10 Nutrient Requirements of the Young Calf

From birth until weaning to dry feed, the calf undergoes tremendous physiologic and metabolic changes (Toullec and Guilloteau, 1989). During the preruminant stage, digestion and metabolism are similar to those of nonruminant animals in many respects. Thus, dietary requirements are best met with high-quality liquid diets formulated from sources of carbohydrates, proteins, and fats that are digested efficiently. The most critical period is the first 2-3 wk of life, during which time the calf's digestive system is immature but developing rapidly with regard to digestive secretions and enzymatic activity (Toullec and Guilloteau, 1989; Davis and Drackley, 1998).

Calves raised for purposes other than veal production should be encouraged to consume dry feed at an early age to stimulate development of a functional rumen. Development of the ruminal epithelial tissue that is responsible for absorption of volatile fatty acids (VFA) depends on the presence of the VFA, particularly butyrate (Sander et al., 1959). The chemical composition and physical form of the starter feed are important characteristics (Warner, 1991). The starter should be relatively high in readily fermentable carbohydrates but adequate in digestible fiber to support the fermentation necessary for proper ruminal tissue growth (Brownlee, 1956; Flatt et al., 1958; Williams and Frost, 1992; Greenwood et al., 1997). The rumen and its microbial population are immature at this stage (Anderson et al., 1987a,b) and ruminal cellulose digestibility is limited (Williams and Frost, 1992). Consequently, long hay is not as effective as concentrates in developing a functional rumen and limits metabolizable energy intake in young calves (Stobo et al., 1966). Long hay should not be fed to calves until after weaning (Quigley, 1996a; Davis and Drackley, 1998). Nevertheless, adequate particle size of starter feed—whether pelleted, ground, or texturized—is important to prevent abnormal development and keratinization of ruminal papillae and to prevent impaction of fine particles between papillae (McGavin and Morrill, 1976; Greenwood et al., 1997; Beharka et al., 1998).

With respect to the nutrient requirements of the calf, three phases of development related to digestive function are recognized (Davis and Clark, 1981):

- Liquid-feeding phase. All or essentially all the nutrient requirements are met by milk or milk replacer. The quality of these feeds is preserved by a functional esophageal groove, which shunts liquid feeds directly to the abomasum and so avoids microbial breakdown in the reticulo-rumen (Orskov, 1972).
- Transition phase. Liquid diet and starter both contribute to meeting the nutrient requirements of the calf.
- Ruminant phase. The calf derives its nutrients from solid feeds, primarily through microbial fermentation in the reticulo-rumen.

This chapter discusses nutrient requirements of calves in each of those phases.

ENERGY REQUIREMENTS OF CALVES

Energy requirements of calves, like those of other ages and classes of cattle, can be expressed in numerous ways (see Chapter 2). Regardless of the system preferred, it is imperative to understand where the major losses of energy occur as the energy-yielding components of the diet undergo digestion and metabolism. If the efficiencies of conversion of gross energy to digestible energy or metabolizable energy and of conversion of metabolizable energy to net energy (both NE_M and NE_G) are known, users can select the system that best fits their needs.

In this edition, the energy requirements of calves have been derived on the basis of metabolizable energy; however, requirements and feed composition also are given in units of net energy and digestible energy for those who prefer to use those systems.

Data on energy requirements are organized around replacement calves fed only milk or milk replacer (Table 10-1); calves fed milk and starter feed or milk replacer and

TABLE 10-1 Daily Energy and Protein Requirements of Young Replacement Calves Fed Only Milk or Milk Replacer

			Energy				Protein		
Live Weight (kg)	Gain (g)	Dry Matter Intake[a] (kg)	NE_M[b] (Mcal)	NE_G[c] (Mcal)	ME[d] (Mcal)	DE[e] (Mcal)	ADP[f] (g)	CP[g] (g)	Vitamin A[h] (IU)
25	0	0.24	0.96	0	1.12	1.17	18	20	2,750
	200	0.32	0.96	0.26	1.50	1.56	65	70	2,750
	400	0.42	0.96	0.60	2.00	2.08	113	121	2,750
30	0	0.27	1.10	0	1.28	1.34	21	23	3,300
	200	0.36	1.10	0.28	1.69	1.76	68	73	3,300
	400	0.47	1.10	0.65	2.22	2.31	115	124	3,300
40	0	0.34	1.37	0	1.59	1.66	26	28	4,400
	200	0.43	1.37	0.31	2.04	2.13	73	79	4,400
	400	0.55	1.37	0.72	2.63	2.74	120	129	4,400
	600	0.69	1.37	1.16	3.28	3.41	168	180	4,400
45	0	0.37	1.49	0	1.74	1.81	28	30	4,950
	200	0.46	1.49	0.32	2.21	2.30	76	81	4,950
	400	0.59	1.49	0.75	2.82	2.94	123	132	4,950
	600	0.74	1.49	1.21	3.50	3.64	170	183	4,950
50	0	0.40	1.62	0	1.88	1.96	31	33	5,500
	200	0.45	1.62	0.34	2.37	2.47	78	84	5,500
	400	0.63	1.62	0.77	3.00	3.13	125	135	5,500
	600	0.78	1.62	1.26	3.70	3.86	173	185	5,500

[a]Dry matter intake necessary to meet ME requirements for calves fed milk replacer composed primarily of milk proteins and containing ME at 4.75 Mcal/kg of dry matter.
[b]NE_M (Mcal) = 0.086 $LW^{0.75}$, where LW is live weight in kilograms.
[c]NE_G (Mcal) = (0.84 $LW^{0.355}$ × $LWG^{1.2}$) × 0.69, where LW and LWG (live weight gain) are in kilograms.
[d]ME (Mcal) = 0.1 $LW^{0.75}$ + (0.84 $LW^{0.355}$ × $LWG^{1.2}$), where LW and LWG are in kilograms.
[e]DE (Mcal) = ME/0.96.
[f]ADP (apparent digestible protein, g/d) = 6.25 [1/BV(E + G + M × D) − M × D]. BV (biologic value) is assumed to be 0.8. E (endogenous urinary nitrogen) is 0.2 $LW^{0.75}$/d, where LW is in kilograms. M (metabolic fecal nitrogen) is 1.9 g/kg of dry matter intake (D). G (nitrogen in live weight gain) is 30 g/kg of LWG.
[g]CP (crude protein) = ADP/0.93. The digestibility of undenatured milk proteins is assumed to be 93 percent.
[h]Vitamin A (IU) = 110 IU/kg of LW. See Chapter 7.

starter feed (Table 10-2); calves reared for veal on only milk or milk replacers (Table 10-3); and weaned replacement calves to 100 kg of body weight fed starter or grower diets (Table 10-4). The amount of liquid feed (milk or milk replacer) offered to replacement calves is restricted to encourage intake of dry feed (starter), but calves reared for veal are fed milk or milk replacer at near ad libitum intakes.

Young Replacement Calves Fed Milk or Milk Replacer Only

The energy requirements of young calves fed only milk or milk replacer and weighing 25-50 kg are given in Table 10-1. On the basis of available data, NE_M is set at 0.086 Mcal/$kg^{0.75}$ of live weight (LW) daily as in the previous edition of this publication (National Research Council, 1989). This equates reasonably well with estimates of fasting metabolism of young milk-fed calves that are limited in activity (see chapter 4 of Davis and Drackley, 1998). The efficiency of use of metabolizable energy (ME) from milk or milk replacer to meet maintenance requirements is set at 86 percent. Consequently, maintenance ME is defined as 0.100 Mcal/$kg^{0.75}$ daily. The values for ME and efficiency of ME use for maintenance are within the range of values in the scientific literature (Van Es et al., 1969; Johnson and Elliott, 1972a,b; Holmes and Davey, 1976; Okamoto et al., 1986; Arieli et al., 1995; Gerrits et al., 1996). The Agricultural Research Council (ARC) specified an ME requirement of 0.102 Mcal/$kg^{0.75}$ daily, with an efficiency of use of ME for maintenance of 85 percent (Agricultural Research Council, 1980).

Requirements for ME were calculated with the equation derived by Toullec (1989) as follows:

$$\text{ME requirement (Mcal/d)} = 0.1\ LW^{0.75} + (0.84\ LW^{0.355})(LWG^{1.2}), \quad (10\text{-}1)$$

where LW and daily liveweight gain (LWG) are in kilograms. The first portion of the equation sets the ME required for maintenance at 100 kcal/$kg^{0.75}$ per day. The second portion of the equation is used to derive the ME required for LWG, which is a function of both body size (LW) and rate of gain (LWG). This equation was derived on the basis of an efficiency of conversion of ME to NE_G of 69 percent for calves fed only milk or milk replacer, which is consistent with most published values (Gonzalez-Jimenez and Blaxter, 1962; Van Es et al., 1969; Johnson and Elliott, 1972a,b; Vermorel et al., 1974; Webster et al., 1975; Donnelly and Hutton, 1976a,b; Holmes and Davey, 1976; Neergard, 1976; Toullec, 1989; Gerrits et al., 1996). The energy content of LWG predicted by equation 10-1 is 1556 kcal/kg LWG for a 40-kg calf gaining 200 g/d, and 2567 kcal/kg LWG for a 75-kg calf gaining 800 g/d. Values

TABLE 10-2 Daily Energy and Protein Requirements of Calves Fed Milk and Starter or Milk Replacer and Starter

			Energy				Protein		
Live Weight (kg)	Gain (g)	Dry Matter Intake[a] (kg)	NE_M[b] (Mcal)	NE_G[c] (Mcal)	ME[d] (Mcal)	DE[e] (Mcal)	ADP[f] (g)	CP[g] (g)	Vitamin A[h] (IU)
30	0	0.32	1.10	0	1.34	1.43	23	26	3,300
	200	0.42	1.10	0.28	1.77	1.89	72	84	3,300
	400	0.56	1.10	0.65	2.33	2.49	122	141	3,300
35	0	0.36	1.24	0	1.50	1.61	25	29	3,850
	200	0.47	1.24	0.30	1.96	2.09	75	87	3,850
	400	0.61	1.24	0.68	2.55	2.73	125	145	3,850
40	0	0.40	1.37	0	1.66	1.78	25	33	4,400
	200	0.51	1.37	0.31	2.14	2.29	78	90	4,400
	400	0.66	1.37	0.72	2.76	2.95	128	148	4,400
	600	0.83	1.37	1.16	3.44	3.68	178	205	4,400
45	0	0.44	1.49	0	1.81	1.94	31	36	4,950
	200	0.56	1.49	0.32	2.31	2.47	80	93	4,950
	400	0.71	1.49	0.75	2.96	3.16	130	151	4,950
	600	0.88	1.49	1.21	3.67	3.93	180	209	4,950
50	0	0.47	1.62	0	1.96	2.10	33	38	5,500
	200	0.60	1.62	0.34	2.48	2.65	83	96	5,500
	400	0.76	1.62	0.77	3.15	3.37	133	154	5,500
	600	0.94	1.62	1.26	3.89	4.17	183	212	5,500
	800	1.13	1.62	1.78	4.69	5.02	233	270	5,500
55	0	0.51	1.74	0	2.11	2.25	36	41	6,050
	200	0.63	1.74	0.35	2.64	2.83	85	99	6,050
	400	0.80	1.74	0.80	3.33	3.57	135	157	6,050
	600	0.99	1.74	1.30	4.10	4.39	185	215	6,050
	800	1.18	1.74	1.84	4.93	5.27	236	273	6,050
60	0	0.54	1.85	0	2.25	2.41	38	44	6,600
	200	0.67	1.85	0.36	2.80	3.00	88	102	6,600
	400	0.84	1.85	0.83	3.51	3.76	138	159	6,600
	600	1.04	1.85	1.34	4.31	4.61	188	217	6,600
	800	1.24	1.85	1.90	5.16	5.52	238	275	6,600

[a] These data apply to calves fed milk replacer (MR) plus starter. MR contains ME at 4.75 Mcal/kg of DM and starter ME at 3.28 Mcal/kg. It is assumed that MR provided 60 percent and starter 40 percent of dry matter intake; thus, dry matter consumed contained ME at 4.16 Mcal/kg. The DMI here is the total necessary to meet ME requirements and is not intended to predict voluntary intake.

[b] NE_M (Mcal) = $0.086\ LW^{0.75}$, where LW is live weight in kilograms.

[c] NE_G (Mcal) = $(0.84\ LW^{0.355} \times LWG^{1.2}) \times 0.69$, where LW and LW gain (LWG) are in kilograms.

[d] ME (Mcal) was computed as follows:

ME (maintenance) = $NE_M/0.825$. Efficiency of use of ME for maintenance (0.825) was computed as average of efficiencies of 0.86 for MR and 0.75 for starter, weighted according to proportions of ME supplied by each feed.

ME (gain) = $NE_G/0.652$. Efficiency of use of ME for gain (0.652) was computed as weighted average of efficiencies of 0.69 and 0.57 for MR and starter, respectively.

[e] DE (Mcal) = ME/0.934. Efficiency of conversion of DE to ME is assumed to be 0.96 for MR and 0.88 for starter.

[f] ADP (apparent digestible protein, g/d) = 6.25 [1/BV(E + G + M × D)- M × D]. BV (biologic value) = 0.764 (weighted average of MR = 0.8 and starter = 0.70); E (endogenous urinary nitrogen, g) = $0.2LW^{0.75}$; G (nitrogen content of gain, g) = 30 g/kg gain; M (metabolic fecal nitrogen, g/d) = 2.46 × dry matter intake, D, kg). Metabolic fecal nitrogen for MR assumed to be 1.9 g/kg of DMI and for starter 3.3 g/kg of DMI.

[g] CP (crude protein, g) = ADP/0.8645. Digestibility of protein was assumed to be weighted average of 93 percent for MR and 75 percent for starter; MR was assumed to contain 21 percent CP and starter 18 percent CP.

[h] Vitamin A (IU) = 110 IU/kg of LW. See Chapter 7.

predicted by this equation are similar to those in the 1989 edition of this publication for smaller calves at low rates of gain (1460 kcal/kg LWG for a 40-kg calf gaining 200 g/d) but are substantially higher than the 1989 edition for larger calves at higher rates of gain (1869 kcal/kg LWG for a 75-kg calf gaining 800 g/d). Values predicted by the present equation agree well with available experimental data on body composition of dairy calves (Webster et al., 1975; Donnelly and Hutton, 1976b; Holmes and Davey, 1976; Neergard, 1976; Gerrits et al., 1996). Data for composition of LWG for dairy calves of current genotypes would be useful for future refinement of requirements for growth.

The ME requirements given in Table 10-1 for calves weighing 30-60 kg and gaining at different rates are in close agreement with most published data. The digestible energy (DE) values in Table 10-1 are calculated from ME, assuming an efficiency of 96 percent for conversion of DE to ME (Neergard, 1976; National Research Council, 1989; Toullec, 1989; Gerrits et al., 1996). Users that desire requirements for higher rates of gain than included in Table 10-1 for calves fed milk or milk replacer only should refer to Table 10-3.

Users should be aware that ME requirements for maintenance may be underestimated for calves during the first week of life because of the high and variable basal meta-

TABLE 10-3 Daily Energy and Protein Requirements of Veal Calves Fed Only Milk or Milk Replacer

			Energy				Protein		
Live Weight (kg)	Gain (g)	Dry Matter Intake[a] (kg)	NE_M[b] (Mcal)	NE_G[c] (Mcal)	ME[d] (Mcal)	DE[e] (Mcal)	ADP[f] (g)	CP[g] (g)	Vitamin A[h] (IU)
40	0	0.34	1.37	0	1.59	1.66	26	28	4,400
	300	0.49	1.37	0.51	2.32	2.42	97	104	4,400
	600	0.69	1.37	1.16	3.28	3.41	168	180	4,400
50	0	0.40	1.62	0	1.88	1.96	31	33	5,500
	300	0.56	1.62	0.55	2.67	2.79	102	109	5,500
	600	0.78	1.62	1.26	3.71	3.86	172	185	5,500
	900	1.02	1.62	2.05	4.85	5.05	244	262	5,500
60	0	0.45	1.85	0	2.16	2.25	35	38	6,600
	300	0.63	1.85	0.58	3.00	3.13	106	114	6,600
	600	0.86	1.85	1.34	4.10	4.27	177	190	6,600
	900	1.12	1.85	2.18	5.32	5.54	248	267	6,600
70	0	0.51	2.08	0	2.42	2.52	39	42	7,700
	300	0.70	2.08	0.62	3.32	3.45	110	119	7,700
	600	1.94	2.08	1.42	4.48	4.66	181	195	7,700
	900	1.21	2.08	2.31	5.76	6.01	253	272	7,700
	1,200	1.50	2.08	3.26	7.14	7.44	324	348	7,700
80	0	0.56	2.30	0	2.68	2.79	44	47	8,800
	300	0.76	2.30	0.65	3.61	3.76	115	123	8,800
	600	1.02	2.30	1.49	4.83	5.03	186	200	8,800
	900	1.30	2.30	2.42	6.18	6.44	257	276	8,800
	1,200	1.61	2.30	3.42	7.63	7.95	328	353	8,800
90	0	0.62	2.51	0	2.92	3.04	48	51	9,900
	300	0.82	2.51	0.68	3.90	4.06	119	128	9,900
	600	1.09	2.51	1.55	5.17	5.39	190	204	9,900
	900	1.38	2.51	2.55	6.62	6.85	263	283	9,900
	1,200	1.70	2.51	3.56	8.09	8.42	332	357	9,900
100	0	0.67	2.72	0	3.16	3.29	52	55	11,000
	300	0.88	2.72	0.70	4.18	4.35	122	132	11,000
	600	1.16	2.72	1.61	5.50	5.72	194	208	11,000
	900	1.46	2.72	2.62	6.96	7.25	265	285	11,000
	1,200	1.80	2.72	3.70	8.52	8.88	336	362	11,000
	1,500	2.14	2.72	4.84	10.17	10.59	408	438	11,000
110	0	0.72	2.92	0	3.40	3.54	55	60	12,100
	300	0.94	2.92	0.72	4.45	4.63	126	136	12,100
	600	1.22	2.92	1.66	5.81	6.05	198	212	12,100
	900	1.54	2.92	2.71	7.32	7.63	269	289	12,100
	1,200	1.88	2.92	3.83	8.94	9.32	340	366	12,100
	1,500	2.24	2.92	5.00	10.65	11.09	412	443	12,100
120	0	0.76	3.12	0	3.63	3.78	59	64	13,200
	300	0.99	3.12	0.75	4.71	4.91	130	140	13,200
	600	1.29	3.12	1.72	6.12	6.39	201	217	13,200
	900	1.62	3.12	2.80	7.68	8.00	273	293	13,200
	1,200	1.97	3.12	3.69	9.34	9.74	329	353	13,200
	1,500	2.34	3.12	5.16	11.10	11.56	416	447	13,200
130	0	0.81	3.31	0	3.85	4.01	63	67	14,300
	300	1.05	3.31	0.77	4.97	5.17	134	144	14,300
	600	1.35	3.31	1.77	6.41	6.68	205	220	14,300
	900	1.69	3.31	2.88	8.02	8.35	276	297	14,300
	1,200	2.05	3.31	4.06	9.74	10.14	348	374	14,300
	1,500	2.43	3.31	5.31	11.54	12.02	420	451	14,300
140	0	0.86	3.50	0	4.07	4.24	66	71	15,400
	300	1.10	3.50	0.79	5.22	5.43	137	148	15,400
	600	1.41	3.50	1.82	6.70	6.98	209	224	15,400
	900	1.76	3.50	2.95	8.35	8.70	280	301	15,400
	1,200	2.13	3.50	4.17	10.11	10.53	352	378	15,400
	1,500	2.52	3.50	5.45	11.97	12.45	423	455	15,400
150	0	0.90	3.69	0	4.29	4.46	70	75	16,500
	300	1.15	3.69	0.81	5.46	5.69	141	152	16,500
	600	1.47	3.69	1.86	6.98	7.27	212	228	16,500
	900	1.82	3.69	3.02	8.67	9.03	284	305	16,500
	1,200	2.21	3.69	4.27	10.48	10.91	355	382	16,500
	1,500	2.61	3.69	5.58	12.38	12.90	427	459	16,500

[a] The DMI necessary to meet ME requirements when veal calves are fed a milk replacer containing ME at 4.75 Mcal/kg of DM.
[b] NE_M (Mcal) = 0.086 $LW^{0.75}$, where LW is live weight in kilograms.
[c] NE_G (Mcal) = (0.84 $LW^{0.355}$ × $LWG^{1.2}$) × 0.69, where LW and LW gain (LWG) are in kilograms.
[d] ME (Mcal) = 0.1 $LW^{0.75}$ + (0.84 $LW^{0.355}$ × $LWG^{1.2}$), where LW and LWG are in kilograms.
[e] DE (Mcal) = ME/0.93.
[f] ADP (apparent digestible protein, g/d) = 6.25 [1/BV(E + G + M × D) − M × D]. BV (biologic value) is assumed to be 0.8. E (endogenous urinary nitrogen) is 0.2 $LW^{0.75}$/d, where LW is in kilograms. M (metabolic fecal nitrogen) is 1.9 g/kg of dry matter intake (D). G (nitrogen in live weight gain) is 30 g/kg LWG.
[g] CP (crude protein) = ADP/0.93. The digestibility of undenatured milk proteins is assumed to be 93 percent.
[h] Vitamin A (IU) = 110 IU/kg of LW. See Chapter 7.

TABLE 10-4 Daily Energy and Protein Requirements of Weaned (Ruminant) Calves[a]

			Energy				Protein		
Live Weight (kg)	Gain (g)	Dry Matter Intake (kg)	NE_M[b] (Mcal)	NE_G[c] (Mcal)	ME[d] (Mcal)	DE[e] (Mcal)	ADP[f] (g)	CP[g] (g)	Vitamin A[h] (IU)
50	0	0.70	1.62	0	2.16	2.58	40	53	5,500
	400	1.13	1.62	0.77	3.51	3.92	151	201	5,500
	500	1.27	1.62	1.01	3.93	4.35	179	238	5,500
	600	1.86	1.62	1.26	4.36	4.77	207	276	5,500
60	0	0.80	1.85	0	2.47	2.89	46	61	6,600
	400	1.26	1.85	0.83	3.92	4.33	156	209	6,600
	500	1.41	1.85	1.08	4.36	4.77	185	246	6,600
	600	1.56	1.85	1.34	4.83	5.23	213	284	6,600
	700	1.71	1.85	1.62	5.31	5.70	241	322	6,600
	800	1.87	1.85	1.90	5.80	6.19	269	359	6,600
70	0	0.90	2.08	0	2.77	3.19	51	68	7,700
	400	1.39	2.08	0.87	4.31	4.71	163	217	7,700
	500	1.54	2.08	1.14	4.77	5.17	191	254	7,700
	600	1.70	2.08	1.42	5.26	5.66	219	292	7,700
	700	1.86	2.08	1.71	5.77	6.16	247	330	7,700
	800	2.03	2.08	2.00	6.29	6.67	275	367	7,700
80	0	0.99	2.30	0	3.07	3.48	57	75	8,800
	400	1.51	2.30	0.92	4.67	5.07	168	224	8,800
	500	1.66	2.30	1.20	5.16	5.56	196	262	8,800
	600	1.83	2.30	1.49	5.68	6.07	225	300	8,800
	700	2.00	2.30	1.79	6.21	6.59	253	337	8,800
	800	2.18	2.30	2.10	6.75	7.13	281	375	8,800
90	0	1.16	2.51	0	3.35	3.76	62	82	9,900
	600	2.09	2.51	1.55	6.07	6.46	231	309	9,900
	700	2.28	2.51	1.87	6.62	7.00	260	346	9,900
	800	2.48	2.51	2.19	7.19	7.57	288	385	9,900
	900	2.68	2.51	2.52	7.78	8.15	317	423	9,900
100	0	1.25	2.72	0	3.63	4.04	68	90	11,000
	600	2.22	2.72	1.61	6.45	6.83	237	316	11,000
	700	2.42	2.72	1.94	7.02	7.40	265	354	11,000
	800	2.63	2.72	2.27	7.62	7.99	294	392	11,000
	900	2.84	2.72	2.62	8.22	8.59	323	430	11,000

[a]These data apply to small-breed female calves from 50 to 80 kg gaining 0.4 to 0.5 kg/d and large-breed calves from 60 to 100 kg gaining from 0.6 to 0.9 kg/d.
[b]NE_M (Mcal) = 0.086 $LW^{0.75}$ (NRC 1989), where LW is live weight in kilograms.
[c]NE_G (Mcal) = (0.84 $LW^{0.355}$ × $LWG^{1.2}$) × 0.69, where LW and LW gain (LWG) are in kilograms.
[d]ME, maintenance (Mcal) = NE_M/0.75. ME values of diets (Mcal/kg of DM) are 3.10 for calves weighing 60, 70, and 80 kg and 2.90 for calves weighing 90 and 100 kg. ME, gain (Mcal) = NE_G/0.57.
Sum of ME values for maintenance plus gain equals total ME requirement.
[e]DE (Mcal) = (ME + 0.45) /1.01 (see Chapter 2).
[f]ADP (apparent digestible protein, g/d) as follows: ADP (g/d) = 6.25 [1/BV(E + G + M × D) − M × D] where BV is biologic value set at 0.70; E (endogenous urinary nitrogen) = 0.2$LW^{0.75}$; G is nitrogen content of gain, assuming 30 g/kg of gain ; and M is metabolic fecal nitrogen computed as 3.3 g/kg of dry matter consumed (D).
[g]CP (crude protein) calculated as ADP/0.75.
[h]Vitamin A (IU) = 110 IU/kg of LW. See Chapter 7.

bolic rate observed during this time (Roy et al., 1957; Vermorel et al., 1983; Okamoto et al., 1986; Schrama et al., 1992; Ortigues et al., 1994; Arieli et al., 1995). Furthermore, because the digestive tract is immature and developing rapidly, the metabolizability of diets may be lower during this time (Schrama et al., 1992; Arieli et al, 1995), thereby overestimating dietary energy supply. The net result of these effects is that LWG of calves during the first week of life may be considerably less than the predicted energy-allowable gains shown in Table 10-1. As more data become available it may become possible in future editions to model these effects.

Energy requirement values for young calves in this edition represent several improvements over the previous edition (National Research Council, 1989). First, tabulated values in this edition are derived directly from the equations presented, in contrast with values given in the tables of the 1989 edition that could not be calculated from the information provided. Second, as discussed above, values for the energy content of body weight gain (NE_G) in this edition agree more closely with available data on calves derived from slaughter experiments; values in the 1989 edition were too low (see Davis and Drackley, 1998). Third, the equations used to derive the NE_M and NE_G values for milk or milk replacers in the previous edition were those of Garrett (see National Research Council, 1989) established for feedlot cattle fed diets with ME content of 2.19-2.86 Mcal/kg of dry matter (DM). Those equations result in erroneously low NE values for diets of milk or milk-derived products. Garrett (1980) cautioned against using the established equations to derive NE values for feedstuffs with ME values outside the range stated above. A different approach has been taken in this edition to derive the NE values for liquid diets and starter.

Young Replacement Calves Fed Milk and Starter Feed or Milk Replacer and Starter Feed

Under good management on dairy farms, calves should be consuming appreciable nutrients from starter feed by the second week of life. To encourage early consumption of calf starter, calves should be given free access to water and a nutritious, highly palatable starter feed from the first week of life until they are weaned. Consumption of starter feed is critical to development of an active, functioning rumen. Fermentation products, principally butyrate, from fermentation of solid feeds in the developing rumen are responsible for development of functional ruminal epithelial tissue (Sander et al., 1959).

Deriving the energy requirements of calves fed a combination diet (liquid plus dry feed) requires the application of basic knowledge from related areas because there are few data on the subject. Only one study, which used three calves per treatment, has examined this question directly by using calorimetry (Holmes and Davey, 1976). The maintenance requirement and efficiency of use of ME by calves did not differ appreciably between an all-milk diet and a diet consisting of milk and dry feed.

Regardless of the diet fed, the NE required for maintenance and gain should not change. Efficiencies of utilization of ME for maintenance and gain will be somewhat lower for starter feeds than for milk or milk replacer (National Research Council, 1978). As described for Table 10-1, calves use the ME from milk or milk replacer with efficiencies of 86 percent and 69 percent for maintenance and gain, respectively. Efficiency of ME use from milk or milk replacer is assumed not to change when starter also is consumed. The previous edition of this publication (National Research Council, 1989) used the equations of Garrett (1980) to derive the efficiencies of utilization of ME (percent) from starter for maintenance (k_m) and gain (k_g):

$$k_m = 51.045\ ME - 10.836\ ME^2 + 0.754\ ME^3 - 7.35 \quad (10\text{-}2)$$

$$k_g = 76.149\ ME - 15.755\ ME^2 + 1.062\ ME^3 - 69.7 \quad (10\text{-}3)$$

where ME is expressed as Mcal/kg DM.

However, these data were for older growing cattle fed feedlot diets and are not appropriate for young calves. For example, the Garrett (1980) equations yield efficiencies of ME use for maintenance and gain of 69.4 and 46.4 percent, respectively, for a starter containing 3.1 Mcal ME/kg DM. These efficiencies are lower than those calculated from experimental data (Holmes and Davey, 1976) and used in other systems (Agricultural Research Council, 1980). Furthermore, the Garrett (1980) equations were developed using ME values calculated as 0.82 DE (National Research Council, 1989). Because methane production is minimal even in young calves consuming 44 percent of their ME from concentrates (Holmes and Davey, 1976), these derived ME values are too low when compared with experimental data (Spanski et al., 1997). Consequently, the use of the Garrett (1980) equations for young calves has been discontinued in this edition.

The Agricultural Research Council (1980) calculated efficiencies of ME use for maintenance and gain as a function of the metabolizability (ME/GE, or "q") of the diet. Over the range of ME concentrations expected for calf starters and growers (2.5–3.4 Mcal/kg), the efficiency of ME use for maintenance would vary from only about 72 to 77 percent, and that for gain from 50 to 59 percent. In this edition, efficiencies of ME use from dry feeds for maintenance and gain were fixed at 75 and 57 percent, respectively. The efficiency of use of ME from the total diet is then calculated as the average of individual efficiencies for milk and starter, weighted according to their contribution to the total ME in the diet.

In the example given in Table 10-2, it was assumed that a calf at about 2 wk of age would consume on the average a diet in which 60 percent of DM intake (DMI) is derived from milk replacer (ME at 4.75 Mcal/kg of DM) and 40 percent from starter (ME at 3.28 Mcal/kg of DM). In this diet, milk-replacer supplies 68 percent of the total ME, and starter supplies 32 percent. Consequently, the overall efficiencies for use of ME in the combined diet (milk replacer plus starter) are 82.5 and 65.2 percent for maintenance and gain, respectively, calculated as the weighted average (weighted by contribution to the total ME supply) of the individual efficiencies. The computer model included with this edition calculates these values for varied proportions of DMI from milk and starter or milk replacer and starter.

A comparison of the ME requirement of a 50-kg calf gaining 400 g/d when fed only milk or milk replacer (see Table 10-1) with the ME requirement of the same calf fed milk and starter or milk replacer and starter (Table 10-2) reveals a relatively small difference (3.00 vs 3.15 Mcal/d). The ME requirements given here for calves consuming both starter and milk or milk replacer are markedly lower than those given in the 1989 edition (5.90 Mcal/d) but are similar to those given by Roy (1980). A comparison of LWG predicted by this model with actual performance of calves receiving both milk or milk replacer and starter in 16 published research studies reveals good agreement (Stewart and Schingoethe, 1984; Jenny et al., 1991; Jaster et al., 1992; Reddy et al., 1993; Akayezu et al., 1994; Quigley et al., 1994a; Abdelgadir and Morrill, 1995; Quigley et al., 1995; Abdelgadir et al., 1996a, b; Quigley, 1996b; Quigley and Bernard, 1996; Quigley and Welborn, 1996; Terui et al., 1996; Quigley et al., 1997b; Lammers et al., 1998).

Table 10-2 also presents requirements for energy in units of DE. Values for DE were calculated as ME/0.934, representing the weighted average of conversion of DE to ME for milk or milk replacer (0.96) and starter (0.88). The conversion from ME to DE for starter was calculated as (ME + 0.45)/1.01 (National Research Council, 1989), as described in Chapter 2 (also see later discussion on energy values for feeds).

The DMI listed in Tables 10-1 through 10-4 have been computed as the amount of DM necessary to provide the ME requirement. Consequently, these should not be construed to be predictions of voluntary feed intake. An analysis of literature data presented elsewhere (see chapter 16 of Davis and Drackley, 1998) predicts that intake of DM from starter increases from about 0.8–1.0 percent of BW at 3 wk of age to about 2.8–3.0 percent of BW at 8 wk of age.

Veal Calves

The calculations used to derive the ME requirements for veal calves (Table 10-3) are the same as those for milk-fed replacement calves (Table 10-1). Veal calves are fed essentially for ad libitum intake, so rates of gain will be higher than those of limit-fed replacement calves. The ME and DM requirements given here agree closely with those reported by Webster et al. (1975) on the basis of an energy-balance study with veal calves.

Ruminant Calves (Large-Breed and Small-Breed Females) from Weaning to Body Weight of 100 Kilograms

In the previous edition of *Nutrient Requirements of Dairy Cattle*, (National Research Council, 1989) no information was given on the nutrient requirements of calves from weaning to 100 kg of body weight even though this is a critical period in the life of the replacement calf. Similar to calves consuming milk and starter, very few research data determined by calorimetry or comparative slaughter studies exist for this class of cattle. However, the subcommittee believes that estimates should be made. Methods used in this edition to establish requirements for growth of heifers from 100 to 500 kg of body weight could not be extrapolated accurately to calves weighing less than 100 kg. Given the paucity of data on tissue growth and nutrient use for this class of calves, estimated requirements have been derived using the same methodology as described already for younger calves. Users will note that requirements for ruminant calves weighing less than 100 kg do not merge smoothly into requirements for larger calves.

Energy-allowable LWG was predicted using this model from LW and estimated ME intakes from 25 treatments in 19 published studies (Stewart and Schingoethe, 1984; Beharka et al., 1991; Chester-Jones et al., 1991; Jenny et al., 1991; Quigley et al., 1991; Quigley et al., 1992; Reddy et al., 1993; Akayezu et al., 1994; Jackson and Hemken, 1994; Kuehn et al., 1994; Maiga et al., 1994; Quigley et al., 1994a; Abdelgadir and Morrill, 1995; Abdelgadir et al., 1996a,b; Quigley, 1996b; Terui et al., 1996; Kincaid et al., 1997). Comparisons were expressed as predicted/observed; the mean was 1.04. Twelve predicted values were greater than observed, twelve were less than observed, and one was equal. As more research information becomes available, future editions of this publication may be better able to define requirements for this group of calves. However, in comparing requirements established here with literature data on average daily gains, the methodology presented in this edition adequately predicts gains of large-breed calves up to 100 kg and small-breed calves to 80 kg.

Table 10-4 shows the requirements of weaned calves weighing 50–100 kg and gaining at various rates. Calves weighing 50–80 kg were assumed to be fed a starter containing ME at 3.1 Mcal of ME per kg of DM, and those weighing 90–100 kg a starter or grower containing ME at 3.0 Mcal per kg of DM. Given the paucity of data, no distinction is made between large and small breed calves. Similarly, no distinction is made between male and female calves since differences are negligible before about 100 kg LW (National Research Council, 1978).

Effects of Environmental Temperature on Energy Requirements of Young Calves

The calf is born with limited body energy reserves and only modest insulation afforded by hair coat and body fat. A newborn calf is estimated to have enough body energy stores in the form of fat and glycogen to last no more than about 1 d under very cold conditions (Alexander et al., 1975; Okamoto et al., 1986; Rowan, 1992).

Energy standards are based on the premise that the animal is in a thermoneutral environment during measurements of energy transformations. In such an environment, the animal is not required to elicit specific heat-conserving or heat-dissipating mechanisms to maintain core body temperature (National Research Council, 1981). The thermoneutral zone shifts depending on many factors, the more important factors being age, amount of feed intake, amount of subcutaneous fat, and length and thickness of hair coat. The thermoneutral zone in very young calves ranges from 15–25°C. Thus, when the environmental temperature drops below 15°C, which is referred to as the lower critical temperature, the calf must expend energy to maintain its body temperature. In practical terms, the maintenance energy requirement is increased. For older calves and calves at greater feed intakes, the lower critical temperature may be as low as −5 to −10°C (Webster et al., 1978).

Data in Table 10-5 illustrate the effects of a decrease in environmental temperature below the lower critical temperature of the calf on energy requirements for maintenance. The values were calculated from research data of Schrama (1993). Note in the example given in Table 10-5 that if the lower critical temperature is 10°C and the effective ambient temperature is 0°C, the maintenance energy requirement is increased by 27 percent. This calculation agrees with experimental findings (Scibilia et al., 1987). Effects of cold stress in increasing maintenance requirements have been incorporated into the computational model provided with this publication.

It is clear from these and other data that calves, especially very young calves, should be fed extra energy during cold weather to satisfy the increase in maintenance energy requirements. That can be accomplished by increasing the amount of liquid diet being fed, by adding additional milk solids to the liquid diet, or by incorporating additional fat into the liquid diet (Schingoethe et al., 1986; Scibilia et al., 1987; Jaster et al., 1990). However, additional fat in milk replacer or starter decreases starter intake (Kuehn et al., 1994), which negates at least a portion of the increased energy density from fat supplementation. If additional solids are fed, the DM concentration of milk replacer should not exceed 20 percent to avoid problems with excessive mineral intake (Jenny et al., 1978; Ternouth et al., 1985), and supplemental water should be provided. The availability of free water is critically important to starter intake (Kertz et al., 1984); provision of warm water 2-3 times daily during cold weather may help to stimulate starter feed intake, which also would help to counteract cold stress.

PROTEIN REQUIREMENTS OF CALVES

In contrast with the 1978 edition of *Nutrient Requirements of Dairy Cattle* (National Research Council, 1978), the 1989 edition provided little information on the protein requirements of young calves weighing less than 100 kg. The tabular data given for protein requirements in the 1989 edition could not be reproduced with information provided (see chapter 9 of Davis and Drackley, 1998). The present edition computes the protein requirement of calves weighing up to 100 kg with the factorial method of Blaxter and Mitchell (1948).

The requirement is partitioned into components of maintenance and gain. Maintenance constitutes obligatory nitrogen (N) losses in urine and feces, whereas gain pertains to N stored in tissues. The protein requirement is expressed in terms of apparent digestible protein (ADP, g/d) and is computed as follows:

$$\text{ADP, g/d} = 6.25\,[1/\text{BV}\,(\text{E} + \text{G} + \text{M} \times \text{D}) - \text{M} \times \text{D}] \qquad (10\text{-}4)$$

where BV = biological value (discussed below). Endogenous urinary N (E, g/d) is computed as $0.2\text{LW}^{0.75}$ (Agricultural Research Council, 1980), where live weight (LW) is in kilograms. This value is somewhat higher than that ($0.165\ \text{LW}^{0.75}$) computed with the formula (2.75 g of net protein per kilogram $\text{LW}^{0.5}$) given in the 1989 National Research Council publication; however, both are within the range of values in the scientific literature (Blaxter and Wood, 1951; Cunningham and Brisson, 1957; Roy, 1970). The amount of N in gain (G) is assumed to be constant at 30 g N/kg LWG, which is in the range of values reported by others (Blaxter and Wood, 1951; Roy, 1970; Donnelly and Hutton, 1976b; National Research Council, 1978; Davis

TABLE 10-5 Effect of Environment on Energy Requirement of Young Calves[a]

Environmental Temperature		Increase in Maintenance Energy Requirement (kcal of NE_M/day)		Maintenance Energy Requirement (kcal of ME/day)[b]		Increase in ME Required for Maintenance	
°F	°C	Birth to 3 wk of age[c]	>3 wk of age[d]	Birth to 3 wk of age[c]	>3 wk of age[d]	Birth to 3 wk of age[c]	>3 wk of age[d]
68	20	0	0	1,735	1,735	0	0
59	15	187	0	1,969	1,735	13	0
50	10	373	0	2,203	1,735	27	0
41	5	560	187	2,437	1,969	40	13
32	0	746	373	2,671	2,205	54	27
23	−5	933	568	2,905	2,437	68	40
14	−10	1,119	746	3,139	2,671	86	54
5	−15	1,306	933	3,373	2,905	94	68
−4	−20	1,492	1,119	3,607	3,139	108	81
−13	−25	1,679	1,306	3,834	3,373	121	94
−22	−30	1,865	1,492	4,066	3,607	134	107

[a]Calculated for calf weighing 45.35 kg (100 lbs; 17.35 $\text{kg}^{0.75}$). Extra heat production = 2.15 kcal/$\text{kg}^{0.75}$ per day for each degree decrease in environmental temperature (°C) below lower critical temperature (Schrama, 1993). Because heat production is in terms of net energy (NE), metabolizable energy (ME) was computed as ME = NE/0.8.

[b]Maintenance energy requirement 100 kcal/$\text{kg}^{0.75}$ per day.

[c]Calves from birth to 3 wk of age have lower critical temperature in range of 15–25 °C. Data above were calculated on basis of lower critical temperature 20° C.

[d]Data for calves older than 3 wk of age were calculated on basis of lower critical temperature 10° C.

and Drackley, 1998). Insufficient data were available to describe changes in N content of LW gain as a function of increasing growth rate. Metabolic fecal N (M) is set as 1.9 g/kg of dry matter consumed (D) from milk or milk replacer and 3.3 g/kg of starter DM consumed (Roy, 1980); these values are additive for calves fed both milk and starter.

Loss of N in scurf (hair and skin) is ignored in the present edition. The 1989 edition calculated the loss as 0.032 g of N/kg of $LW^{0.6}$, which equates to a daily loss of 0.33 g of N for a 50-kg calf. In practice, this loss is compensated by the higher endogenous N losses predicted in the present edition (3.76 g of N for a 50-kg calf) than in the 1989 edition (3.10 g of N).

The biological value (BV) of milk proteins, equated to the efficiency of N use for growth above maintenance, is assigned a value of 0.80 (Donnelly and Hutton, 1976a). The same factor is assumed to apply for efficiency of use of dietary protein for maintenance functions. This value was determined at limiting protein intakes and assumes that the diet being fed is properly balanced for all essential nutrients and that energy intake is sufficient to support protein synthesis. Protein intake must not be in excess of that required for the targeted gain allowed by energy intake. The BV decreased as protein intake was increased in the studies of Donnelly and Hutton (1976a). The 1978 National Research Council publication used a value of 0.77. Recent studies by Terosky et al. (1997) found that apparent BV for milk replacers containing 21 percent CP from skim milk protein, whey protein concentrate, or mixtures of the two ranged from 0.692 to 0.765. Estimates of true biological value (corrected for endogenous N loss and metabolic fecal N) from that study are in excess of 0.80.

The conversion of CP to ADP was assumed to be 93 percent for milk proteins (Agricultural Research Council, 1980), which is slightly higher than the value for conversion of dietary CP to absorbable amino acids (91 percent) used in an earlier edition of this publication (National Research Council, 1978). Users should note that requirements for ADP and crude protein (CP) have been established on the basis of diets containing milk proteins with high digestibility and BV; calves might not use alternative, nonmilk proteins in milk replacers at these high efficiencies, and appropriate adjustments may need to be made when such protein sources are used to ensure adequate supply of amino acids for growth (Davis and Drackley, 1998). Furthermore, because digestion of even high-quality milk proteins is immature during the first 2–3 weeks of age (Arieli et al., 1995; Terosky et al., 1997), the value of milk proteins may be overestimated during the early liquid-feeding period. Similar to the situation for energy requirements, however, the subcommittee concluded that information was insufficient to model increasing CP digestibility in the young calf.

The BV of absorbed proteins supplied by starter is set at 0.70 (National Research Council, 1978). Calves fed milk plus starter and weaned calves (fed starter only) derive a portion of their protein needs from microbial protein produced in the rumen. However, insufficient data were available to allow calculations of the amounts of rumen-degradable protein (RDP) or rumen-undegradable protein (RUP) supplied with any degree of confidence; thus, the factorial approach using ADP was adopted for calves weighing up to 100 kg. Requirements also are presented in terms of CP. The conversion of CP to ADP is assumed to be 75 percent for starter and grower feeds (Agricultural Research Council, 1980). Quigley et al. (1985) found that an average of 58 percent of the protein reaching the abomasum of weaned calves was of microbial origin; flows of N to the abomasum were not reported. Assuming that N flow to the abomasum approximated N intake, that microbial CP is 80 percent true protein that is 80 percent digestible (National Research Council, 1989), and that undegraded feed proteins are 80 percent digestible (National Research Council, 1989) leads to a conversion of CP to ADP of about 71 percent; adoption of the slightly higher value of 75 percent from Agricultural Research Council (1980) leads to better agreement with literature data. The BV and conversions of ADP to CP for calves fed starter and milk or starter and milk replacer are assumed to be additive on the basis of the relative amounts of CP supplied by starter and milk (or milk replacer).

Examples of requirements for ADP and CP for calves fed milk or milk replacer only, milk replacer plus starter, veal calves, and weaned (ruminant) calves are found in Tables 10-1, 10-2, 10-3, and 10-4, respectively.

MINERAL AND VITAMIN REQUIREMENTS OF CALVES

Detailed information on the specific roles of mineral elements and vitamins in the nutrition and metabolism of dairy cattle is presented in Chapters 6 and 7. Since the last edition (National Research Council, 1989), there have been few definitive studies of and few problems associated with the field application of the previous recommendations that warrant making major changes in recommendations for most mineral elements or vitamins in diets of young calves. Changes that have been made in the recommendations are discussed below.

Minerals

The recommended dietary concentrations of mineral elements and vitamins are shown in Table 10-6. For calcium and phosphorus recommended concentrations in milk-replacer diets were increased compared with those

TABLE 10-6 Mineral and Vitamin Concentrations Recommended for Diets of Young Calves, Compared with Average for Fresh Whole Milk (DM basis)

Nutrient[a]	Milk Replacer[b]	Starter Feed	Grower Feed	Whole Milk
Minerals				
Ca (%)	1.00	0.70	0.60	0.95
P (%)	0.70	0.45	0.40	0.76
Mg (%)	0.07	0.10	0.10	0.10
Na (%)	0.40	0.15	0.14	0.38
K (%)	0.65	0.65	0.65	1.12
Cl (%)	0.25	0.20	0.20	0.92
S (%)	0.29	0.20	0.20	0.32
Fe (mg/kg)	100[c]	50	50	3.0
Mn (mg/kg)	40	40	40	0.2–0.4
Zn (mg/kg)	40	40	40	15–38
Cu (mg/kg)	10	10	10	0.1–1.1
I (mg/kg)	0.50	0.25	0.25	0.1–0.2
Co (mg/kg)	0.11	0.10	0.10	0.004–0.008
Se (mg/kg)	0.30	0.30	0.30	0.02–0.15
Vitamins				
A (IU/kg of DM)	9,000	4,000	4,000	11,500
D (IU/kg of DM)	600	600	600	307
E (IU/kg of DM)	50	25	25	8

[a] B-complex vitamins are necessary only in milk-replacer diets. Required concentrations (mg/kg of DM): thiamin, 6.5; riboflavin, 6.5; pyridoxine, 6.5; pantothenic acid, 13.0; niacin, 10.0; biotin, 0.1; folic acid, 0.5; B_{12}, 0.07; choline, 1,000.

[b] Required concentrations specified for milk replacer fed at 0.53 kg of DM per day to 45-kg calf. Assuming ME content of 4.75 Mcal/kg, this amount of milk replacer would provide energy-allowable growth of 0.3 kg/d. Concentrations of minerals and vitamins specified will provide adequate daily amounts of minerals and vitamins as defined in Chapters 6 and 7 and in text of this chapter. User is cautioned that feeding larger or smaller amounts of milk replacer, or same amount of milk replacer to larger or smaller calf, changes expected growth and, consequently, requirements for many vitamins and minerals.

[c] For veal calves, decrease to less than 50 mg/kg of DM.

of National Research Council (1989), from 0.7 to 1.0 percent for calcium and from 0.6 to 0.7 percent for phosphorus. Recommended concentrations are closer to those found in whole milk (see Table 10-6). Previous calcium recommendations were made considering a fat content in milk replacer of 10 percent, whereas a majority of commercial milk replacers today contain fat at 18–22 percent. Higher dietary fat results in increased loss of calcium in the feces because of soap formation between calcium and long-chain fatty acids in the gut (Toullec et al., 1980).

The recommended content of sodium in milk replacer was increased from 0.10 to 0.40 percent and from 0.20 to 0.25 percent for chloride (Table 10-6). The committee is unaware of any problems in young calves posed by the previous recommendations for sodium and chloride, but whole milk and most milk replacers that contain milk products usually are substantially higher in sodium and chloride than even the new recommendations, thus making practical deficiencies unlikely. As stated earlier, the solids content of milk replacers should be maintained less than 20 percent and free drinking water should be available to avoid problems with excessive intakes of sodium and chloride.

The potassium requirement was left unchanged at 0.65 percent of DM for milk-replacer, starter, and grower diets. Weil et al. (1988) compared dietary potassium concentrations of 0.55, 0.84, 1.02, and 1.32 percent of DM for calves from 4 to 14 wk of age. They detected no differences in feed intake, average daily gain, or mineral status among treatments. In a second trial, Weil et al. (1988) compared dietary potassium concentrations of 0.34 and 0.58 percent for calves from 6 to 14 wk of age. Feed intake and live weight gain were greater for calves fed 0.58 percent potassium. The authors concluded that potassium requirement of growing dairy calves was "within the range of 0.34 to 0.58 percent," but no concentrations between 0.58 and 0.84 percent were tested. Consequently, the subcommittee concluded that there was insufficient evidence to decrease the requirement from the current value of 0.65 percent of DM.

Requirements for most of the trace minerals are unchanged from the previous edition of *Nutrient Requirements of Dairy Cattle* (National Research Council, 1989). The required concentrations of iodine were increased from 0.25 mg/kg to 0.50 mg/kg on the basis of information described in Chapter 6, although, as in the situation with sodium and chloride, no indication of deficiency has been noted under practical conditions. The content of cobalt was increased slightly, from 0.10 to 0.11 mg/kg, to be consistent with requirements for other classes of cattle (Chapter 6). Recommended contents of most macromineral elements in milk replacer and starters are close to those of whole milk, whereas recommendations for many of the trace mineral elements are higher than those found in milk, to prevent deficiencies. Caution should be exercised in making drastic changes in dietary concentrations of a specific mineral element without being aware of the possible effects of such changes on the status of other mineral elements (McDowell, 1992).

Vitamins

VITAMIN A

The subcommittee has markedly increased requirements for vitamin A in all classes of dairy cattle for reasons discussed in Chapter 7. The requirement for vitamin A in calves was increased from 42.4 (National Research Council, 1989) to 110 IU/kg of LW in the present edition. Eaton et al. (1972) suggested, on the basis of changes in cerebrospinal fluid pressure, that the requirement for vitamin A should be 96.7 IU/kg of LW for growing Holstein calves. In the *Nutrient Requirements of Dairy Cattle* (National Research Council, 1989), these data were discussed, but the requirement was not increased; the subcommittee stated that "if substantial evidence for a higher vitamin A requirement is forthcoming, the requirement should be raised." Data from Swanson et al. (2000) demonstrated that an intake of about 134 IU/kg of LW (9,000 IU/kg of DM) maintained liver vitamin A stores in male Holstein calves fed milk replacer, whereas 93 IU/kg or less resulted in decreases in liver concentrations of vitamin A. Calves in that study had received adequate colostrum after birth, were healthy, and were housed under nonstressful environmental conditions throughout the study. No clinical measures were affected in that study, even at vitamin A intake (34 IU/kg of LW) less than the previous requirement. However, the liver concentration of vitamin A is believed to be a much more sensitive indicator of vitamin A status than measures used previously to establish requirements. The new requirement was set to be the same as for other classes of cattle and is between the estimates made by Eaton et al. (1972) and Swanson et al. (2000). Required concentrations have been increased to 9,000 IU/kg of DM for milk replacer and 4,000 IU/kg of DM for starter and grower diets in the present edition. The concentration recommended here for starter or grower feeds will provide required amounts of vitamin A for weaned calves weighing less than 100 kg and gaining 400–900 g/d (Table 10-4).

The presumed safe limit for vitamin A is 66,000 IU/kg of dietary DM for lactating and nonlactating cattle (National Research Council, 1987), but safe limits specifically for young calves have not been established. Supplementation levels of several times the requirement established in the present edition are common in commercial milk replacers (Tomkins and Jaster, 1991). Data to firmly support such a practice are not available. Eicher et al. (1994) found improved fecal consistency in calves fed milk replacer that contained vitamin A at 87,000 IU/kg, with no effect on vitamin E status. In contrast, several studies have reported adverse effects of high vitamin A on vitamin E status and on other measures of calf health and growth (see Nonnecke et al., 1999). Calves fed a milk replacer containing vitamin A at 44,000 IU/kg of DM rapidly accumulated vitamin A in liver but showed no signs of toxicity during 28 days of feeding (Swanson et al., 2000). Supplementation with vitamin A in amounts greater than recommended in the present edition cannot be justified on the basis of available data. In particular, caution should be observed in formulation of milk replacers for veal calves and for replacement calves in accelerated-growth schemes to avoid potential problems with excessive vitamin A intake.

VITAMIN E

The requirement for vitamin E for calves continues to be debated. Requirements for vitamin E were increased substantially for lactating and dry cows in the present edition (Chapter 7). The subcommittee has increased the requirement for vitamin E for calves by 25 percent, from 40 IU/kg of dietary DM to 50 IU/kg. The decision to increase the vitamin E requirement represents a compromise until more-definitive data are available. The increase is based on two main factors. First, although 40 IU/kg of DM is adequate to prevent classic signs of deficiency, such as muscular dystrophy or retardation of growth of calves in controlled systems, calves under conditions of stress more typical in practice might require higher intakes of vitamin E to augment the immune system. Vitamin E supplementation improved immune-system responses, as measured by lymphocyte stimulation indexes, IgM concentrations, serum cortisol concentrations, and antibody response to a booster vaccine (Reddy et al., 1986, 1987b). Indicators of cell-membrane damage (serum creatine kinase, glutamic oxalacetic transaminase, and lactic acid dehydrogenase) suggested that Vitamin E supplementation protected membranes from oxidative damage (Reddy et al., 1986, 1987b). Vitamin E functions as an antioxidant and interacts with selenium to maintain the structural integrity of tissues (Combs, 1992; McDowell, 1992).

Reddy et al. (1987a) suggested—on the basis of a study in which calves were supplemented with 125, 250, or 500 IU of vitamin E per day—that the requirement was about 2.4 IU/kg of body weight. However, no supplementation levels lower than 125 IU/d were tested, and numbers of animals were insufficient to determine clinical responses. The subcommittee felt that, in the absence of large-scale dose-response studies to determine clinical responses, such a large increase was not justified. Furthermore, increased requirements for dry cows should increase concentrations of vitamin E in colostrum (Quigley and Drewry, 1998), which could provide more vitamin E to calves than was consumed by calves in the Kansas State University studies.

Second, the relationship of vitamin E with other dietary nutrients must be considered. For the young calf, dietary vitamin E should be balanced with the content of essential fatty acids (1.5–2.5 IU of vitamin E per gram of linoleic acid; Stobo, 1983) to prevent oxidative stress from increased intake of polyunsaturated fatty acids, as in young nonruminant animals. With typical daily intakes of 10–15 g of linoleic acid from milk replacers, 15–38 IU of vitamin E daily would be necessary, according to guidelines of Stobo (1983). To supply adequate vitamin E to meet this guideline for a calf fed 600 g of milk-replacer DM daily, vitamin E content would need to be 25–63 IU/kg of DM.

Some evidence suggests that increased vitamin A in the diet decreases the bioavailability of vitamin E (see Nonnecke et al., 1999). Consequently, the moderate increase in the vitamin E requirement also is justified because of the substantially increased vitamin A requirement. Diarrhea and gut infections decrease fat digestion and hence lower the absorption of the fat-soluble vitamins A, D, and E. Given the widespread occurrence of digestive disturbances in young calves before weaning, the increases in recommendations for both vitamin A and vitamin E should be beneficial in practical situations. The subcommittee recognizes that the requirement for vitamin E might need to be adjusted in future editions if data from large-scale dose-response studies become available.

VITAMIN D AND WATER-SOLUBLE VITAMINS

Requirements for vitamin D were not changed from the 1989 edition (Table 10-6). Water-soluble vitamins must be included in the milk-replacer diet of calves (see Table 10-6). Once the calf is weaned to dry feed, there is no evidence that these vitamins need to be supplemented to the diet, inasmuch as the microorganisms in the digestive tract synthesize ample amounts to meet the needs of the calf.

FEED-COMPOSITION DATA WITH APPLICATION TO DIET FORMULATIONS FOR CALVES

Values for digestible energy and metabolizable energy for feedstuffs for calves in the National Research Council (1989) are realistic compared with known gross energy and digestibility data and agree closely with values assigned by other sources. However, as pointed out earlier in this chapter, the NE_M and NE_G values for milk, milk byproducts, and milk replacers given in the 1989 edition were too low according to reported efficiencies of use of ME by young milk-fed calves (see chapter 9 in Davis and Drackley, 1998). The problem arose from the inappropriate use of the equations derived by Garrett (1980) from growth studies with feedlot cattle to derive the net energy of liquid diets for nonruminant calves. A different approach has been taken in the present edition to establish the net energy values for calf diets.

Gross energy (GE) values have been calculated from data on composition and heat of combustion. For milk and milk-derived ingredients used in milk replacers,

$$\text{GE (Mcal/kg)} = 0.057\ \text{CP\%} + 0.092\ \text{fat\%} + 0.0395\ \text{lactose\%}, \qquad (10\text{-}5)$$

where lactose was calculated as 100 − CP% − fat% − ash%; all components are expressed on a DM basis. For whole milk, milk replacers, and milk-derived ingredients, DE was calculated as 0.97 GE. For all milk and milk products, including milk replacers, ME was calculated as 0.96 DE. Values calculated by these methods agree closely with those in the previous edition of this publication (National Research Council, 1989).

The NE_M values for milk , milk-derived ingredients, and milk replacers is calculated as 0.86 ME, consistent with the NE_M requirements discussed earlier. This is similar to the value of 0.85 used by the Agricultural Research Council (1980). The approach used to derive values for NE_G for milk and milk-derived ingredients is based on the relationship between the metabolizability (q) of the diet (ME/GE) and the efficiency of use of ME for maintenance and gain (Agricultural Research Council, 1980). The NE_G values for milk-based diets can then be estimated as follows (Agricultural Research Council, 1980):

$$NE_G = (0.38q + 0.337)\ \text{ME} \qquad (10\text{-}6)$$

Values for q have been computed and are included in Table 10-7, which provides composition data for ingredients used in milk replacers. The values for NE_M and NE_G calculated by these methods agree well with efficiencies of use of ME of 80 and 69 percent for maintenance and gain, respectively, determined by others (Roy, 1980; Toullec, 1989).

A slightly different procedure was used to calculate NE_M and NE_G values for ingredients used in starter and grower diets. For all nonmilk ingredients,

$$\text{GE (Mcal/kg)} = 0.057\ \text{CP\%} + 0.094\ \text{ether extract (EE)\%} + 0.0415\ \text{carbohydrate\%} \qquad (10\text{-}7)$$

where carbohydrate was calculated as 100 − CP% − fat% − ash%. The DE values were calculated as the sum of the products of digestible CP, EE, and carbohydrates multiplied by their heats of combustion; this is the approach described in Chapter 2 to calculate energy values for feeds fed to other classes of dairy cattle in this edition. Values for ME were calculated with the approach in the previous edition (National Research Council, 1989), except that the equation was corrected to reflect increased efficiency of use of fat:

TABLE 10-7 Energy, Protein, Calcium, and Phosphorus Concentrations in Feedstuffs Commonly Used in Formulation of Milk Replacers for Young Calves[a]

Feed	International Feed Number	DM (%)	GE (Mcal/kg of DM)	DE (Mcal/kg of DM)	ME (Mcal/kg of DM)	ME/GE (q)	NE_M (Mcal/kg of DM)	NE_G (Mcal/kg of DM)	CP	EE	Ca	P	Ash
									% of DM				
Whole milk	5-01-168	12.5	5.76	5.59	5.37	0.93	4.62	3.70	25.4	30.8	1.00	0.75	6.3
Skim milk, fresh	5-01-170	10	4.31	4.19	4.02	0.93	3.46	2.77	35.5	0.3	1.35	1.02	6.9
Skim milk, powder	5-01-175	94	4.38	4.25	4.08	0.93	3.51	2.82	37.4	1.0	1.29	1.08	6.9
Whey-powder	4-01-182	93	3.92	3.80	3.65	0.93	3.14	2.52	13.5	1.0	0.76	0.68	8.1
Whey protein concentrate	—	93	4.48	4.35	4.17	0.93	3.59	2.88	37.1	2.2	0.54	0.60	6.0
Whey, fresh	4-08-134	7	3.89	3.78	3.62	0.93	3.12	2.50	14.2	0.7	0.73	0.65	8.7
Whey, delactosed	4-01-186	93	3.65	3.54	3.40	0.93	2.92	2.34	17.9	0.7	1.71	1.12	16.5
Whey permeate	—	98	3.66	3.55	3.41	0.93	2.93	2.35	3.7	0	1.77	0.97	9.0
Casein	5-01-162	91	5.45	5.29	5.08	0.93	4.37	3.50	92.7	0.7	0.40	0.35	4.0

[a] Data from NRC (1989); Toullec (1989); Tomkins and Jaster (1991). Calculations are described in text.

$$ME = (1.01 \times DE - 0.45) + 0.0046\,(EE - 3) \qquad (10\text{-}8)$$

where ME and DE are Mcal/kg and EE is percent of dietary DM. These ME values are analogous to ME values at maintenance for older cattle (Chapter 2) and are more consistent with known efficiencies of conversion of DE to ME, given that methane production in young calves is extremely low (Gonzlalez-Jimenez and Blaxter, 1962; Holmes and Davey, 1976). Values for NE_M and NE_G were calculated as described in the section on energy requirements earlier in this chapter. For NE_M and NE_G, ME as calculated above was multiplied by the respective efficiencies of 0.75 for maintenance and 0.57 for gain. These efficiencies are similar to those estimated by others from the metabolizability (q) of ingredients. For example, Agricultural Research Council (1980) calculated NE_M as (0.287q + 0.554)ME and NE_G as (0.78q + 0.006)ME. For a calf starter with q = 0.70, efficiencies for maintenance and gain would be 75 and 55 percent when calculated with the Agricultural Research Council equations.

Table 10-8 presents composition data on examples of three typical milk replacers, a starter diet, and a grower diet for calves. The values presented for NE_M and NE_G content are considerably higher for all feeds than those calculated with the previous methods (National Research Council, 1989). The computer model automatically calculates ME, NE_M, and NE_G concentrations for feeds used for young calves. Users are cautioned that the requirements and feed values are designed to be used together. Use of NE_M and NE_G values from previous editions with the present growth model, or vice versa, will result in erroneous predictions.

Values for total digestible nutrients (TDN) are not given for calf requirements or feeds in this edition. If desired, TDN can be calculated as described for feeds for other classes of cattle (see Chapter 2). For milk, milk replacer, and milk ingredients,

$$TDN = 0.93\,CP + (EE \times 2.25) + 0.98\,(100 - CP - EE - Ash) - 7 \qquad (10\text{-}9)$$

OTHER ASPECTS OF CALF NUTRITION

Fetal Nutrition

Although severe undernutrition can impair normal fetal development (National Research Council, 1968), the developing fetal calf is afforded a high priority for maternal nutrients. Moderate underfeeding of either protein or energy did not result in measurable changes in calf birth weight, viability, or health (Davis and Drackley, 1998; Quigley and Drewry, 1998). Prolonged restriction of protein or energy during gestation decreased thermogenic abilities of beef calves at birth (Carstens et al., 1987; Ridder et al., 1991).

Maternal deficiencies of phosphorus, manganese, cobalt, copper, zinc, and selenium can result in deficiencies in the fetus and newborn calf (National Research Council, 1968). The fetus has the ability to concentrate some of these minerals, particularly copper (Hidiroglou and Knipfel, 1981) and selenium (Van Saun et al., 1989a), providing some protection against marginal deficiencies in the mother. Selenium supplementation of pregnant cows increased selenium reserves in the newborn calves (Abdelrahman and Kincaid, 1995). Placental transfer of vitamin E to the developing fetus is low, although the fetal calf appears to have some ability to concentrate vitamin E from the dam (Van Saun et al., 1989b). The calf is born with a low vitamin E status and is highly dependent on intake of colostrum and then milk or milk replacer to obtain needed vitamin E during early postnatal life. If diets for pregnant cows are balanced to meet recommendations for pregnancy and maternal growth (see Chapters 6 and 7), as well as for optimal transition success (see Chapter 9), nutrient supply should be adequate for normal growth and development

TABLE 10-8 Energy, Protein, Fiber, and Mineral Composition of Three Milk Replacers (MR), a Starter Feed, and a Grower Feed for Young Calves

Feed	GE[a] (Mcal/kg DM)	DE[a] (Mcal/kg of DM)	ME[a] (Mcal/kg of DM)	NE_M (Mcal/kg of DM)	NE_G (Mcal/kg of DM)	CP (%)	EE (%)	ADF (%)	NDF (%)	Ca (%)	P (%)
MR-1	4.61	4.47	4.29	3.69[b]	2.96[c]	22	10	—	—	1.0	0.70
MR-2	5.10	4.95	4.75	4.09[b]	3.28[c]	20	20	—	—	1.0	0.70
MR-3	5.07	4.91	4.72	4.06[b]	3.26[c]	18	20	—	—	1.0	0.70
Starter	4.49	3.69	3.28	2.46[d]	1.78[e]	18	3	11.6	12.8	0.7	0.45
Grower	4.36	3.65	3.24	2.43[d]	1.61[e]	16	3	8.0	18.0	0.6	0.40

[a]Energy values calculated as follows:
Gross energy (GE) is calculated from composition and heat of combustion. For milk replacers, GE (kcal/kg) = 0.057 CP + 0.092 fat + 0.0395 lactose. For starter and grower, GE (kcal/kg) = 0.057 CP + 0.092 EE + 0.0415 carbohydrate.
For MR, digestible energy (DE) = 0.97 GE. For starter and grower, DE is calculated as sum of digestible protein, fat, and carbohydrates, each multiplied by heat of combustion.
For MR, metabolizable energy (ME) calculated as 0.93 GE (ME/GE of whole milk has been measured at 0.93; Roy, 1980). For starter and grower feeds, ME = (1.01 × DE − 0.45) + (0.0046EE − 3) (see text and Chapter 2).
[b]NE_M = 0.86 ME. See text for details.
[c]NE_G = (0.38q + 0.337) × ME. Based on q of 0.93 yielding an efficiency of 0.69 for ME use (ARC, 1980).
[d]NE_M = ME × 0.75.
[e]NE_G = ME × 0.57.

of the fetal calf (Davis and Drackley, 1998; Quigley and Drewry, 1998).

Colostrum

Calves are born with negligible circulating concentrations of immunoglobulins (McCoy et al., 1970). Early provision of high-quality colostrum in amounts sufficient to provide at least 100 g of IgG is critical to calf survival and well-being (Davis and Drackley, 1998; Quigley and Drewry, 1998). The immunoglobulin content of colostrum is highly variable (Pritchett et al., 1991); therefore, to maximize the likelihood of obtaining sufficient IgG, it is recommended that calves be fed at least 3 L of colostrum from multiparous cows within an hour after birth. Holstein calves can be administered as much as 3.8 L of colostrum in a single feeding after birth to ensure delivery of sufficient IgG (Besser et al., 1991; Hopkins and Quigley, 1997).

In addition to disease protection, early provision of colostrum is important as a source of nutrients (Davis and Drackley, 1998; Quigley and Drewry, 1998). Because supplies of endogenous fuels are exhausted within hours without feed (Okamato et al., 1986; Rowan, 1992), the carbohydrate, fat, and protein in colostrum are essential as fuels for the newborn. Most of the essential minerals and vitamins are substantially more concentrated in colostrum than in milk (Foley and Otterby, 1978). Consumption of adequate amounts of colostrum by the newborn calf, followed by consumption of milk or milk replacer that is adequate in mineral and vitamin content, is important to compensate for any maternal inadequacies during gestation. Increasing evidence in calves and other species indicates that colostrum also provides a number of hormones and growth factors necessary to stimulate growth and development of the digestive tract and other organ systems (Hammon and Blum, 1998).

Commercial products containing immunoglobulins may be useful to supplement poor-quality colostrum (Garry et al., 1996; Morin et al., 1997; Arthington et al., 2000). Other products are designed to be injected to increase serum immunoglobulins in calves (Quigley and Welborn, 1996). At present, none of the commercially available supplements or substitutes can completely replace colostrum in providing passive immunity to calves (Arthington et al., 2000). High-quality colostrum should be provided whenever possible; supplements are of little additional value when sufficient amounts of high-quality colostrum are administered (Hopkins and Quigley, 1997). Development of products that can deliver sufficient biologically active immunoglobulins to the newborn calf might be increasingly important for use in biosecurity programs to control contagious diseases, such as Johne's disease, in which it would be desirable to avoid the feeding of any colostrum or whole milk to calves. Although the nutritional aspects of colostrum probably could be replaced by a properly formulated milk replacer, the consequences of the absence of the growth factors and hormones normally consumed in colostrum are not known.

Water and Electrolytes

Water is the most important nutrient and, although essential, is often overlooked. Too often, it is assumed that if a calf is being fed a liquid diet, its needs for water will be satisfied. Fresh water, in addition to water consumed as part of the diet, is essential for optimal growth and consumption of dry feed (Leaver and Yarrow, 1972; Kertz et al., 1984).

Aside from constituting 70–75 percent of the weight of the calf, water plays important roles as a solvent for nutrients, a thermoregulator, and an osmoregulator (Davis and Drackley, 1998). Calves, because of their greater propensity to develop digestive disturbances (diarrhea), experience greater problems with water balance than do older animals.

During incidents of diarrhea, 10–12 percent of body weight can be lost as water. The water loss in feces carries with it major losses of the electrolytes sodium, chloride, and potassium (Lewis and Phillips, 1978; Phillips, 1985). Such losses of water and electrolytes result in severe dehydration and electrolyte imbalances, which if not rapidly corrected will result in death. In fact most deaths associated with diarrhea occur from these phenomena rather than directly from infectious agents (Booth and Naylor, 1987). Recent evidence indicates that electrolyte disturbances are more important than dehydration itself in causing death from diarrhea (Walker et al., 1998).

At the first signs of diarrhea, a calf should be started on oral rehydration (Davis and Drackley, 1998). Current information suggests that the calf should continue to receive a portion of, if not all, its regular feeding of milk or milk replacer with the oral electrolyte product (McGuirk, 1992; Garthwaite et al., 1994) as long as it is alert and willing to drink. Calves that are severely dehydrated, recumbent, or acidemic will require intravenous fluid therapy for recovery.

Milk Replacers

Milk replacers are used on a majority of dairy farms in the United States (Heinrichs et al., 1995). Substantial changes in milk-replacer formulation have occurred since the last edition of this publication (National Research Council, 1989). Increases in market prices for dried skim milk, coupled with development of low-temperature ultrafiltration techniques for preparation of high-quality whey protein concentrates, have led to the almost complete replacement of dried skim milk with whey-derived products (Davis and Drackley, 1998). Milk-replacer formulations generally are classified as all-milk protein or as alternative protein. Milk replacers of all-milk protein contain whey protein concentrate, dried whey, and delactosed whey as protein sources. Many alternative-protein formulations are available, in which portions of the milk proteins (typically 50 percent) are replaced with lower-cost ingredients, such as soy protein concentrate, soy protein isolates, animal plasma or whole-blood proteins, and modified wheat gluten (Davis and Drackley, 1998). Examples of formulations and a review of recent research can be found in chapter 14 of Davis and Drackley (1998). Aspects of milk replacer use also have been reviewed by Heinrichs (1994, 1995).

The ability of these protein sources to supply an adequate amount and profile of amino acids for growth of preruminant calves depends on the amino acid profile of the protein, the quality of the manufacturing process, and the ability of the calf to digest the protein. High temperatures during drying can damage proteins and lessen their biologic value (Wilson and Wheelock, 1972). Furthermore, antinutritional factors present in some protein sources can decrease efficiency of amino acid use (Huisman, 1989; Lallès, 1993). Whey protein concentrate is digested and utilized as least as well as skim milk protein by young calves (Terosky et al., 1997; Lammers et al., 1998).

The proteolytic digestive system of the young calf is immature at birth, and until the age of about 3 weeks the calf is less able to digest most nonmilk proteins (Toullec and Guilloteau, 1989). Therefore, for optimal growth during the first 3 weeks of life, it is recommended that milk replacers containing only milk proteins be used. Older calves are able to use formulations that contain nonmilk proteins.

Milk replacers typically contain tallow, choice white grease, or lard as a fat source. The degree of homogenization is critical for high digestibility (Raven, 1970). Emulsifiers, such as lecithin and monoglycerides, often are added to enhance mixing characteristics and fat digestibility. In general, vegetable oils and fat sources that contain large amounts of free fatty acids are poorly used by calves (Jenkins et al., 1985). Research data on optimal concentrations of fat in milk replacers are conflicting, with little definitive evidence that a fat content beyond 10–12 percent is needed, at least in moderate environments (Heinrichs, 1995).

Feed Additives

A variety of feed additives have been examined for inclusion in milk replacers or dry feeds (Heinrichs, 1993). The addition of medications to milk replacers in the US is regulated by the Food and Drug Administration. Antibiotics such as oxytetracycline and neomycin are widely used in milk replacers (Heinrichs et al., 1995). Antibiotics consistently improve growth rates and feed efficiency and decrease incidence and severity of scouring of calves (Morrill et al., 1977; Quigley et al., 1997a), although the mode of action still is poorly understood. Benefits of antibiotic inclusion may be more evident for calves raised intensively in large numbers, for shipped-in calves originating from different farms, and for calves raised under conditions of stress (Morrill et al., 1977; Morrill et al., 1995; Davis and Drackley, 1998).

Lasalocid and decoquinate added to feeds are effective in control of coccidiosis (Hoblet et al., 1989; Heinrichs et al., 1990; Heinrichs and Bush, 1991; Eicher-Pruiett et al., 1992; Quigley et al., 1997b). Supplementation in calf starter requires adequate feed intake to achieve effective dosages, but infection with coccidia often occurs before starter intake is sufficient (Quigley et al., 1997b). Bacterial probiotic products have shown some benefit in improving calf health and performance (Jenny et al., 1991; Higginbotham and Bath, 1993; Morrill et al., 1995; Abe et al., 1995; Cruywagen et al., 1996) although responses have been variable and inconsistent (Morrill et al., 1977). Experimental results from additions of fungal (Beharka et al., 1991) or yeast (Quigley et al., 1992) culture products to starter diets have been inconclusive.

Sodium bicarbonate increased starter intake and growth of young calves in one study (Curnick et al., 1983) but did not affect intake or calf performance in another study (Quigley et al., 1992).

Practical Feeding Considerations

As mentioned in the introduction to this chapter, female calves in the United States destined for herd replacements should be fed restricted amounts of milk or milk replacer (typically 8–10 percent of birth weight) to encourage early consumption of calf starter (National Research Council, 1989). Development of early starter intake is inversely proportional to the amount of liquid fed (Hodgson, 1971). Growth rates of young calves during the liquid feeding period thus are much lower than the maximal growth rates of calves (Khouri and Pickering, 1968; Hodgson, 1971), and feed efficiency is lower than that in the young of other farm animals that consume milk ad libitum (Khouri and Pickering, 1968; Davis and Drackley, 1998). Nevertheless, restricted liquid feeding encourages earlier starter intake and ruminal development, which in turn allows for earlier weaning and more economic body weight gains. Ad libitum or increased liquid feeding programs researched to date have resulted in greater growth rates and improved feed efficiency during the liquid feeding period, but lower consumption of dry feed and variable effects on calf health (Khouri and Pickering, 1968; Hodgson, 1971; Huber et al., 1984; Nocek and Braund, 1986; Richard et al., 1988). Methods to capitalize on the early growth potential are being researched in the context of accelerated rearing programs for heifers that encompass all stages of growth from birth to first calving. However, these programs are still under development and evaluation, and cannot yet be recommended at this time.

During the early liquid feeding period, growth of calves fed milk or milk replacer is directly proportional to the amount of liquid provided (Khouri and Pickering, 1968; Hodgson, 1971; Huber et al., 1984). In contrast, in restricted liquid feeding programs, growth rates are directly proportional to the amount of calf starter consumed (Kertz et al., 1979, 1984). Users should be aware that typical milk replacers contain 10–20 percent less energy than comparable volumes of whole milk because of the lower fat content of milk replacers. A 40-kg calf fed milk replacer at 9 percent of body weight would consume 454 g of DM. If the milk replacer contains ME at 4.7 Mcal/kg of DM, the calf would consume enough energy for maintenance and a body weight gain of 234 g/d under thermoneutral conditions. According to the model presented in this edition, feeding the same volume of whole milk would support a gain of 331 g/d. In contrast, if the same calf is housed at 20°C below its lower critical temperature, 454 g/d of milk replacer powder is insufficient even for maintenance. Increasing evidence suggests that these low feeding rates also are inadequate to support optimal health and function of the immune system, especially under adverse environmental conditions (Williams et al., 1981; Griebel et al., 1987; Pollock et al., 1993, 1994).

High intakes of milk or milk replacer are important for veal production. The effects of increasing intake of whole milk and milk replacer for a 40-kg calf are illustrated in Figure 10-1. Note that the difference in growth performance predicted between whole milk and milk replacer fed at equal amounts is accounted for entirely by the 13 percent greater ME content of whole-milk solids versus the milk replacer solids. Gains predicted here agree closely with literature studies with high rates of milk feeding (Khouri and Pickering, 1968; Hodgson, 1971).

Large-breed calves can be weaned easily when consuming at least 0.68 kg of a good-quality starter daily for 3

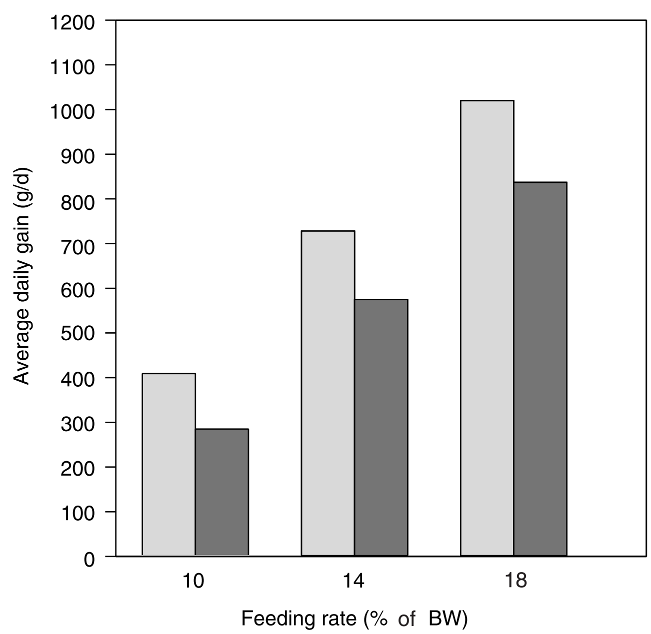

FIGURE 10-1 Example of growth rate predicted by the model in this edition for a 40-kg calf fed whole milk (open bars) or milk replacer (dark bars) at 10, 14, or 18 percent of body weight. Whole milk contains ME at 5.37 Mcal/kg of DM. Milk replacer contains ME at 4.75 Mcal/kg of DM and is assumed to be reconstituted to 12.5 percent solids, similar to total solids content of whole milk.

consecutive days. Under good management, with restricted milk or milk replacer feeding this can occur as early as the age of 4 weeks (Kertz et al., 1979, 1984). More aggressive milk-feeding programs will delay development of starter intake and weaning age (Hodgson, 1971; Huber et al., 1984). Other factors important for early development of dry-feed intake include free access to supplemental water; provision of palatable starter feeds (generally of coarse texture rather than finely ground); keeping feeds fresh, dry, and free of mold; and good health of calves. A major metabolic factor could be the establishment of stable ruminal fermentation with pH greater than 5.5 (Williams and Frost, 1992).

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