.06	0.63	—	—
Rye, grain, (4)	89	11.9	9.4	76	3351	2748	1.6	—	—	2.3	0.06	0.34	0.0	0.0
Safflower, seeds w hulls, (5)	93	16.3	13.0	82	3616	2965	29.8	—	—	26.6	—	—	—	—
Safflower, seed, mech-extd grnd, (5) (Safflower meal)	91	19.7	16.9	57	2513	2061	6.0	—	—	30.9	0.23	0.71	—	—
Safflower, seeds w hulls, solv-extd grnd, (5) (Safflower meal)	92	21.5	17.2	52	2293	1880	6.9	—	—	32.8	—	—	—	—
Safflower, seeds wo hulls, solv-extd grnd, (5) (Safflower meal without hulls)	91	42.5	36.6	64	2822	2314	6.7	—	—	8.5	—	—	—	—
Sorghum, aerial pt w heads, s-c, (1) (Sorghum fodder)	86	6.8	2.6	53	2337	1916	2.1	—	—	22.3	0.34	0.15	18.7	31.2
Sorghum, grain variety, aerial pt wo heads, s-c, (1) (Grain sorghum stover)	92	4.6	1.6	46	2028	1663	1.8	—	—	29.4	0.37	0.10	6.2	10.3
Sorghum, distillers grains, dehy (4)	94	28.0	20.3	79	3483	2856	7.4	—	—	13.8	0.16	0.78	—	—
Sorghum, Johnsongrass, hay, s-c, (1)	91	7.0	3.1	51	2249	1844	1.9	—	—	30.3	0.74	0.28	33.7	56.2
Sorghum, sudangrass, hay, s-c, (1)	89	11.3	4.9	52	2293	1880	2.0	—	—	25.7	0.50	0.28	—	—
Sorghum, grain variety, aerial pt w heads, ensiled, (3) (Grain sorghum silage)	29	2.3	0.6	16	705	578	0.8	—	—	7.8	0.11	0.06	9.7	16.2
Sorghum, sorgo, aerial pt w heads, ensiled, (3)	25	2.5	0.7	17	750	615	0.8	—	—	6.9	0.03	0.05	—	—
Sorghum, sudangrass, aerial pt, ensiled, (3)	26	2.2	1.5	14	617	506	0.7	—	—	8.8	0.11	0.04	—	—
Sorghum, kafir, grain, (4)	87	11.1	9.0	78	3439	2820	2.5	—	—	2.5	—	—	—	—
Sorghum, milo, grain, (4)	89	11.0	8.6	84	3704	3037	2.8	—	—	2.4	—	—	—	—
Sorghum, milo, heads, chop, (4)	91	9.3	7.1	78	3439	2820	2.5	—	—	7.1	—	—	—	—
Soybean, hay, s-c, (1)	89	14.5	9.0	47	2072	1699	2.7	10	28	28.6	1.15	0.20	31.7	52.8
Soybean, hulls, (1) (Soybean flakes)	91	12.5	8.1	73	3219	2640	2.1	—	—	35.4	0.54	0.15	—	—
Soybean, straw, (1)	88	4.8	1.4	38	1675	1374	1.2	—	—	38.8	1.40	0.05	—	—
Soybean, aerial pt, ensiled, (3)	28	4.1	2.6	15	661	542	0.9	—	—	8.7	0.35	0.14	21.8	36.3
Soybean, seeds, mech-extd grnd, (5) (Soybean meal)	90	43.8	37.2	77	3395	2784	4.7	—	—	5.8	0.27	0.63	0.2	0.3
Soybean, seeds, (5)	91	36.8	33.1	81	3571	2928	17.4	—	—	6.4	0.25	0.59	—	—
Soybean, seeds, solv-extd grnd, (5) (Soybean meal)	89	45.8	41.2	73	3219	2640	0.9	—	—	5.8	0.32	0.67	0.2	0.3
Sudangrass, see Sorghum														
Sugarcane, molasses, (4)	74	3.0	1.7	67	2954	2422	0.1	—	—	0.0	0.66	0.08	—	—

TABLE 4. Continued

Feeds	Dry Matter	Protein Total	Protein Digestible	TDN	Energy per Kg Digestible[2]	Energy per Kg Metabolizable[2]	Fat	Lignin	Cellulose	Crude Fiber	Calcium	Phosphorus	Carotene	Vitamin A Equivalent[3]
	%	%	%	%	kcal	kcal	%	%	%	%	%	%	mg/kg	IU/gm
Sugarcane, molasses, dehy, (4)	96	10.3	6.1	63	2778	2278	1.0	—	—	0.0	—	—	—	—
Tankage, see Animal														
Timothy, hay, s-c, pre-blm, (1)	87	11.8	6.4	54	2381	1952	3.0	—	—	31.3	0.57	0.30	—	—
Timothy, hay, s-c, mid-blm, (1)	88	7.5	4.0	54	2381	1952	2.4	—	—	29.5	0.36	0.16	46.3	77.2
Timothy, hay, s-c, late blm, (1)	87	6.9	3.4	51	2249	1844	2.3	—	—	29.5	0.30	0.18	—	—
Timothy, aerial pt, ensiled, (3)	38	3.9	2.2	22	970	795	1.3	—	—	12.9	0.21	0.11	30.0	50.0
Trefoil, birdsfoot, hay, s-c, (1)	90	14.2	9.8	48	2116	1735	3.0	7	18	—	3.30	0.16	9.0	15.0
Turnip, roots, (4)	9	12.0	0.8	8	353	289	0.2	—	—	1.1	0.06	0.02	—	—
Vetch, hay, s-c, (1)	88	17.6	11.6	55	2425	1989	2.3	—	—	24.8	1.20	0.30	403.0	672.0
Wheat, hay, s-c, (1)	86	6.5	3.5	45	1984	1627	1.7	—	—	24.0	0.10	0.14	96.0	160.0
Wheat, straw, (1)	90	3.2	0.4	43	1896	1555	1.5	12	45	37.4	0.15	0.07	2.0	3.3
Wheat, bran, (4)	89	16.0	12.5	62	2734	2242	4.1	—	14	10.0	0.14	1.17	—	—
Wheat, flour by-prod, mx 7 fbr, (4) (Wheat shorts)	89	18.0	14.0	78	3439	2820	5.0	—	—	5.3	0.07	0.79	3.1	5.2
Wheat, flour by-prod, mx 9.5 fbr, (4) (Wheat middlings)	90	17.2	12.5	77	3395	2784	4.6	—	—	7.6	0.15	0.91	3.1	5.2
Wheat, germ, grnd, (4)	90	27.3	25.7	85	3748	3073	9.1	—	—	2.6	0.07	1.04	—	—
Wheat, grain, screenings, (4)	89	15.0	10.8	69	3042	2494	3.0	7	5	6.5	0.08	0.39	—	—
Wheat, hard red spring, grain, (4)	90	14.7	11.8	79	3483	2856	1.9	—	—	2.5	0.05	0.47	0.0	0.0
Wheat, hard red winter, grain, (4)	89	13.0	10.1	78	3439	2820	1.6	—	—	2.7	0.05	0.40	0.0	0.0
Wheat, soft red winter, grain, (4)	90	11.1	9.2	80	3527	2892	1.6	—	—	2.2	0.09	0.30	—	—
Wheat, soft white, grain, Pacific Coast, (4)	89	9.9	8.3	80	3527	2892	2.0	—	—	2.7	—	—	—	—
Yeast, brewers, dehy, (5)	93	48.3	40.0	73	3086	2531	1.1	—	—	2.7	0.13	0.43	0.0	0.0
Yeast, torula, dehy, (5)	93	6.6	2.7	70	2260	1853	2.5	—	—	2.4	0.57	1.68	—	—

[1] Values may be different in other publications because data are summarized to date for each publication. The composition of mixed roughages may be computed as weighted means from the figures given for the pure species making up the mixtures. The class to which the feed belongs is indicated by a number in parenthesis after the NRC name as follows: (1) dry roughages; (2) pasture, range plants, and green soiling crops; (3) silages; (4) energy feeds; (5) protein supplements; (6) minerals; (7) vitamins; and (8) additives. Names in parenthesis under NRC names are American Feed Control names or other names. See table on page 26 for abbreviations used in NRC names. A dash (—) indicates that no data are available. This table was prepared by the subcommittee of the National Academy of Sciences—National Research Council Animal Nutrition Committee on Feed Composition, Earle W. Crampton and Lorin E. Harris.

[2] It has not been possible to obtain apparent digestible energy (DE) values for all feedstuffs so where data were not available values have been estimated from TDN values using the following formula: DE (kcal/kg) = lbs TDN × 2,000 kcal/lb TDN × 2.2046. Where data were not available for metabolizable energy (ME), values have been estimated from DE using the following formula: ME (kcal/kg) = DE × 82%. Researchers are urged to work out the DE, ME, and net energy (NE_{M+P} or NE_M or NE_P) values of feeds so the TDN values can be replaced.

[3] Assume that 0.6 μg of β-carotene = one IU of vitamin A as determined by rat growth, or the vitamin A equivalent (IU/gm) = mg carotene × (1667/1000). When using carotene to satisfy vitamin A requirements of dairy cattle, a conversion factor of 4.17 (1667 IU vitamin A equivalent per mg carotene ÷ 400 IU vitamin A equivalent per mg carotene for dairy cattle) should be used since dairy cattle do not convert carotene to vitamin A as efficiently as rats do (see text).

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