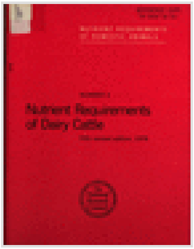

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NATIONAL ACADEMY OF SCIENCES

Washington, D.C. 1978

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

In light of the increasing demands upon the agricultural production system of the United States, enhancement of animal production and efficient use of limited resources are essential. Continued changes in breeding and management, and the introduction of new feedstuffs and methods of feed processing bring with them new factors or introduce extreme situations that influence nutrient metabolism and requirements; hence, there is a continuing need for reevaluation. The data contained in this report reflect the increased knowledge and improved methodology in the establishment of nutrient requirements for dairy cattle during various phases of the life cycle.

This report is one of a series issued under the direction of the Committee on Animal Nutrition, Board on Agriculture and Renewable Resources, Commission on Natural Resources, National Research Council. It was prepared by the Subcommittee on Dairy Cattle Nutrition and replaces the fourth revised edition of *Nutrient Requirements of Dairy Cattle*, issued in 1971. The bulletin has been extensively revised and updated. The authors wish to call the readers' attention especially to the following:

- Protein requirements have been recalculated, using a factorial method. "Digestible protein" has been discontinued.
- The mineral section in the text has been expanded.
- The section on formulating rations has been revised and expanded to increase its usefulness.
- Table 1 lists the requirements of growing cattle at several rates of growth for a given body size.
- Tables 1, 2, and 3 are presented in both metric (in the text) and avoirdupois (in the Appendix Tables 1A, 2A, and 3A) systems of measurement.
- Table 3 has been revised and some values changed.
- Table 4 has been revised and names of some feedstuffs shortened.

The subcommittee expresses appreciation for the many who have contributed to the preparation and review of the manuscript.

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CONTENTS

INTRODUCTION

In this revision, the section on nutrient requirements and deficiencies has been revised and updated extensively, and references have been added. The discussion on minerals has been expanded to include additional elements considered to be essential (and some that now appear to be essential). Discussions of metabolism of mineral elements, toxic elements, maximum dietary levels, and effects of excessive levels of certain elements have been expanded. The section on formulating rations has been revised and expanded to enhance understanding and improve usefulness.

The daily nutrient requirements for growth and maintenance of dairy cattle are presented in Table 1; daily nutrient requirements for milk production are presented in Table 2. These levels of nutrients are adequate to prevent deficiencies, and they provide for acceptable growth, reproduction, and milk production with feeds of at least average composition and digestibility (Agricultural Research Council, 1965; Matthews and Fohrman, 1954a,b; Morrison, 1959; Ragsdale, 1934a,b). Variation among animals in ability to digest feed is relatively small, but larger differences exist in feed capacity, appetite, growth rates, and level of milk production. Liberal feeding of growing animals usually will increase growth rate, whereas feeding less will decrease the growth rate. Very rapid growth may permit earlier sexual maturity and earlier calving, but a moderate rate sometimes is more economical.

In this edition, Table 1 lists requirements of growing cattle at several growth rates for a given body size. This should make the table more versatile. Protein requirements have been recalculated, employing a factorial system; some adjustments from the previous edition have been made. Digestible protein has been omitted because the total protein is more meaningful for coordinating feed composition and nutrient requirements. As in the previous edition, requirements for veal calf diets are based on high-quality milk replacers.

Tables 1, 2, and 3 are presented in both the metric system (in the text) and in the avoirdupois system (in the Appendix Tables 1A, 2A, and 3A).

Table 3 has been revised. Major changes include (1) an increase in the suggested manganese requirement from 20 to 40 ppm, (2) a decrease in the suggested iron requirements from 100 to 50 ppm in all cattle except calves, (3) an increase in the magnesium requirement for all except calves, and (4) inclusion of suggested maximum safe levels for sodium chloride, sulfur, iron, manganese, and iodine. Some minor changes have been made in calcium and phosphorus requirements for calves. The mineral requirements were changed to percent from grams per kilogram for major minerals and to parts per million from milligrams per kilogram for trace elements to conform to the way most often used. Acid detergent fiber has been added.

In Table 4 several changes have been made by considering additional information from published data and other suggestions. Names of many feedstuffs have been shortened and arranged in a more logical sequence. The cell wall and acid detergent fiber contents of many feeds have been included. In using the data in Table 4, it should be recognized that average values serve only as guides to adequate nutrition and feed composition.

Energy requirements and energy values of feeds are expressed in terms of calories throughout this publication, although many European groups have adopted the joule as the standard energy unit. To convert kilocalories to kilojoules or megacalories to megajoules, multiply by 4.184.

NUTRIENT REQUIREMENTS AND SYMPTOMS OF DEFICIENCY

ENERGY

In young animals, an insufficient supply of energy results in retarded growth and delay in the onset of puberty; in lactating dairy cattle, it results in decline in milk yield and loss of body weight. Severe and prolonged energy deficiency depresses reproductive function.

The energy requirements presented in this report are the amounts usually needed for acceptable growth and production. This does not necessarily mean the maximum levels possible under conditions of *ad libitum* feed intake. Feeding below the recommended levels will result in less than optimum growth rates or lower milk production.

Requirements in Tables 1 and 2 are expressed as digestible energy (DE), metabolizable energy (ME), net energy for maintenance (NE_m), net energy for body gain (NE_g), net energy for lactation (NE_l), and total digestible nutrients (TDN). The use of TDN is retained because many of the available data both for the energy requirements of animals and for value of feeds are reported as TDN. In this report DE has been calculated from TDN on the basis that 1 kg of TDN has 4.409 Mcal of DE. Recent research has provided data for metabolizable energy requirements, so these values are also included. The ME requirements of lactating cows are based on experimental results, while the ME requirements of growing animals were computed from the requirements of NE_m and NE_g. Much less information is available concerning the ME values of feeds, however, and they have been computed assuming ME as a percentage of the DE varies linearly from 80 percent at 50 percent digestibility to 88 percent at 80 percent digestibility by the equation: ME (Mcal/kg DM) = −0.45 + 1.01 DE (Mcal/kg DM) (Moe and Tyrrell, 1976).

Both TDN and DE have been criticized as measures of the useful energy value of feeds because they tend to underestimate the value of concentrates relative to forages (Moore *et al.*, 1953). To avoid this limitation, several net energy (NE) systems have been developed in this country. The NE value of a feed, however, depends on whether it is used for maintenance, fattening, growth, or milk production (Armstrong *et al.*, 1964; Blaxter, 1962; Lofgreen and Garrett, 1968; Moe *et al.*, 1972). Calorimetric studies (Armstrong *et al.*, 1964; Flatt *et al.*, 1965; Moe *et al.*, 1972) have shown that digestible or metabolizable energy is used with different efficiencies for maintenance and body gain in nonlactating animals, but is used with similar efficiencies for maintenance and milk production in lactating animals. For this reason, three net energy values have been used. The net energy value for maintenance (NE_m) is the net energy value of feeds for the maintenance of nonlactating animals. The net energy value for gain (NE_g) is the net energy value of feeds for the deposition of body tissue in nonlactating animals (the term nonlactating as used here refers to growing males and females and mature bulls). Both NE_m and NE_g are needed to express the total energy needs of growing heifers and bulls. The amount of NE_m required for maintenance was computed as 77 kcal/kg$^{0.75}$ body weight; the amount of NE_g required is based on the desired rate of gain. The NE_m and NE_g requirements of growing animals are based generally on the data of Lofgreen and Garrett (1968), which were obtained with growing and fattening beef cattle. Because growing dairy cattle are not fed to as high a degree of fatness as beef cattle, the NE_g requirement per kg of gain was limited to a maximum of 4,500 kcal/kg for growing heifers and bulls.

Since energy is used with similar degrees of efficiency for maintenance and milk production in lactating animals, a single net energy value of feeds (NE_l) is adequate to calculate rations for both maintenance and milk production (Moe *et al.*, 1972). The energy value of feeds is described in terms of its value for milk production (NE_{milk} = NE_l). The requirements for all physiological functions are described in terms of this same unit. Thus, in Table 2, one feed value (NE_l) is used for expressing the requirements for maintenance, pregnancy, milk production, and body weight change. Because the methods of derivation of NE_m and NE_l were substantially different, there are some differences in individual values in Table 4. An example of how to calculate diets by these values is outlined in the section "Formulating Rations."

Milk or milk replacer should be fed to replacement calves in limited amounts for at least the first month of life. Longer periods of milk feeding (up to 2 or 3 months) are beneficial under many commercial dairy farm conditions, but economics usually favors the shorter milk-feeding schedule. Forages and concentrates should be fed at an early age at levels to permit normal continuous growth. Excessive fattening of dairy heifers, however, may impair their milk-producing ability, so this should be avoided. The growth rates recommended for heifers grown as dairy replacements (Table 1) are less than the maximal growth rates possible with *ad libitum* feeding, yet these rates allow early calving and acceptable mature weights at minimal costs (Hansson, 1956; Lofgreen *et al.*, 1951; Reid *et al.*, 1964; Ritzman and Colovos, 1943; Sorensen *et al.*, 1959; Swanson and Hinton, 1964). Because of the large difference in body size among breeds, growth requirements in Table 1 are designated for large and small breeds; the other desired rates of gain may be selected from those listed at each body weight. Feed allowances for each class are designed for feeding close to appetite with maximum use of forage. After 250–300 kg body weight, acceptable growth can be accomplished by feeding only good-quality hay, silage, or pasture.

Requirements for normal growth of veal calves and dairy bulls are also given in Table 1. Veal calves must be fed nearly maximum amounts of milk (or replacer). During the first month or two following birth, there is relatively little difference in growth rates between heifers and bulls; but thereafter bulls consume more feed per day to support faster growth and greater activity. Young dairy bulls may be fed liberally to stimulate early sexual maturity and semen production (Bratton *et al.*, 1961; Flipse and Almquist, 1961; Van Demark and Mauger, 1964). Energy intakes of mature bulls should be controlled to avoid excessive fattening and lowered libido but should be adequate to allow maintenance of good physical condition (Branton *et al.*, 1947).

Energy required for maintenance of cows depends on their activity. Variation among cows of similar size and breed in maintenance requirements, even under controlled activity, is as much as 8–10 percent (Van Es, 1961). Lactating cows apparently have 10–15 percent greater maintenance requirements than do dry, nonpregnant cows. The maintenance values (Table 2) provide energy that is adequate for the usual activity of lactating cows fed in individual stalls or drylot systems but not for grazing. The maintenance requirement of lactating cows was found to be 73 kcal $NE_l/kg^{0.75}$ (Moe *et al.*, 1972). An activity allowance of 10 percent has been included, and the values in Table 2 were computed on the basis of 80 kcal $NE_l/kg^{0.75}$. Although these values should provide adequate energy for maintenance under most management systems, there may be instances where cows are required to move unusually long distances. In this situation the maintenance allowance should be increased by 3 percent for each additional kilometer walked. To support grazing, allowances for maintenance should be increased by 10 percent for good pasture and up to 20 percent for sparse pasture.

The influence of cold temperatures on the energy requirement of lactating cows is probably minimal because of the normally high heat production of cows at high feed intakes. With increased use of loose housing systems, however, it is likely that many cows experience some cold stress during the severe winter conditions that frequently occur in northern parts of the country. Young (1976) summarized experiments in which an average reduction in dry matter digestibility of 1.8 percentage units was observed with ruminants for each 10°C reduction in ambient temperature below 20°C. Much of this lowered digestibility under cold stress is probably related to increased rate of passage through the digestive tract (Kennedy *et al.*, 1976). Because of the possibility of increased heat losses and decreased digestibility, it seems advisable to increase the total feed allowance (maintenance plus production) by up to 8 percent under severe winter conditions in northern states.

The maintenance requirements in units other than NE also include the 10 percent activity allowance. The requirement figures (maintenance and production) for ME, DE, and TDN have been further increased in order to account for the fact that the actual value of the diet in the producing animal may be less than that listed in Table 4. This was done so that the requirements in Table 2 may be used directly with the feed values in Table 4 for computing diets. The maintenance requirements in Table 2 were computed as 133 kcal ME, 155 kcal DE, and 35.2 g TDN per $kg^{0.75}$ of body weight.

There is considerable variation among diets in the effect of level of intake on nutrient availability, but the effect is much greater with mixed diets than with diets of either all forage or all concentrate (Tyrrell and Moe, 1975). The decline in digestibility is greater with diets containing higher proportions of concentrate (Wagner and Loosli, 1967). Van Soest (1968, 1973) has suggested that both the type and amount of cell walls influence the rate of change in digestibility with increasing intake. Improved digestion of starch in corn-silage-based diets containing large amounts of corn grain may be obtained by supplemental limestone (Wheeler and Noller, 1976). Other factors known to affect digestibility at high levels of intake include processing methods such as grinding to various degrees of fineness, pelleting, dry rolling, or steam flaking.

Because of the difficulty of identifying and describing intake effects, and because most available digestibility data were obtained at a maintenance intake, the digestibility (TDN and DE) and ME values of feeds listed in the table of feed composition (Table 4) represent the values of feeds at maintenance intakes. Although these values may overestimate the value of a feed at higher intakes, they allow the comparison of feeds on a standard basis. The TDN, DE, and ME requirements in Table 2 are consistent with the energy values of feeds in Table 4 so that these values can be used directly to compute diets. By contrast, the NE_g or NE_l values of feeds are invariably measured in a growing or lactating animal at intakes above maintenance and are therefore correct at an intake well above maintenance. For this reason, the NE values listed in Table 4 are intended to represent the energy value of feeds at an intake of 3 × maintenance. Although intake effects on NE values are less easily measured than for DE, it is generally accepted that the effect is smaller. Considerably more research is needed to define the net energy value of different rations for high-producing dairy cows. The NE_l values shown in Table 4 were computed from maintenance TDN values according to the equation of Moe and Tyrrell (1976) [NE_l(Mcal/kg DM) = −0.12 + 0.0245 TDN(% of DM)], which incorporates an 8 percent reduction in TDN value at average production levels. This is based on an average reduction in digestibility of 4 percent for each multiple of maintenance increase in intake and an assumed intake of 3 × maintenance. As additional information about factors influencing intake effects is made available, it may be possible to characterize more specifically the magnitude of the intake effect for specific feeds, possibly by a procedure similar to that proposed by Van Soest (1973).

The utilization of energy by dairy cattle depends to a large extent on microbial fermentation that occurs in the rumen. The extent and type of fermentation determine the nature and amounts of the various metabolites that are absorbed from the digestive tract. These affect the efficiency of production and also influence the way energy is used (i.e., milk synthesis vs. body tissue formation). In general, rations that result in low ruminal acetate:propionate ratios (such as high-concentrate rations) lead to increased body fat formation at the expense of milk fat synthesis. Such decreased milk fat synthesis occasionally may be accompanied by modest increase in milk protein.

With respect to reproduction, the fetus and related tissue have been shown to follow an exponential growth curve (Bereskin and Touchberry, 1967; Jakobsen *et al.*, 1957). Becker *et al.* (1950) found that the average increase in body weight of Jersey cows, which was due to combined weights of the fetus, fluids, fetal membranes, and the increase in 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 that also showed that weight increases are 60–100 percent greater in the larger breeds of dairy cows than in Jerseys.

Few quantitative data are available on the energy requirements for gestation. Although feeding standards usually reflect the amounts of nutrients required to perform different physiological functions, large discrepancies exist. Balance experiments (Flatt *et al.*, 1969) indicated that the total energy requirements for a pregnant cow increased markedly during the last 4–8 weeks of pregnancy. However it would appear that an additional 3 to 6 Mcal of NE_l per day during this period would be adequate to meet the total requirements of the fetus and maternal development of the cow, depending on her size, with no allowance for fattening (Moe and Tyrrell, 1972). The requirements for maintenance plus gestation have been adjusted slightly from the previous edition of this bulletin to make the requirements uniform with respect to metabolic body size and have been calculated as follows: 104 kcal NE_l, 173 kcal ME, 201 kcal DE, and 45.8 g TDN per $kg^{0.75}$ body weight.

An allowance for body weight changes during lactation has been added to Table 2. These values are intended to aid in identifying the extent of dietary energy insufficiency during weight loss in early lactation and in estimating feed required to regain body tissue in later lactation. The caloric value of body weight changes in adult dairy cattle is influenced not only by gain or loss of body fat, but also by replacement of body fat with water and by changes in gut fill as well. Estimates range from 5 Mcal per kilogram change in empty body weight based on comparative slaughter experiments (Bath *et al.*, 1965) to infinitely high values when body weight changes are minimal. The values in Table 2 have been computed using an average value of 6 Mcal of body tissue energy per kilogram body weight change (Moe and Tyrrell, 1974). The desired rate of live weight gain will depend on body condition and stage of pregnancy. The replacement of body tissue energy may be more efficient while the cow is lactating than when dry (Moe *et al.*, 1971), but care must be exercised to avoid overfattening, especially with corn-silage-based diets. Cows in good condition should receive minimal levels of feed during the dry period with concentrate feeding increased only during the 2–3 weeks prior to calving to allow the animal and the rumen microorganisms to become adapted to larger amounts of concentrate required in early lactation. Grain feeding in late gestation does not significantly increase the severity of udder edema (Jensen *et al.*, 1942; Schmidt and Schultz, 1959). High-producing cows are often unable to consume enough feed in early lactation to prevent some loss of body energy (Flatt *et al.*, 1965), calcium, phosphorus, and perhaps protein. The losses are minimized by feeding as much of a properly balanced ration as the cow can safely use during the first 6–8 weeks after calving. Adequate feeding immediately after calving also helps to prevent ketosis. Thereafter, milk yields should be used to calculate the allowance of energy.

The values in Table 2 provide a useful guide to adequate feeding, but future refinements and modifications may be made when more data are available. To obtain maximum milk yields, it may be necessary to feed in excess of the energy requirements, which will result in some fat deposition. The extent to which it is economical to overfeed cows depends on many factors, including the relative cost of feeds and the market price of milk. Excessive fattening should be avoided, yet allowances should be made for increases in weight of the reproductive organs and fetus in late gestation.

PROTEIN

Importance of Protein Protein is required to furnish the animal with amino acids, which are necessary for various essential synthetic processes in the body. Amino acids are the building units of all cells and tissues in the body, including the blood, skeleton, vital organs, brain, muscles, and skin. All protein secretions in the body, including enzymes, hormones, mucin, and milk require specific assortments of amino acids. In ruminating cattle, the amino acids required may be obtained from dietary protein and some nonprotein nitrogen compounds. Protein is especially important for the lactating cow, because milk solids contain about 27 percent protein; and a cow secreting 30 kg of milk daily makes about 1 kg of new protein for the milk. This amount is similar to that which might be produced by a 6- to 7-kg gain in body weight.

Effects of Protein Deficiency Protein is required for maintenance, growth, reproduction, and lactation. Cattle may store some protein in the blood, liver, and muscles (Platt *et al.*, 1964). These reserves may be used over a short-term period of protein deficiency, especially to maintain gestation and lactation (Blaxter, 1964; Paquay *et al.*, 1972). The normal turnover of body proteins, however, will soon result in depletion of the reserves and the appearance of signs of protein deficiency. Chronic protein deficiency also reduces feed intake, which results in a combined deficiency of protein and energy (Perkins, 1957; Platt *et al.*, 1964). Long-continued protein deficiency will result in a decrease in protein content of the blood, liver and other organs, and skeletal muscles. Besides effects on appetite, milk yield, and general health and vigor, changes occur in blood plasma that may be used to indicate protein deficiency. Blood serum from cattle with adequate protein nutrition normally contains 3.0 to 3.5 g albumin, 4–5 g globulins, and 10–20 mg urea N per 100 ml (Payne *et al.*, 1973, 1974; Perkins, 1960). On protein-deficient diets urea and albumin decline markedly. Blood serum concentrations of less than 2.5 g albumin and 7.0 mg urea N per 100 ml are indicative of protein-deficient diets (Biddle and Evans, 1973; Payne *et al.*, 1973; Perkins, 1960).

Protein deficiency will reduce growth rate in both the fetus and the calf, resulting in small calves at birth and/or slow-growing young stock. Milk production of cows fed protein-deficient diets will be subnormal (Broster, 1972a,b; Huber, 1975; Perkins, 1957; Thomas, 1971), and the solids-not-fat content of milk will be reduced (Rook, 1961). Cows that are severely protein deficient will lose more weight than usual in early lactation and will not regain weight normally in late lactation. Body condition will be depressed in most high-producing cows that are fed protein-deficient diets for an extended period (Perkins, 1957). Lowered immune and transport proteins of blood and reduced hormone secretions may predispose protein-deficient animals to infectious and metabolic diseases that would not normally appear (Platt *et al.*, 1964).

Apparently Digestible Protein Protein requirements listed in this revision have omitted apparently digestible protein and are presented only as total crude protein, because this is the most accurate means of converting protein from feed composition tables to calculated quantities of protein required in mixed diets (Broster, 1972b; Preston, 1972; Satter and Roffler, 1975). Apparent digestibility of feed proteins is directly related to percentage of protein in the diet (Glover *et al.*, 1957; Holter and Reid, 1959; Knight and Harris, 1966; Preston, 1972). Thus digestibility of protein from a supplement, such as soybean meal, fed in a diet containing 14 percent crude protein will be about 65 percent and not 85–90 percent as listed in previously used feed composition tables (National Research Council, 1971). If a value for digestible protein of a diet is desired, it will be more accurate to calculate it from a prediction equation than to use weighted averages of component feed values (Preston, 1972). Glover *et al.* (1957) showed that the digestion coefficient of crude protein (CPDC) can be derived by: $\text{CPDC} = 70 \log X - 15$. This formula, in which X is the percentage of crude protein in the feed, is applicable to both forages and mixed diets.

Factorial Method for Protein Requirements Protein requirements for each class of cattle have been derived by a factorial method (Mitchell, 1929). Factors used for maintenance components were those calculated by Swanson (1977). The factorial formula is:

$$\text{TCP} = \frac{U + F + S + G + C}{Ep} + \frac{L}{Ep}.$$

TCP is total crude protein requirement in grams per day.

U is 6.25 × urine N, which would be lost on an N-free diet, calculated on the basis of body weight (W) in kilograms as: $U = 2.75\ W^{0.5}$. This formula was derived from data from N-balance trials in which practically N-free diets were fed (Swanson, 1977).

F is 6.25 × fecal metabolic N which would be lost on a N-free diet for ruminating cattle calculated on the basis of fecal dry matter (FDM) as: $F = 0.068$ FDM. F also can be calculated, with slightly less accuracy, as 3 percent of dry matter intake (DMI) when mixed forage-concentrate diets are fed. These formulas were derived from N-balance experiments with cattle in which low-protein diets were fed (Swanson, 1977). Liquid milk diets for preruminating calves result in a high concentration of N in feces, which is calculated as 2 g per kilogram DMI (Swanson, 1977). The protein equivalent value for F from milk-fed calves is: $F = 0.0125$ DMI.

S is protein lost in skin secretions, scurf, and hair, calculated on the basis of body weight (W) in kilograms as: $S = 0.2\ W^{0.6}$. S was assumed to be related to body surface area, which was shown by Brody (1945) to vary with the 0.6 power of body weight. Data on protein losses from skin were obtained from reports of calorimeter experiments at the Pennsylvania Agricultural Experiment Station, which were summarized by Swanson (1977).

G is protein deposited in or associated with the increase in body weight of growing cattle (Reid and Robb, 1971). It was based upon published data on compositions of the ingesta-free bodies of 209 cattle representing ages from birth to 78 months, plus an estimate of the protein of the ingesta, to obtain the increase in protein represented by increments of growth in full body weight. Data analyzed were those of all cattle of less than 29 percent fat, as reported by Ellenberger *et al.* (1950), Haecker (1920), Haigh *et al.* (1920), Jahn *et al.* (1976), Moulton *et al.* (1922, 1923), and Trowbridge *et al.* (1918, 1919). It was found that *G* decreased from 19 percent of gain for newborn calves to 16 percent as animals approach mature size without fattening. Since heifers and bulls grow at different rates, protein content of gains for bulls are higher than those for heifers at the same body weights. The composition of gains of heifers at different body weights, based on data cited above, and developed for this publication, are shown in Figure 1.

C is protein deposited in products of conception (fetus, placenta, fetal fluids, and uterus), according to the formula of Jakobsen (1957). This formula gave an average of 88 g protein daily for the last 60 days of gestation for a 500-kg cow. For other body weights, the daily average protein deposition for 60 days prepartum was calculated as: $C = 1.136\ W^{0.7}$.

L is the net protein required for synthesis of milk protein. It is the sum of milk protein and the *F* losses in feces (6.8 percent of FDM) that result from the *increased* feed allowances for lactation. Overman *et al.* (1939) showed that milk protein varied in a predictable manner with percentage of fat in normal milk. The formula used here to predict milk protein percentage is: milk protein percentage = 1.9 + 0.4 times milk fat percentage. This formula is not applicable to milk in which fat tests have been depressed by high-energy, low-fiber diets, as milk protein resulting from such diets may be increased above normal rather than be depressed with the fat test. Protein requirements per kilogram of milk listed in Table 2 are based upon the sum of milk protein for fat tests specified plus 6.8 percent of FDM for the diet concentration used, divided by the *Ep* for lactation, 0.52.

Ep represents the factors necessary to convert the sums of the net protein requirements to their equivalents in terms of dietary crude protein. The efficiency factors are based upon (*a*) the percentage of dietary protein that may be absorbed as amino acids (Brisson *et al.*, 1957; Hogan and Weston, 1970; Satter and Roffler, 1975), and (*b*) the efficiency of conversion of the absorbed amino acids to body protein, which can be used for maintenance, gain, or milk (Blaxter, 1964; Lofgreen *et al.*, 1951; Reid *et al.*, 1967; Roy *et al.*, 1970; Stobo and Roy, 1973; Swanson and Herman, 1943; Van Es and Boekholt, 1976). The former factor, *a*, is related to but not the same as digestibility. The latter factor, *b*, is related to efficiency of utilization of metabolizable protein.

The *Ep* factors adopted to calculate TCP for various classes are:

1. Baby calves fed only liquid milk ($a \cdot b$: 0.91 × 0.77 = 0.70)
2. 50-kg calves fed milk and concentrates ($a \cdot b$: 0.87 × 0.75 = 0.65)

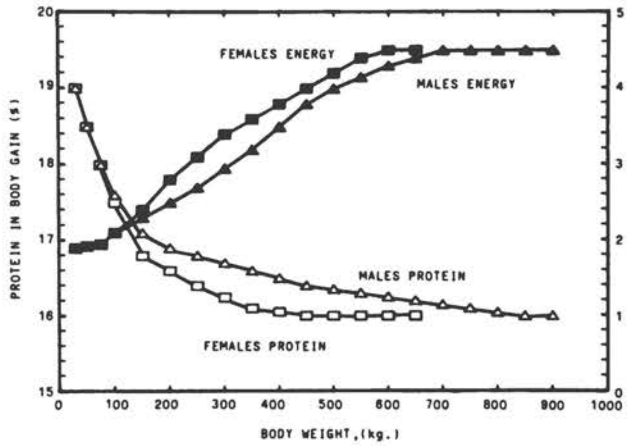

FIGURE 1 Composition of body weight gains of growing, nonfattening dairy heifers and bulls as used for calculation of feed energy and protein requirements.

3. 75-kg calves fed mainly concentrates ($a \cdot b$: 0.80 × 0.70 = 0.56)
4. 100-kg calves fed forages and concentrates ($a \cdot b$: 0.75 × 0.67 = 0.50)
5. 150-kg cattle fed forages and concentrates ($a \cdot b$: 0.75 × 0.63 = 0.47)
6. ≥200-kg cattle, for maintenance and growth ($a \cdot b$: 0.75 × 0.60 = 0.45)
7. Lactation ($a \cdot b$: 0.75 × 0.70 = 0.52)

Protein requirements may be calculated specifically by the factorial method for any individual or homogenous group of cattle and for diets varying in digestibility. The values listed in Tables 1, 1A, 2, 2A, 3, and 3A apply to the designated classes as presented. For other sizes or rates of gain, interpolation is acceptable. Requirements were calculated from the most likely type of diet that would be fed to each of the different classes of dairy cattle when the objective is liberal forage consumption. When diets supplied to cattle differ in energy concentration from the normals used in Tables 1 and 2 (either higher or lower in NE, ME, DE, or TDN), the amount of protein required to cover fecal losses will change inversely with feed digestibility. Thus, as feeds of lower digestibility are fed, the protein requirements listed will be too low; and as high-concentrate, highly digestible feeds are used, the requirements listed will tend to be higher than necessary.

Results of critical experiments on the effects of protein on milk production (Broster, 1972b; Gardner and Park, 1973; Huber, 1975; Paquay *et al.*, 1973; Thomas, 1971; Van Horn and Jacobson, 1971) and growth (Brisson *et al.*, 1957; Broster *et al.*, 1969; Forbes, 1924; Gardner, 1968; Jacobson, 1969; Jahn and Chandler, 1976; Lofgreen *et al.*, 1951) also have been considered so that calculated requirements were comparable to those determined experimentally. In some instances the present protein requirements are different from those in the fourth edition (National Research Council, 1971). Revisions are due partly to differences in dietary assumptions and partly to the different basis for calculations, i.e., calculating total crude protein directly rather than back from digestible protein requirements, using constant digestibility coefficients.

Protein Fed Above Requirements Experiments with cattle fed diets of mixed roughages and starch-rich concentrates indicate that most efficient digestion and fermentation in the rumen requires about 11 percent crude protein or more (Burroughs *et al.*, 1949; Hungate, 1966). When diets are too low in protein, digestibility of the total diet will be reduced, which will result in reduced feed intake and poorer efficiency of utilization of the feed energy (Broster, 1972a; Schurman and Kesler, 1974; Waldo, 1968). When milk cows (Huber and Thomas, 1971) or fattening cattle (Brannan *et al.*, 1973) were fed mainly corn silage and/or high-concentrate diets, it was found that more than 12 percent dietary crude protein (DM basis) must be fed to maximize feed intake and production efficiency. Thus, although protein requirements per se may be met in some classes with a lower percentage of dietary protein, from the aspect of feed efficiency it may be economical to feed at least 11–12 percent crude protein in the dry matter of mixed roughage-concentrate diets.

Very high concentration of protein in feed may cause a decrease in milk yields (Broster, 1972b). However, excess protein can be fed without danger to cattle health, as it normally produces no harmful accumulation of toxic metabolites (Perkins, 1957). Excess ammonia that results from high-protein diets is converted to urea and excreted in urine; so high-protein diets require increased water intake for waste removal and urine secretion (Waldo, 1968).

Protein–energy relationships for dairy cattle have been reviewed by Broster (1972a). Utilization of protein may be limited by inadequate energy in the diet, and the available energy for rumen microorganisms is an important factor in protein nutrition. Also, rumen microorganisms require dietary protein or nonprotein nitrogen (NPN) to grow and digest feed nutrients. The interaction of NPN, protein, and other feed components in the rumen is an important aspect of feeding efficiency (Waldo, 1968). With some low-protein feeds the energy value of the diet may be increased by feeding more protein than shown in the tables of requirements. This effect is the basis for the frequent observation that feeding protein at a moderate level above listed requirements may improve growth rate or milk production.

Unavailable Feed Protein Protein in feeds that have been heated, charred, browned, or caramelized will be denatured to some extent, which results in reduced availability of nitrogen compounds for nutritional use (Bechtel *et al.*, 1943; Goering *et al.*, 1972; Gordon *et al.*, 1961; Sutton and Vetter, 1971). Low-moisture silage or haylage, and hay put in storage with too much moisture, are frequently damaged, as revealed by a brown color with a caramel odor. For calculating protein needs in diets containing moderately heat-damaged feeds, it is recommended that only 80 percent of the actual crude protein be used. If the forage is dark brown or blackened, less than 50 percent of the crude protein may still be in usable form. Diets containing badly heat-damaged feeds must be corrected for unavailable protein if the possibility of protein deficiency is to be avoided. Nitrogen content of acid detergent fiber is an indication of unavailable protein (Goering *et al.*, 1972).

Protein Solubility Solubility of feed crude protein also may affect its nutritive value. Highly soluble crude protein is quickly attacked in the rumen by bacterial enzymes and degraded to simpler compounds and to ammonia. When this released ammonia exceeds the capacity of rumen bacteria to use it to make protein, the result is an immediate loss of part of the dietary nitrogen via excretion in the urine. Direct cut grass silages and high-moisture corn or sorghum silages often contain more than 60 percent of water-soluble crude protein, and this is not utilized very efficiently on all-silage diets. Some concentrate feeds have a high percentage of soluble crude protein, which makes them less suitable for feeding with silages than other concentrates; e.g., corn grain has less soluble crude protein than most by-product feeds. On the other hand, the solubility of protein of corn or other grains that have been fermented in moist storage is increased. Caution is necessary in all cattle ration formulation to assure that balancing the feed for protein requirements will not be underestimated because of unavailable protein or inefficient use of crude protein in the feed mixture.

Urea and Other NPN Urea and other nonprotein nitrogen (NPN) compounds that can be converted to ammonia in the rumen and used as a source of nitrogen for growth of rumen microbes are often added to ruminant diets in place of part of the protein (Conrad and Hibbs, 1968; Helmer and Bartley, 1971; Huber, 1975; National Research Council, 1976). Feedstuffs also contain naturally produced NPN and soluble nitrogen compounds that readily contribute to rumen ammonia. Furthermore, all natural feed proteins may be partially degraded by rumen bacteria with production of ammonia. Feeding management and/or feed processing, which results in release of ammonia that is coordinated with rapid bacterial growth in a mixture of easily fermentable carbohydrates in the rumen, will result in best conversion of NPN to protein. High-concentrate diets allow for better use of NPN than do high-roughage diets; and certain steam-processed, starchy feeds improve ammonia utilization over natural grain sources (Helmer and Bartley, 1971).

Because the percentage of ammonia in rumen fluid increases in proportion to the level of crude protein in the diet, at some level of protein in each dietary situation it will be found that more ammonia is available than the rumen microbes can use efficiently. At this point it would be useless to supplement the diet with NPN, because all that NPN can furnish is more ammonia. Therefore, if the dietary protein requirements exceed this critical level, supplementary protein from low-solubility sources is necessary to ensure that the extra protein fed actually can be utilized by the animal. For cattle fed high-roughage, low-energy diets the critical point of NPN utilization may be as low as 7 percent dietary crude protein (National Research Council, 1976), whereas for those fed high-energy diets containing both roughage and concentrates the critical crude protein percentage could be about 13 percent. It has been suggested (Satter and Roffler, 1975) that NPN not be added to certain 75 percent TDN diets above a moderately low protein percentage; but other evidence (Bartley and Deyoe, 1975; Conrad and Hibbs, 1968; Huber, 1975) indicates that NPN under different dietary conditions can be utilized efficiently at somewhat higher percentages of crude protein. Optimum utilization of NPN will depend upon a relatively slow and constant intake of NPN, thoroughly mixed with the feed, and a type of feed that will yield high energy from starchy sources and promote vigorous rumen bacterial growth.

Excessive levels or poorly mixed additions of urea to feed can cause toxicity due to rapid ammonia production (Helmer and Bartley, 1971; National Research Council, 1976). Such an effect may be avoided by limiting added NPN to 0.5 percent of the total dry matter fed (0.5 percent NPN is practically equivalent to 1 percent urea). Because rumen microorganisms require 2 to 3 weeks to adapt fully to diets containing added NPN compounds, abrupt changes to such mixtures should be avoided.

MINERALS

Calcium, phosphorus, magnesium, potassium, sodium, chlorine, sulfur, iodine, iron, copper, cobalt, manganese, zinc, selenium, molybdenum, fluorine, chromium, silicon, vanadium, and probably nickel and tin have been established as being required by one or more species of animals and appear to be required by dairy cattle. Future research may establish the essentiality of additional mineral elements.

Some of the essential mineral elements are needed for bones and teeth; for use as constituents of the proteins and lipids that make up the muscles, connective tissues, skin, hair, blood cells, organs, and other soft tissues; and for use in numerous enzyme systems of the body. Some are involved in the maintenance of osmotic relationships and acid-base equilibria and exert characteristic and essential effects on the irritability of muscles and nerves.

In excessively high concentrations, all nutrients, including all essential mineral elements, can have detrimental and/or toxic effects on dairy cattle. Although the range between the minimum required level and that where toxic effects occur is relatively wide for most of the essential mineral elements, especially the trace elements, it is important that the safe tolerances not be exceeded. Likewise, substantially higher-than-minimum required levels of almost any essential mineral element can increase the requirement for one or more other elements.

Toxicity of a few of the essential mineral elements, including fluorine, selenium, molybdenum, and copper, can be a problem under some practical feeding situations. Others that have not been shown to be essential also are of practical or potential concern because of their toxicity. These include lead, cadmium, and mercury.

Calcium

Calcium is a critical nutrient in the ration of dairy cattle. Although about 98 percent of the total calcium is in the skeleton (Ellenberger *et al.*, 1950), this element has numerous crucial functions in the soft tissues. The calcium content of the blood plasma is homeostatically regulated within a relatively narrow range. Substantial deviations from this fine regulation can result in dire consequences, as illustrated by parturient paresis, the symptoms of which are associated with reduced plasma calcium. When intake is inadequate, cattle are able to withdraw calcium from the skeleton. However, over a long period, large amounts of calcium may be withdrawn, greatly weakening the bones (Becker *et al.*, 1933). The percentage of the dietary calcium that is absorbed changes widely and fairly quickly in response to the needs of the animal relative to the dietary intake (Agricultural Research Council, 1965; Black *et al.*, 1973; Braithwaite, 1974; Smith and St-Laurent, 1970; Verdaris and Evans, 1974).

The estimated calcium requirements presented in the tables have been calculated primarily by the factorial method. The available calcium needed for maintenance, growth and pregnancy, and/or lactation were totaled and the dietary requirements calculated from these data with a factor for the percentage of the calcium in the feed that is absorbed.

Large differences exist in estimated requirements, depending upon the experimental techniques employed. The two aspects in the factorial procedure for which information is most inadequate are the maintenance requirement (endogenous or metabolic losses) and the true absorption (availability) of the dietary calcium. Although isotope-tracer techniques for measuring the maintenance requirement (Agricultural Research Council, 1965; Hansard *et al.*, 1954; Kleiber *et al.*, 1951) may not result in true values, these data appear to be the best available. The maintenance requirement for calcium, calculated from these data, of 1.6 g per 100 kg (with adjustments for differences in metabolic size of mature animals) was used in developing the tables. This value apparently does not change materially with level of dietary calcium or age of the animal (Agricultural Research Council, 1965).

Slaughter data (Agricultural Research Council, 1965; Ellenberger *et al.*, 1950; Hogan and Nierman, 1927) showed that the percentage of calcium retained per kilogram of gain decreases as cattle grow larger. Likewise, the more rapid weight gains for a given period of time result in a lower content of calcium per kilogram of tissue deposited. Calcium deposited during gestation is low until the last 2 months, during which 75 percent of the total fetal calcium is deposited.

Each kilogram of milk with 4 percent fat contains an average of 1.23 g of calcium. Assuming an availability of 45 percent, the requirement for lactation is 2.7 g of calcium per kilogram of milk (Table 2).

Perhaps the weakest link in the determination of the minimum calcium requirement of dairy cattle is the information on the true availability of calcium in feeds. As mentioned earlier, dairy cattle maintain calcium reserves by increasing or decreasing the percentage absorbed. Thus, feeding a higher level of calcium relative to the needs of the animal reduces the percentage absorbed. This regulatory mechanism, which permits the animal to perform normally with a widely varying intake of calcium, greatly complicates experimental determination of the true availability of calcium under different conditions (Miller, 1975).

Recognizing the weaknesses in much of the published data due to the above homeostatic control mechanism, the effect of age on calcium absorption has been considered in developing the tables. Studies on availability of calcium indicate that calves absorbed as much as 90 percent of the calcium in milk. In older animals, true absorption was extremely variable, ranging from 22 to 55 percent, with an average of about 45 percent. Calcium absorption and retention from milk was more efficient than from rations of forages and concentrate mixtures. Younger animals appeared to be somewhat more efficient in absorbing calcium (Hansard *et al.*, 1957).

Indirect evidence indicated that calcium from inorganic sources was more available than that from organic sources (Hansard *et al.*, 1957). However, differences due to age were greater than those due to feed source (Hansard *et al.*, 1954, 1957). The absorption of calcium also may be affected by other factors, including vitamin D, phosphorus intake, and acid-base balance. High-fat diets increase fecal calcium losses through the formation of soaps (Oltjen, 1975).

The calcium requirement values obtained by the factorial method are consistent with results from many feeding experiments (Agricultural Research Council, 1965). However, when interpreting results of feeding trials, it is essential to keep in mind that the animal is able to reduce skeletal calcium reserves over long periods of time before growth and milk production are adversely affected. Likewise, it must be recognized that many factors other than calcium adequacy of the diet affect results of calcium balance studies. Thus, balance studies alone do not provide a definitive measure of the calcium requirement.

Spontaneous leg fractures occurred in 3- to 6-month old calves receiving 3.2 g Ca per day (0.14 percent) (Wentworth and Smith, 1961). In another experiment, despite normal growth at lower levels, the calcium requirement for maximum bone density was greater than 0.22 percent of the ration (Wentworth and Smith, 1961). Converse (1954) concluded that the minimal requirement of calcium for growth of dairy heifers was 0.14 percent of the ration dry matter and that 0.16 percent was sufficient for gestation, but bones were not examined. Likewise, there was some evidence of reduced withers height and low blood calcium (below 9 mg per 100 ml), which might indicate an extreme deficiency. As pointed out by the Agricultural Research Council (1965), normal bone storage of Ca would have about equalled total Ca intake by the heifers of Converse (1954).

Although the estimated calcium requirement for milk production is consistent with results of feeding practices and many feeding experiments, mention of two well-known deviations follows. Converse (1954) concluded that there was no need for supplemental calcium when the diet contained 0.15 percent of calcium in the dry matter. However, he calculated that during three lactations 90–97 percent of the dietary calcium was secreted into the milk. Although no bone data were presented by Converse (1954), obviously depletion of reserves must have occurred as described by Becker *et al.* (1933). In contrast to this very low recommendation, Ward *et al.* (1972), from balance trials in early lactation, concluded that the calcium requirement should be increased substantially. However, results of short-term calcium balance trials do not agree with feeding trials and other information. Likewise, there is a lack of conclusive evidence that small negative calcium balances in early lactation that are compensated for later are detrimental. In fact, calcium depleted from the skeleton during lactation can be replaced later. On the basis of all evidence available, the estimated calcium requirements presently in the tables should be sufficient for maximum performance of dairy cattle under all typical farm conditions.

In young calves, a calcium-deficient diet prevents normal bone growth and retards general growth and development. Their bones are low in calcium and phosphorus and fracture spontaneously. In mature cows, the feeding of rations low in calcium over a long period of time may cause a depletion of calcium and phosphorus in the bones, resulting in fragile, easily fractured bones and reduced milk yield (Arnold and Becker, 1936), but there is no reduction in the calcium concentration in the milk (Becker *et al.*, 1933; Converse, 1954).

Parturient paresis (milk fever) in cows is caused by a disturbance in calcium metabolism manifested by a marked drop in blood serum calcium at parturition or soon thereafter. Calcium intake during the dry period influences this problem. High calcium intake during the dry period (over 100–125 g per cow per day) tends to increase the problem (Jorgensen, 1974), while a low-calcium diet (8 g Ca daily per 450 kg body weight) fed 14 days prepartum prevented the problem (Goings *et al.*, 1974). Similarly, feeding a low-Ca diet (33–44 g/day) prepartum and a Ca-rich diet (148–197 g/day) postpartum prevented milk fever and excessively low plasma Ca (Westerhuis, 1974). Although there has been some work indicating that the Ca:P ratio in the prepartum ration may be critical (Gardner and Park, 1973; Kendall *et al.*, 1970), other evidence suggests that calcium level may be more important.

Information on the maximum amount of calcium that can be tolerated is much less adequate than that related to minimum requirements. Within relatively wide limits, cattle are able to avoid toxicity from high dietary calcium through excretion of the excess via feces. However, excessive calcium has an antagonistic effect on the metabolism of several other elements, including phosphorus, manganese, and possibly zinc. Many of these effects have been studied in laboratory animals but have not been evaluated quantitatively in cattle. Thus, it is recommended that calcium levels greatly above those presented herein be avoided. Moderate excesses of calcium fed to lactating cows have not resulted in reported harmful effects. However, in bulls fed three to five times the amount of calcium recommended, a high incidence of osteopetrosis, vertebral ankylosis, and degenerative osteoarthritis has been reported (Krook *et al.*, 1969).

Phosphorus

Wise *et al.* (1958) reported that, with dairy calves of 90–125 kg body weight, 0.22 percent of phosphorus in the air dry rations was required for maximum gains. However, bone ash was higher with 0.30 than 0.22 percent phosphorus, but still higher levels of phosphorus intake did not improve any measure of performance. Calves fed diets with 0.22 and 0.30 percent of phosphorus consumed an average of 5.8 and 7.9 g of phosphorus daily, respectively. The authors (Wise *et al.*, 1958) recommended that 0.30 percent phosphorus be considered the minimum safe dietary allowance.

On the basis of research information, it appears that the availability (true digestibility) of phosphorus declines with age of cattle (Agricultural Research Council, 1965; Kleiber *et al.*, 1951; Lofgreen and Kleiber, 1953, 1954). (The estimated requirements in Table 1 are based on a decline in true digestibility of phosphorus from about 90 percent in calves to 55 percent in animals over 400 kg live weight.) However, additional more definitive data are needed to determine adequately the true phosphorus availability under most conditions. Phytate phosphorus, present largely in plant seeds, is not readily available to nonruminants but appears to be utilized by ruminants about as readily as phosphorus from inorganic sources (McGillivray, 1974).

Requirements for growth and pregnancy were calculated from the data of Ellenberger *et al.* (1950) and Hogan and Nierman (1927). For gestation, the requirement is based on slaughter data indicating that a 40-kg calf contains 298 g of phosphorus, of which 75 percent is deposited the last 2 months of gestation. The phosphorus requirement for milk production is based on the phosphorus content of milk and a 55 percent phosphorus availability to the animal.

The ratio of calcium to phosphorus in bone is about 2:1 in older animals and somewhat lower in young animals. In milk the ratio is approximately 1.3:1.0. Except for prepartum rations, a high ratio of calcium to phosphorus in the diet is far less critical for ruminants than it is for laboratory animals (Smith and St-Laurent, 1970). However, a calcium to phosphorus ratio below 1:1 can reduce performance.

Growth rate and feed utilization of calves were satisfactory with calcium to phosphorus ratios ranging from 1:1 to 7:1. Decreased performance and nutrient conversions were noted at ratios above and below this range (Wise *et al.*, 1963). A ratio of 8:1 resulted in poor growth and feed utilization by Holstein steers (Ricketts *et al.*, 1970). No significant differences were found in lactating cows fed rations containing various levels of calcium and phosphorus at ratios of 1:1, 4:1, and 8:1 (Smith *et al.*, 1966). In long-term experiments with pregnant heifers better absorption of both elements occurred with a 2:1 Ca to P ratio than with a 1:1 ratio (Manston, 1967).

Most of the phosphorus requirements in Table 1 are similar to those in the 1971 publication, as are the requirements for maintenance and pregnancy of mature cows in Table 2. Suggestions for greatly increased phosphorus requirements based on short-term balance trials (Ward *et al.*, 1972) or effects on reproduction and blood changes (Stevens *et al.*, 1971) were considered but not used because results of many other studies indicate that the recommendations in the 1971 revision of this bulletin are adequate.

It was suggested that, during a period of shortage of feed phosphorus, the requirements might be decreased by 10 percent on a short-term basis, but that recommended intakes should be resumed when the shortage was over (National Research Council, 1974). Under these conditions the levels of calcium and vitamin D become more critical, since excess calcium could increase the requirement for phosphorus and adequate vitamin D is needed to ensure efficient use of phosphorus.

With phosphorus deficiency, the mineral content of the bones is low and they become fragile. Appetite declines, growth rate is retarded, and feed utilization efficiency is reduced (Eckles *et al.*, 1932), often before the appetite is affected (Beeson *et al.*, 1941). The anorexia (decreased appetite) is not of definitive diagnostic value, as it is associated with other deficiencies. Depraved appetite, e.g., chewing of such things as wood, bones, and hair, is often observed. However, cows may suffer from severe phosphorus deficiency without manifesting depraved appetite. The clinical symptoms of phosphorus and cobalt deficiencies are similar but usually can be differentiated by hemoglobin and plasma phosphorus values.

In chronic phosphorus deficiency, the animal sometimes becomes stiff in the joints. Anestrus and low conception rates may be manifested in females of breeding age with inadequate phosphorus intakes, but the phosphorus content of the milk does not decrease. With a phosphorus deficiency, blood plasma inorganic phosphorus declines to subnormal levels. (Normal values are 4–6 mg per 100 ml for cows and 6–8 mg per 100 ml for calves under 1 year of age.) Thus, unlike calcium, plasma phosphorus is not closely regulated by homeostatic control mechanisms. Accordingly, where inadequate diets are fed, signs of phosphorus deficiency generally become evident at a much earlier stage than with a calcium deficiency.

Sodium and Chlorine (Salt)

Aines and Smith (1957) established that sodium was the limiting component in deficiency of common salt (NaCl). Chlorine has many essential functions, but a specific deficiency has never been observed or experimentally produced in cattle. In contrast, the sodium content of many feeds is inadequate to meet the needs of dairy cattle.

When a diet severely deficient in salt (sodium) is fed to dairy cows, an intense craving for salt and pica, manifested by licking and chewing various objects, can occur within 2–3 weeks (Babcock, 1905; Underwood, 1966). Other symptoms, which may not develop for several months (the time is related to level of milk production), include decreased or loss of appetite, unthrifty haggard appearance, lusterless eyes, rough hair coat, decreased milk production, and rapid loss of weight (or in growing animals reduced gains). Terminal symptoms include shivering, incoordination, weakness, cardiac arrhythmia, and death. With adequate salt supplementation cows recover quickly and completely.

The long delay in the development of most symptoms of salt deficiency results from the remarkable ability of cattle to conserve salt by reducing endogenous losses of sodium and chlorine in urine, sweat, and feces to very low levels when low-salt diets are fed. When dietary sodium intake is inadequate, saliva sodium is reduced and saliva potassium increased long before most clinical signs appear (Morris and Gartner, 1971; Netherlands Committee on Mineral Nutrition, 1973; Van Leeuwen, 1970).

Although quite variable (Agricultural Research Council, 1965), sodium content of milk is increased by mastitis but not materially influenced by the dietary level (Kemp, 1964; Schellner *et al.*, 1971). Mean values from several experiments of 0.63 g sodium and 1.15 g chlorine per kilogram of milk have been reported (Agricultural Research Council, 1965).

Smith and Aines (1959) found that 15 g of supplemental salt per head daily were insufficient for milking cows, but that 30 g were ample for the production of at least 20 kg of milk. They estimated the total requirements for sodium at these production levels to be about 21.3 g per cow daily. Kemp (1964) calculated a comparable amount (23.3 g) from balance trials. A sodium level of 0.14 percent in forage dry matter has been reported to be adequate for cows producing more than 30 kg of milk per day (Kemp and Geurink, 1966).

From balance experiments involving many different rations, sodium balance was always negative when sodium content of the diet of lactating cows was lower than 0.2 percent or when that of the diet of adult, nonpregnant dry cows was lower than 0.1 percent (Lomba *et al.*, 1969).

The sodium and chlorine secreted into milk is a substantial part of the total requirement. Nonlactating cattle have a lower requirement per unit of feed intake (Morris and Gartner, 1971). The sodium content of body gain in cattle is about 1.4 g/kg and the chlorine content 0.9 g/kg (Agricultural Research Council, 1965).

A reasonable estimate of the dietary requirement for lactating cows is 0.18 percent sodium (equivalent to 0.46 percent sodium chloride) in the ration dry matter. Not all of this must come from supplemental salt. The estimated sodium requirement for nonlactating dairy cattle is 0.10 (equivalent to 0.25 percent salt) in the dry matter of the total diet. The requirement for chlorine has not been established, but lactating cows appear to need less than 0.28 percent (equivalent to 0.46 percent salt) in the dry matter. Cows consume more granular salt than block salt, but the intakes of block salt are adequate to meet the needs of lactation (Smith *et al.*, 1953). Cattle are able to tolerate a relatively high level of salt in the diet, especially when water is readily available. In one experiment, beef steers were not adversely affected by 9.3 percent salt in the total ration (Meyer *et al.*, 1955). In contrast, the salt content in water required to produce toxicity is much lower than in feed. In one study, beef heifers were unaffected by 1 percent salt in the water, but were adversely affected by 1.2 percent (Weeth and Haverland, 1961). The amount of salt that can be tolerated safely by lactating dairy cows has not been clearly established. However, it is suggested that salt (sodium chloride) not exceed 5 percent of the total dry matter intake.

Potassium

Symptoms of relatively severe potassium deficiencies (0.06 and 0.15 percent K in the dry matter of the diet) in lactating cows include a marked decrease in feed intake, reduced weight gains, decreased milk production, pica, loss of hair glossiness, decreased pliability of hides, lower plasma and milk potassium, and higher hematocrit readings (Pradhan and Hemken, 1968). With a borderline potassium deficiency (0.45–0.55 percent K in dry diet), the most noticeable sign is lower feed consumption (Dennis *et al.*, 1976). In other species potassium deficiency has been associated with overall muscular weakness and poor intestinal tone.

Research data (Dennis *et al.*, 1976; Pradhan and Hemken, 1968; Ward, 1966) indicate that the potassium requirement of lactating dairy cows is approximately 0.8 percent of the dry diet. Although the data are less definitive, apparently the requirement is similar for other dairy cattle.

Generally, forages contain considerably more potassium than required by dairy cattle. However, the content of many concentrates is below the requirement. Thus, the amount in rations composed predominantly of concentrates may not be adequate to meet the requirement. Potassium concentration decreases with advancing maturity of forages and can be reduced further by leaching of mature standing forages in humid areas.

Young, very lush forages grown in highly fertilized (especially with potassium) soils in cool weather may be extremely high in potassium, often about 3 percent of the dry matter. The high potassium in such forage appears to interfere with magnesium metabolism and/or utilization and may be a factor in grass tetany of lactating cattle (Kemp, 1960; Miller *et al.*, 1972; Ward, 1966). Especially in situations where grass tetany is not a factor, the level of potassium that can be tolerated by dairy cattle is not well defined (Ward, 1966).

Magnesium

The adult animal body contains about 0.05 percent magnesium by weight (Miller *et al.*, 1972). Retention of absorbed magnesium by dairy cattle is related to body needs with most of the excess excreted in the urine. While 60 percent of the body magnesium is stored in the bones in mature cattle (Rook and Storry, 1962), this reserve is slowly mobilized. Consequently, an abrupt change from normal diets to those with inadequate available magnesium can result in hypomagnesemia within 2 to 18 days, even though the previous feed was high in magnesium (Dishington and Tollersrud, 1967). In the young calf, however, 30 percent or more of the skeletal magnesium can be mobilized and translocated to other areas of the body (Blaxter *et al.*, 1954).

Under practical conditions two types of magnesium deficiency occur. The least prevalent is that in calves fed an all-milk diet or other animals fed a magnesium-deficient diet for extended periods until body reserves are depleted. The second type, "grass tetany" or hypomagnesemic tetany, often occurs before there is any material depletion of body reserves. Grass tetany can be a major problem, especially in lactating cows grazing lush, rapidly growing pastures highly fertilized with nitrogen and/or potassium during cool seasons. Older cows are much more susceptible to grass tetany, apparently due to decreased ability to mobilize magnesium from bones.

Among the symptoms of experimentally produced magnesium deficiency in calves are anorexia, hyperemia, greatly increased excitability, and calcification of soft tissue (Blaxter *et al.*, 1954; Moore *et al.*, 1938). The calf becomes susceptible to convulsions (tetany), falling on its side with its legs alternately rigidly extended and relaxed. Death may occur during the convulsions. Frothing at the mouth and profuse salivation are evident (Blaxter *et al.*, 1954). Grass tetany symptoms are similar in cows (Rook, 1963), but may progress much more rapidly with death often following convulsions (Rook and Storry, 1962).

The symptoms of grass tetany are caused by inadequate magnesium in the critical extracellular fluids (plasma and interstitial fluid). This component, which comprises only 1 percent of the total body magnesium, can drop very quickly when there is inadequate magnesium absorption and/or mobilization.

The apparent availability (net absorption) of dietary magnesium to dairy cattle varies greatly and, consequently, is a major determinant of the level of dietary magnesium required. Because of the experimental difficulties in determining "true availability" of magnesium, most of the data available, including those cited herein, are apparent availabilities (net absorption) (Miller *et al.*, 1972). Availability values for magnesium as high as 70 percent have been observed in young, milk-fed calves, but these decline to 30–50 percent in older calves (Peeler, 1972; Rook and Storry, 1962).

Generally, magnesium in grains and concentrates is more available to cattle than that in forages (Miller *et al.*, 1972; Peeler, 1972). Likewise, magnesium in preserved forages is more available than that in pasture. In sharp contrast to most nutrients, net magnesium absorption is lowest from young, highly succulent pasture and increases with forage maturity. The mean availability to dairy cows of magnesium in pasture forage was 17 percent, with a range of 7–33 percent (Blaxter and McGill, 1956; Kemp, 1963).

Milk contains a relatively high magnesium level (about 0.013 percent). Thus, when expressed as a percentage of the diet, the requirement increases with level of milk production (Underwood, 1966).

A dietary intake of 12 to 16 mg of magnesium per kilogram of body weight was sufficient to maintain normal blood levels in calves fed milk (Blaxter and McGill, 1956; Huffman *et al.*, 1941). The maintenance requirement of cows was approximately 2.0 to 2.5 g of available magnesium plus 0.12 g for each kilogram of milk produced (Blaxter and McGill, 1956; Kemp, 1963). However, because of the many factors that affect the magnesium requirement under practical conditions, it is difficult to select a dietary level that is adequate for most practical situations without frequently having materially more than needed. Since cattle apparently have a good homeostatic control mechanism for eliminating moderate excesses of magnesium (by excreting the excess mainly via urine) and relatively poor homeostatic control against a deficiency (Miller, 1975), modest errors on the high side should have less serious consequences.

The suggested magnesium requirement is 0.07 percent in the diet of young calves, increasing to 0.20 percent in the diet of lactating cows fed substantial amounts of preserved forages and/or concentrates. Under conditions conducive to grass tetany (i.e., most of the nutrients from lush, highly fertilized pastures in cool seasons) in high-producing lactating cows, 0.25 percent or more dietary magnesium is suggested. In these situations it is generally wise to provide some supplemental magnesium in a readily available form such as magnesium oxide. Often supplemental magnesium is fed in the concentrate or as a part of a mineral mixture.

Magnesium toxicity is not known to be a practical problem in dairy cattle. The amount that can be tolerated without adverse effects has not been established (Miller *et al.*, 1972). However, about 0.6 percent supplemental magnesium (as magnesium oxide) has been used in low-roughage rations to correct milk fat depression without apparent harm except for occasional diarrhea (Miller *et al.*, 1972).

Iodine

The primary physiological requirement for iodine is for synthesis by the thyroid gland of hormones that regulate rate of energy metabolism. The dietary requirement is affected by the efficiency of thyroid collection of iodine fed, the extent of iodine recycling within the body, and the rate of secretion of iodine from the thyroid.

Research with radioactive iodine has shown that, on iodine intakes near the minimum requirements, cattle commonly bind in the thyroid glands 30 percent or more of their daily consumption (Lengemann and Swanson, 1957; Miller *et al.*, 1975), but at iodine intakes considerably above requirements iodine taken up by the thyroid is less than 20 percent (Swanson *et al.*, 1957). On low intakes of iodine it is possible for the thyroid to bind 65 percent or more of the daily intake (Lengemann and Swanson, 1957). Such high efficiency is due to the recycling of plasma iodine through the abomasum which delays its excretion (Miller *et al.*, 1975). When dietary iodine is adequate, lactation has little effect on the percentage bound by the thyroid (Blincoe, 1975; Swanson *et al.*, 1957). Thyroxine secretion rates (TSR) of cattle of different ages, sex, and lactation status have been determined by many investigators using different methods (Anderson, 1971; Bodoh *et al.*, 1972; Mixner *et al.*, 1962, 1966; Post and Mixner, 1961; Premachandra *et al.*, 1958; Sorensen, 1958; Swanson, 1972).

Most reported daily TSR's have been within the range 0.21–0.31 mg per 100 kg body weight, which is equal to 0.14–0.2 mg iodine. With a daily TSR iodine requirement of 0.2 mg per 100 kg and thyroid uptake efficiency of 30 percent of dietary iodine, the dietary requirement could be calculated as 0.67 mg per 100 kg body weight daily.

At a dry feed intake of 2.5 kg per 100 kg, the iodine requirement in feed would be 0.27 mg per kilogram (0.27 ppm). Considering that about 15 percent of thyroxine iodine may be recycled (Miller *et al.*, 1975), 0.25 ppm in feed dry matter would be adequate for growing or nonlactating cattle on nongoitrogenic diets.

Lactating cows may require more iodine than nonlactating cattle, because about 10 percent of the iodine intake is normally excreted in milk; and this percentage may increase with the level of milk production (Miller *et al.*, 1975). It has been shown also that many protein supplements (feeds) are mildly goitrogenic (Hemken *et al.*, 1971; Iwarsson, 1973), because they reduce availability of dietary iodine. To ensure that iodine needs of high-producing lactating cows are met under usual feed conditions, it is recommended that their dietary iodine concentration be 0.5 ppm. Cows in the last 2 months of gestation also should be fed 0.5 ppm because of the possible harmful effect on the fetus if iodine is deficient (Hemken *et al.*, 1971).

Iodine analyses of forages indicate that 0.25 ppm will usually be attained except in areas in which iodine is deficient in soil and water (Fisher and Carr, 1974). Generally, it is advisable to provide iodized salt to ensure adequate iodine intake. Iodized salt should contain about 0.01 percent of iodine. Including iodized salt at 1 percent in the concentrate mix is equivalent to 1 ppm iodine, which at a forage-to-concentrate ratio of 2:1 will add about 0.33 ppm iodine; this plus the iodine in the feed will normally supply 0.5 ppm in the diet as recommended for lactating cows (Table 3).

Iodine deficiency in cattle is first observed as an enlargement of the thyroid glands (goiter) in slaughtered cattle or newborn calves. Birth of goitrous calves is a sign of borderline or definite dietary iodine deficiency even though the cows may appear in normal condition (Hemken *et al.*, 1971). More than a year may be required on low-iodine diets before deficiency signs are noticed (Hemken *et al.*, 1971; Swanson, 1972). Long-term deficiencies may result in decreased milk yields and some signs of hypothyroidism (Hemken *et al.*, 1971).

Iodine deficiency can be detected by analysis of blood serum or milk for iodine. Total iodine concentrations of less than 40 μg per liter of serum or 10–20 μg per liter of milk are indicative of iodine deficiency. When bulk herd milk is below 20 μg iodine per liter, iodine in the diet may be too low (Alderman and Stranks, 1967; Iwarsson, 1973; Leskova and Weiser, 1969). Iodine deficiency may appear in cattle at the intakes recommended above if as much as one-fourth of the feed is from strongly goitrogenic crops, especially *Brassica* forages such as kale, rape, and turnips. Under these conditions the recommended dietary iodine is 0.5 ppm for growing and nonlactating cattle and 1.0 ppm for late gestation and lactating cows.

Some trace mineral salt mixtures contain more than 0.01 percent (100 ppm) iodine. Iodine compounds are sometimes fed to prevent foot rot and for such purpose are fed in excess of nutritional requirements (Miller and Tillapaugh, 1967). Care must be exercised with such salt mixes and other uses to avoid excess iodine. Excessive levels of dietary iodine result in high blood iodine, excretion of large amounts of iodine in urine and feces, and increased secretion into milk. When the diet consistently contains 50–100 ppm of iodine, toxic signs may appear (Newton *et al.*, 1974). Young stock are more sensitive to excess iodine than are lactating cows (Miller and Swanson, 1973). Signs of toxicity are excessive tears running from eyes, more saliva formed than normal, a watery nasal discharge, and tracheal congestion that causes coughing. Feed intake and growth rate will be subnormal. Recovery from iodine toxicity is rapid after the excess iodine is eliminated from the diet.

Cobalt

The minimum cobalt requirement of dairy cattle is about 0.10 ppm of the dry ration (Ammerman, 1970; Underwood, 1971). Since the required level is more than the amount contained in many forages and some concentrates, supplemental cobalt is needed in many practical situations. Cobalt is an essential component of vitamin

B_{12}, which is synthesized by rumen microorganisms. Cobalt should be fed, since injected cobalt is quite ineffective in alleviating cobalt deficiency symptoms.

Generally, a cobalt deficiency becomes evident only after animals have been on a deficient diet for a considerable time and then progresses slowly as vitamin B_{12} stores in liver and other tissues are depleted. Cattle do not store significant amounts of cobalt in usable forms; thus vitamin B_{12} synthesis declines very quickly when dietary cobalt is inadequate.

The most conspicuous early feature of a cobalt deficiency is decreased appetite and feed consumption resulting in listlessness, retarded growth or weight loss, and decreased milk production. Other symptoms, especially with an extreme and extended deficiency, can include emaciation or wasting of the musculature, paleness of the skin and mucous membranes, muscular incoordination, a stumbling gait, rough hair coat, and high mortality rate among calves (Neal and Ahmann, 1937; Underwood, 1971). Apparently the starvation that is responsible for the symptoms of a cobalt deficiency results from inability of vitamin B_{12}-deficient animals to metabolize propionate, an intermediate product of rumen fermentation, at a sufficient rate.

The clinical manifestations of a cobalt deficiency are not sufficiently specific to permit diagnosis on this basis alone. Response to supplemental dietary cobalt is of diagnostic value, as appetite, temperament, and appearance of cobalt-deficient animals improve rapidly when added cobalt is fed. Liver vitamin B_{12} and feed cobalt have been used as biochemical means of diagnosing cobalt deficiency (Miller and Stake, 1974).

Supplemental dietary cobalt protects animals from the toxic condition, "Phalaris Staggers," which apparently is caused by alkaloids in the grass, *Phalaris tuberosa* (Underwood, 1971). This action of cobalt does not appear to be through its role in vitamin B_{12}.

Calves fed excessive cobalt show reduced appetite, less growth, decreased water consumption, rough hair coat, lack of muscular coordination, increased hemoglobin and packed cell volume, and elevated liver cobalt (Dickson and Bond, 1974; Ely *et al.*, 1948; Keener *et al.*, 1949; Underwood, 1971). Although the toxicity threshold level is not well defined, cattle are able to tolerate high amounts of cobalt relative to the minimum requirement.

Keener *et al.* (1949) estimated that growing dairy animals can tolerate 110 mg of cobalt per 100 kg of body weight daily or about 30 ppm in the diet. This is 300 times the required level and higher than the level that is generally accepted as safe. Usually 10 ppm in the dry diet is accepted as a safe level; however, there is no evidence to indicate that 20 ppm would produce any adverse effects.

Copper

Reviews covering copper nutrition have been published by Ammerman (1970), Marston (1952), and Underwood (1971).

Since first observed by Neal *et al.* (1931), copper deficiency in grazing cattle has become recognized as a major practical problem in many parts of the world. The copper deficiency results either from too little copper per se or from influences of interfering substances, especially high molybdenum (Ammerman, 1970; Thornton *et al.*, 1972; Underwood, 1971).

Thus, a minimum copper requirement cannot be established without considering molybdenum level and, in some instances, other interfering substances (especially sulfate or other materials in pasture forages). The copper requirement of cattle is higher than that of many other species (Underwood, 1971). Likewise, the copper requirement of cattle when grazing often is higher than when stored forage or concentrates are fed (Hartmans, 1974; Netherlands Committee on Mineral Nutrition, 1973).

Although 4 ppm copper (dry matter basis) will meet the requirement under some conditions, 10 ppm is a more practical minimum requirement. More than 10 ppm copper may be needed with pastures containing very high concentrations of molybdenum or other interfering substances (Hartmans, 1974; Underwood, 1971). The addition of 0.5 percent copper sulfate to salt is often recommended in copper-deficient areas.

A wide variety of clinical symptoms, most of which are nonspecific, have been associated with copper deficiency (Allcroft and Lewis, 1957; Becker *et al.*, 1953; Netherlands Committee on Mineral Nutrition, 1973; Underwood, 1971). These include reduced growth or weight loss, unthriftiness, and decreased milk production. With an extreme deficiency, often (but not invariably) the following are observed: severe diarrhea; rapid weight loss; cessation of growth; rough hair coat; a change in hair coat color, which may be faded, bleached, graying, dirty-yellowish (white hair), or brownish (black hair); a change in hair texture; swelling at the ends of the leg bones, especially above the pasterns; fragile bones that often result in multiple fracture of ribs, femur, or humerus; stiff joints that may result in a "pacing gait" in older cattle; depressed or delayed estrus and reduced reproduction; difficulty in calving and retained placenta; birth of calves with congenital rickets; "falling disease" or sudden death due to acute heart failure; and anemia. Sometimes the black hair around the eye loses pigment and develops a gray-spectacled appearance that apparently is specific for copper deficiency (Netherlands Committee on Mineral Nutrition, 1973). With inadequate copper, performance may be subnormal when there are no obvious deficiency symptoms other than possibly nonspecific unthriftiness (Miltimore *et al.*, 1973; Thornton *et al.*, 1972).

Copper toxicity can occur in cattle consuming excessive amounts of supplemental copper or feeds contaminated with copper compounds used for other agricultural or industrial purposes (Underwood, 1971). When excessive copper is consumed, cattle are able to accumulate extremely high amounts in the liver before obvious symptoms of toxicity become evident. The toxicity symptoms are due to the sudden liberation of large amounts of copper from the liver to the blood causing a hemolytic crisis. This is characterized by considerable hemolysis, jaundice, methemoglobinemia, hemoglobinuria, generalized icterus, widespread necrosis, and often death (Allcroft and Lewis, 1957; Todd and Thompson, 1965; Underwood, 1971).

The maximum amount of copper that can be tolerated by cattle is not well defined. Chronic outbreaks of copper poisoning occurred in a small percentage of 10–12-week-old calves fed milk substitute containing 115 ppm (in dry matter) copper (Shand and Lewis, 1957). In contrast, young calves fed increasing levels (up to 500 ppm after 14 weeks) generally did not develop clinical symptoms until 20 weeks (Todd and Thompson, 1965). When 4.8 g of copper (as $CuSO_4$) were given dry in gelatin capsules daily to steers for more than 1 year, toxicity symptoms were not observed. In contrast, the same copper sulfate level, given as a liquid drench, caused death within 60 days (Chapman *et al.*, 1962). Just as the minimum requirement of copper is increased by high dietary molybdenum, the tolerance level also is greater with more molybdenum. It is estimated that cattle can safely tolerate 70–100 ppm copper continuously and higher levels for short periods such as a few weeks.

In some situations, susceptibility of milk to the development of oxidized flavor may be increased by excessive intakes of copper. However, feeding cows 1.28 g of supplemental copper per day (as $CuSO_4 \cdot 5H_2O$ or copper EDTA), resulting in a total of 93 ppm copper in the dry matter, did not influence oxidative stability of milk (Dunkley *et al.*, 1968). Therefore, rations containing as much as 80 ppm copper appear not to have an adverse influence on susceptibility of milk to oxidized flavor.

Molybdenum

Molybdenum is an indispensible component of the enzyme xanthine oxidase found in milk and widely distributed in animal tissue. Because of this it is recognized as an essential element for animals. However, a deficiency has never been developed or observed in cattle. Information available from other species suggests that the absolute requirement is very low and that a deficiency probably would not occur under practical conditions. Studies with lambs fed a semipurified diet with 0.36 ppm molybdenum indicated beneficial effect from 2 ppm supplemental molybdenum (Ellis *et al.*, 1958).

Cattle are less tolerant of high molybdenum than other farm animals. Molybdenum toxicity is an important practical problem in grazing cattle in several areas of the world (Underwood, 1971). The molybdenum content of forage is likely to be higher on poorly drained soils, especially with granite alluviums or black shales and on high organic soils such as peats and mucks (Davis *et al.*, 1974; Underwood, 1971). Likewise, higher soil pH increases molybdenum availability to plants, while decreasing copper uptake.

Molybdenum and copper are antagonistic to each other in the animal body. Toxic molybdenum levels interfere with copper metabolism, and increased copper will reduce or eliminate the toxicity. The relative amounts of copper and molybdenum in a feed are important in determining the occurrence of molybdenum toxicity. If copper is low, a smaller amount of molybdenum is poisonous, but as copper increases, so does tolerance to molybdenum.

The major symptoms of molybdenum toxicity are those of copper deficiency with diarrhea (scours) being especially prominent. The names "teart pastures" or "peat scours" have been used to describe the molybdenum toxicity. Molybdenum content of typical teart pastures may range from 20 to 100 ppm (dry basis) with 3–5 ppm or less being regarded as normal (Cunningham, 1960; Underwood, 1971). With molybdenum toxicity, over a period of time there may be a disturbance of phosphorus metabolism with lameness, joint abnormalities, and osteoporosis (Dye and O'Harra, 1959; Underwood, 1971).

Molybdenum toxicity is modified by other dietary components with the effects not clearly defined. Although the research data are somewhat conflicting, generally it appears that at least a normal level of sulfate provides some protection against high molybdenum by increasing excretion (Cunningham *et al.*, 1959; Underwood, 1971; Vanderveen and Keener, 1964). Likewise, natural protein and substances capable of oxidation to sulfate appear to have a similar effect (Underwood, 1971). In addition to copper and sulfate levels, there are indications of differences in molybdenum toxicity with a given level of molybdenum under varying conditions. Molybdenum in pasture often appears to be much more toxic than a similar amount of experimentally added molybdenum (Cunningham, 1950; Vanderveen and Keener, 1964). The maximum amount of molybdenum that could normally be consumed without toxicity is about 6 ppm in the dry matter of the diet. However, under some conditions substantially more can be fed without adverse effects.

Iron

The iron content of cow's milk is very low and not responsive to higher dietary iron (Underwood, 1971). Although quite variable, iron reserves of the calf generally are sufficient to prevent serious anemia if dry feeds are fed beginning in the first few weeks of age. However, when calves are fed exclusively on a milk diet for several weeks, iron deficiency anemia develops (Blaxter *et al.*, 1957). In fact, pale color of meat, the traditional trademark of "good veal," is caused by iron deficiency (MacDougall *et al.*, 1973; Niedermeier *et al.*, 1959).

Iron deficiency seldom occurs in older dairy cattle unless as a result of severe loss of blood caused by parasitic infestations or disease. The iron requirement of cattle, although not well defined, is influenced by several major variables, including age of cattle, growth rate, availability of the dietary iron source, and especially the criteria of adequacy employed.

The young calf generally deposits considerably more iron in the tissue than older animals per unit of feed consumed. This is due to two factors. First, a higher percentage of the total tissue growth in the young calf contains iron. Second, much less feed is required per pound of gain in the young calf. Soluble iron compounds, such as ferrous sulfate and ferric citrate, are more available than ferrous carbonate and are much more available than insoluble iron phytate or ferric oxide (Ammerman *et al.*, 1967; Bremner and Dalgarno, 1973a).

In much of the earlier research related to iron deficiency and requirement of cattle, researchers used such relatively insensitive measures as anemia, hemoglobin, and packed cell volume to evaluate iron status. The iron requirement is higher when a measure of "adequate" iron reserves, such as percent saturation of transferrin, is employed (Miller and Stake, 1974). Thus 40 ppm iron in the dry diet was sufficient to prevent severe anemia in veal calves fed a milk substitute (Bremner and Dalgarno, 1973b), but was not sufficient to prevent an initial drop in blood hemoglobin resulting in a very low transferrin saturation relative to that of calves given 100 ppm iron. Likewise, the demands on dietary iron for hemoglobin synthesis appear to take precedence over demands for synthesis of myoglobin and some iron-dependent enzymes (Bremner and Dalgarno, 1973b; MacDougall *et al.*, 1973).

Another factor complicating the determination of iron requirements is the major influence of iron status on the percentage of dietary iron absorbed and retained. When iron deficiency (even borderline) occurs, the percentage of dietary iron retained may increase sharply, substantially reducing gross deficiency effects. For example, Matrone *et al.* (1957) calculated iron utilization values of 60 percent when 30 mg was given per calf daily compared to 30 percent with a 60 mg intake. Whether iron utilization increases substantially before the health of cattle is affected adversely by low dietary iron has not been clearly established.

An iron level of 100 ppm in the dry diet should be adequate for all needs of calves to 3 months of age with 50 ppm sufficient for other dairy cattle. If the pale color of veal is of crucial importance, the mild deficiency associated with approximately 30–40 ppm intake may make this a more desirable level.

In addition to the hematological changes noted above, iron-deficiency symptoms in calves may include: reduced weight gains, listlessness, inability to withstand circulatory strain, atrophy of the papillae of the tongue, and reduced appetite (Blaxter *et al.*, 1957; Thomas, 1970). However, except in extreme situations, these effects generally are not major problems in practical dairy cattle operations.

Sufficiently excessive levels of dietary iron can reduce weight gains and feed consumption in cattle. However, the amount of dietary iron required to produce measurable adverse effects has been quite variable with as little as 400–1,000 ppm supplemental iron reducing weight gain (Standish *et al.*, 1969, 1971). In other studies, calves were able to tolerate 1,000–1,900 ppm iron with little or no adverse effect (Hartley *et al.*, 1959; Koong *et al.*, 1970). In the studies of Koong *et al.* (1970), 2,500 ppm had a decidedly detrimental effect on growth. Soluble sources of supplemental iron may adversely affect cattle performance at lower levels than iron in most natural feeds. High iron levels in water also can produce detrimental effects (Coup and Campbell, 1964). It is believed that cattle generally can tolerate 1,000 ppm dietary iron under most conditions, especially if the iron is from natural feed sources and adequate levels of other minerals are supplied.

Sulfur

Sulfur is an essential component of proteins in all animal tissues. In ruminants it makes up about 0.15 percent of the body tissue and about 0.03 percent of milk. Much of this is in the form of the amino acids, methionine and cystine, but many other sulfur-containing compounds are also involved. An important part of protein synthesis occurs where rumen bacteria and protozoa may use inorganic sulfur. In the practical feeding of dairy cattle, a sulfur deficiency is most likely to occur when considerable added NPN and/or corn silage are fed. The use of urea as a nonprotein nitrogen supplement in ruminant rations has increased the need for sulfur supplementation, because the protein-rich feeds replaced by urea are the usual sources of sulfur (Goodrich *et al.*, 1971). Corn silage is often low in sulfur (0.05–0.10 percent sulfur).

Several sources such as sodium sulfate, potassium sulfate, magnesium sulfate, ammonium sulfate, and calcium sulfate are effective in meeting the sulfur requirement of ruminants. Elemental sulfur is utilized but much less efficiently. The ability of inorganic sulfur to sustain positive sulfur balance in cattle and sheep, first indicated by Warth (1932), has been confirmed by many workers in recent years (Bird, 1970; Goodrich *et al.*, 1971; Thomas *et al.*, 1951). Block and Stekol (1950) reported that radioactive sulfur as sodium sulfate administered orally to a dairy cow appeared in the cystine and methionine of milk protein. Thomas *et al.* (1951) demonstrated that sulfur deficiency limits nonprotein nitrogen utilization in purified diets and that sulfate sulfur as the only source of this element corrected the deficiency. Sulfur amino acid synthesis and reduction of sulfate by rumen microorganisms have been established (Block and Stekol, 1950; Block *et al.*, 1951; Emery *et al.*, 1957; Henderickx, 1961a,b; and Lewis, 1955).

Many attempts to supplement ruminant diets with amino acids containing sulfur were inconclusive, because only small amounts of sulfur amino acids were used and frequently the diet already contained adequate sulfur (Rimington, 1929; Smuts and duToit, 1941; Thomas *et al.*, 1951). Elemental sulfur has been used as a source of sulfur in ruminant diets (Hale and Garrigus, 1953; Johnson *et al.*, 1971; Spais *et al.*, 1968; Whiting *et al.*, 1954), but it is poorly absorbed compared to sodium sulfate and methionine (Johnson *et al.*, 1971; Spais *et al.*, 1968). Methionine hydroxy analog has been used in dairy cattle feeding (Bray and Hemsley, 1969; Goodrich and Tillman, 1966; Rosser *et al.*, 1971; Salsbury and Haenlein, 1964), but its effects on dry matter intake and milk protein production are not always positive. Likewise, since much of the methionine hydroxy analog may not be broken down in the rumen, its effect, if any, on cow performance may involve more than just that due to the sulfur component. Bouchard and Conrad (1973) found that inorganic sulfur from sodium, calcium, potassium, and magnesium sulfate could sustain optimum sulfur balance when fed in the complete diet at the level of 0.20 percent sulfur to high-producing dairy cows.

For efficient utilization of urea, a nitrogen sulfur ratio of 10:1 has been suggested by Moir *et al.* (1968) using largely sheep data. However, Bouchard and Conrad (1973) found that nitrogen to sulfur ratios of 12:1 were adequate to maintain maximum feed intake in lactating dairy cows. Inadequate sulfur results in reduced feed intake, lower digestibility, slower gains, and depressed milk production. Excessive amounts of sulfur will decrease feed intake and may overload the urinary excretion system. Likewise, too much sulfur may adversely affect the animal by interfering with the metabolism of other minerals, particularly selenium.

The estimated sulfur requirement for lactating dairy cows is 0.20 percent in the average diet; that for nonlactating dairy cattle is calculated from the minimum protein requirement with a nitrogen to sulfur ratio of 12:1.

The maximum amount of sulfur that can be tolerated is even less well defined than the minimum needs (Bouchard and Conrad, 1973, 1974). Until more definitive data are available, it is suggested that generally the maximum should be limited to about 0.35 percent of the diet with no more than 0.20 percent from added sulfate sulfur. Apparently, dairy cattle can tolerate a higher level of sulfur from natural feed ingredients than from added sulfate.

Manganese

General symptoms of manganese deficiency include impaired growth, skeletal abnormalities, disturbed or depressed reproduction, and abnormalities (including ataxia) of the newborn (Underwood, 1971).

In cattle the manganese requirement is substantially higher for reproduction and birth of normal calves than for growth (Anke and Groppel, 1970; Anke *et al.*, 1973; Bentley and Phillips, 1951; Rojas *et al.*, 1965). In one experiment all calves born from cows fed 16–17 ppm dietary manganese for a 12-month period had neonatal deformities (Rojas *et al.*, 1965). The deformities include weak legs and pasterns, enlarged joints, stiffness, twisted legs, general weakness, and reduced bone strength. Heifers and cows fed low-manganese diets are slower to exhibit estrus, are more likely to have "silent heats," and have a lower conception rate. An increased ratio of male to female young born to manganese-deficient goats and cows has been reported (Anke *et al.*, 1973). Cows fed 7–10 ppm dietary manganese for extended periods exhibited abscessed livers and had practically no bile in the gall bladders (Bentley and Phillips, 1951).

The manganese requirement of cattle has not been well defined. No biochemical measures are available that permit the diagnosis of a borderline deficiency (Miller and Stake, 1974). To determine the effects of borderline manganese deficiency on reproductive functions and calf abnormalities with reasonable precision would require experiments with large numbers of animals. Such data are not available.

Although high dietary calcium and phosphorus appear to increase the requirement for manganese in cattle (Hawkins *et al.*, 1955; Vagg and Payne, 1971), the quantitative relationship has not been defined. Likewise, the degree to which other dietary factors and genetic variability among cattle affect the manganese level needed by cattle has not been established.

The suggested manganese dietary requirement is 40 ppm. Corn grain contains an average of about 5 ppm manganese and barley about three times this level (Adams, 1975; Underwood, 1966). Most other dairy cattle feeds contain substantially more with some forages having several hundred parts per million. Severe manganese deficiency is not a major practical problem with dairy cattle. Likewise, if a borderline deficiency is of major significance, it has not been clearly established.

The limited research indicates that cattle can tolerate a relatively high level of dietary manganese without obvious adverse effects (Cunningham *et al.*, 1966; Robinson *et al.*, 1960). Weight gains and feed consumption were not adversely affected by 820 ppm supplemental manganese, but were decreased by 2,460 ppm. Based on limited information, it is estimated that dairy cattle can tolerate 1,000 ppm dietary manganese without adverse effects.

Zinc

Zinc deficiency in dairy calves fed semipurified diets containing 4–6 ppm zinc has been corrected with the addition of 40 ppm of zinc (Miller, J. K., and Miller, W. J., 1960, 1962; Miller, W. J., 1970; Miller, W. J., *et al.*, 1965c; Mills *et al.*, 1967; Ott *et al.*, 1965, 1966; Pitts *et al.*, 1966). In male calves fed semipurified diets, growth was not significantly increased with zinc levels above 8–10 ppm (Miller, W. J., *et al.*, 1963, 1965c; Mills *et al.*, 1967). However, growth rate on the semipurified diet was somewhat less than occurs with some practical diets. Subsequent studies indicate that zinc requirements would be expected to be somewhat higher with more rapid growth (Stake *et al.*, 1973). Research with lambs indicates that the zinc requirement is greater for reproduction than for growth: 17.4 ppm was adequate for growth, but testicular growth and sperm production were markedly improved with 32.4 ppm zinc (Underwood and Somers, 1969).

In several experiments adding supplemental zinc to practical diets containing 18–29 ppm did not improve performance of calves or feedlot cattle (Miller, J. K., *et al.*, 1962; Perry *et al.*, 1968; Zurcher, 1970). However, in some experiments with comparable zinc levels in the basal practical diets, supplemental zinc improved rate of gain and/or performance (Perry *et al.*, 1968; Zurcher, 1970).

With lactating Holstein cows fed a high beet pulp basal diet, 17 ppm zinc was fully adequate (Neathery *et al.*, 1973a). However, when lactating cows were given this relatively low (17 ppm) zinc diet, in comparison with a control diet having 40 ppm zinc, several adjustments in zinc metabolism occurred quite rapidly (Neathery *et al.*, 1973b). These included a substantial increase in the percentage of the dietary zinc absorbed, more rapid zinc turnover, and a 23 percent reduction in milk zinc content. However, the average total zinc content of the various body tissues was not affected (Neathery *et al.*, 1973c). In another experiment, milk production of cows fed a corn silage and concentrate diet containing 25 ppm zinc was increased by supplemental zinc (Voelker *et al.*, 1969). However, in a Brazilian study, performance of lactating cows fed a corn silage and concentrate diet containing 34 ppm was not improved by supplemental zinc (Galvao *et al.*, 1973).

Whether genetic differences have an effect on zinc requirement of most cattle has not been established. However, a small percentage of Dutch–Friesian calves are born with an apparently inherited defect that causes a very severe zinc deficiency (Andresen *et al.*, 1970; Kroneman *et al.*, 1975; Miller, W. J., 1971). The deficiency can be temporarily corrected by very high amounts of dietary zinc.

Zinc deficiency in calves is characterized by decreased weight gains; lower feed consumption and feed efficiency; decreased testicle growth; listlessness; development of swollen feet with open scaley lesions; alopecia; a general dermatitis that is most severe on the legs, neck, head, and around the nostrils; and other parakeratotic lesions (Miller, J. K., *et al.*, 1962; Ott *et al.*, 1965).

Lactating cows fed 6 ppm zinc developed clinical zinc deficiency symptoms comparable to those of calves (Schwarz and Kirchgessner, 1975). One effect of a zinc deficiency in calves is failure of wounds to heal normally (Miller, W. J., *et al.*, 1965b). Secondary factors, such as trauma, determine the location of the parakeratosis on the body.

Supplementation of a diet containing 3–4 ppm zinc with 100–260 ppm zinc reduced listlessness and improved feed consumption within hours and corrected skin lesions and other symptoms in Holstein calves within 3–4 weeks. In calves a zinc deficiency can be produced within 3 weeks. Cattle adjust quickly to levels of dietary zinc by increasing or decreasing the percentage of zinc absorbed. Ruminants fed a zinc-deficient diet show a rapid and large increase in percentage of dietary zinc absorbed and some reduction in endogenous fecal zinc losses. The decreased absorption observed with age does not appear to be due to inability to absorb zinc, but to homeostatic control associated with a decreased demand factor. Lactating Holstein cows fed 17 ppm zinc had a net absorption of 53 percent (compared to 50 and 47 percent for 2- and 6-month-old calves) and secreted 18 percent of the dietary zinc into the milk (Neathery *et al.*, 1973a; Stake *et al.*, 1975).

Generally, milk contains about 4 ppm zinc. This has been about doubled with a very high, but nontoxic, zinc intake or decreased about one-fourth with a low, but nondeficient, diet (Miller, W. J., *et al.*, 1965a; Neathery *et al.*, 1973a). Zinc content of tissues, other than plasma, decreases quite slowly, if at all, when a zinc-deficient diet is fed (Miller, W. J., 1969).

The toxicity threshold for zinc appears to be influenced by other variables. With other species of animals, high levels of zinc accentuate borderline deficiencies of some other elements, including iron. The degree to which age of animals and organic make up of the diet affect the toxicity threshold has not been established. Lactating dairy cows fed normal rations containing 1,279 ppm of zinc had no adverse responses (Miller, W. J., *et al.*, 1965a). Levels of 900 ppm of zinc for growing cattle fed a corncob-concentrate ration produced subnormal gains and lowered feed efficiency; 1,700 ppm and above reduced feed consumption and caused depraved appetite (Ott *et al.*, 1966). Zinc content in a number of calf tissues, including liver, kidney, and pancreas, was increased severalfold when 600 ppm supplemental zinc was fed, and before any symptoms of toxicity appeared (Miller, W. J., *et al.*, 1970). This phenomenon, which does not occur in the rat, is due to a breakdown in some homeostatic control mechanism(s) for zinc.

The estimated zinc requirement for dairy cattle is 40 ppm in the diet. The toxicity threshold is estimated to range from 500 to 1,500 ppm.

Selenium

Although long recognized as a toxic element, selenium is now firmly established as an essential element. Selenium deficiency occurs in farm animals over much larger areas of the world, including much of the United States, than does selenium toxicity (Muth *et al.*, 1967; National Research Council, 1971; Underwood, 1971). Because many more animals are affected, selenium deficiency is of much greater practical importance than toxicity. Selenium deficiencies are more likely to occur when feeds are grown on acidic soils.

Selenium is an integral component of glutathione peroxidase (Rotruck *et al.*, 1973). The activity of this enzyme in certain tissues may be a useful biochemical measure of selenium status (Ammerman and Miller, 1975). While the role of selenium in glutathione peroxidase is the best-defined function of selenium in animals, it probably has other essential functions of major importance (Hoekstra, 1974).

A major sign of a pronounced selenium deficiency is "white muscle disease" (nutritional muscular dystrophy), which usually occurs in young calves (Ammerman and Miller, 1975; Andrews *et al.*, 1968; Hartley and Grant, 1961; National Research Council, 1971; Underwood, 1971). Animals with white muscle disease have chalky white striations, degeneration, and necrosis in cardiac and skeletal muscles. Also, heart failure, paralysis usually of hind legs, a dystrophic tongue, and elevated SGOT (serum glutamic oxalacetic transaminase) values may be evident. Selenium-responsive unthriftiness, varying from subclinical growth depression to progressive loss of condition usually associated with diarrhea, can occur in cattle of all ages (Andrews *et al.*, 1968). Likewise, fertility in females may be adversely affected. In cows fed diets inadequate in selenium, the inclusion of supplemental selenium has substantially decreased the incidence of retained placenta (Julien *et al.*, 1976). Subclinical selenium deficiency, which reduces animal performance, often is difficult to detect. Hopefully, tissue glutathionine peroxidase determinations will make such diagnosis easier.

Although not well defined, the requirement for selenium by ruminants is approximately 0.1 ppm, depending upon the chemical form of selenium and the levels of interfering or enhancing factors in the diet, including vitamin E, sulfur, lipids, proteins, amino acids, and several microelements (Ammerman and Miller, 1975). The relationship of selenium to vitamin E is discussed in the vitamin E section. The lowest toxic level is approximately 3–5 ppm, depending upon the protein, sulfur, and arsenic levels (higher amounts of each reduce the toxicity) of the diet and the chemical form of selenium. Apparently, the naturally occurring organic selenium of plants is much more toxic than the inorganic form. The range between the requirement and toxic levels is 30–50-fold.

Selenium toxicity, which occurs under practical conditions in several areas of the world, is often classified as acute or chronic alkali disease (National Research Council, 1971; Oldfield *et al.*, 1974; Rosenfeld and Beath, 1964; Underwood, 1971). Acute selenium poisoning is characterized by dullness, slight ataxia, characteristic posture, rapid weak pulse, labored respirations, diarrhea, lethargy, and death due to respiratory failure (National Research Council, 1971; Shortridge *et al.*, 1971). Signs of chronic selenium toxicity (alkali disease) include: lameness; loss of vitality; loss of appetite; emaciation; sore feet; deformed, cracked, and elongated hoofs; loss of hair from the tail; liver cirrhosis; and nephritis.

Fluorine

Studies with laboratory animals indicate that fluorine probably is an essential element for animals (Fleischer *et al.*, 1974; Messer *et al.*, 1974; Tao and Suttie, 1976; Schwarz, 1974). However, there is no evidence to indicate that a fluorine deficiency would ever be a practical concern with dairy cattle.

Fluorine is important in dairy cattle nutrition because of its toxic effects (Griffith-Jones, 1977; Hobbs and Merriman, 1962; National Research Council, 1974; Shupe *et al.*, 1963, 1972; Stoddard *et al.*, 1963; Suttie *et al.*, 1957, 1961; Underwood, 1977). In fact, dairy cattle are the most sensitive of domestic animals to fluorine toxicity (Underwood, 1977). The major sources of excessive levels of fluorine for dairy cattle are nondefluorinated phosphates (rock phosphate often contains 3–4 percent fluorine), and contamination of feeds near industrial plants. Also, in some areas water or soil naturally may have unusually high amounts of fluorine.

Usually fluorine toxicity in dairy cattle results from the chronic fluorosis, which develops slowly over a long period of time. Fluorine concentrations in most soft tissues vary remarkably little with widely varying intakes. Under normal conditions, fluorine accumulates in the skeleton of the animal throughout life. However, when excessive fluorine is ingested, bones and teeth accumulate abnormal amounts that induce changes. Developing teeth of young cattle (especially from 6 months to 3 years of age) are very sensitive to excess fluorine when fed even for relatively short periods (National Research Council, 1974). Teeth changes may include mottling, staining, excessive wear, erosion, or pitting of enamel, depending on the degree of fluorosis. Excessive fluorine ingestion causes bone lesions, including enlarged areas and a chalky white surface. The effects on bones and teeth can result in leg stiffness, lameness, reduced feed intake, a decline in general health, and lower milk production.

Most dairy cattle can tolerate approximately 30 ppm fluorine in the dry matter of the total diet without major adverse effects on health or performance, even over long periods (Shupe *et al.*, 1972). Young animals are most sensitive to excess fluorine. If the first exposure to elevated fluorine takes place when the cattle are 3–4 years old, 40 ppm can be fed with little or no adverse effect on performance for at least two or three lactations. Histologic and pathologic changes in bone and tooth structure may appear at lower levels than required to affect performance. Finishing cattle can tolerate 100 ppm fluorine in the ration during the average feeding period because of the short duration.

The toxicity of fluorine-containing compounds appears to be related to their solubility. The tolerances discussed above are based on highly soluble compounds. When the fluorine comes from less-available sources, such as phosphates, the tolerance is increased somewhat. Toxic effects of fluorine may be counteracted or reduced to a limited extent by dietary aluminum salts, high calcium levels, green forages, or liberal grain-feeding.

If elevated fluorine is only ingested intermittently or for short periods, cattle are able to tolerate a somewhat higher level than if it is consistently high. When dietary fluorine intake increases, urinary excretion also increases. Urinary excretion remains elevated after dietary intake is reduced, thereby slowly reducing the total body burden and the potential toxicity.

Chromium, Silicon, Vanadium, Tin, and Nickel

The essentialities of chromium and silicon for small animals appear to be firmly established (Carlisle, 1974; Underwood, 1971). Although these elements are believed to be essential for dairy cattle, a deficiency has never been produced; likewise, there is no information to suggest that a deficiency would ever be a practical problem.

Considerable research information with laboratory animals indicates that vanadium, tin, and nickel probably are essential elements (Hopkins and Mohr, 1974; Miller, 1974; Nielsen and Ollerich, 1974; Schwarz, 1974). Thus very likely they, also, are essential for dairy cattle. However, there is no information to indicate that a deficiency would ever be a problem with dairy cattle.

TOXIC MINERALS

Lead

Lead is one of the most frequently observed causes of poisoning in cattle (Neathery and Miller, 1975). The young calf is extremely susceptible. Lead poisoning in cattle is one mainly of acute toxicity. Important sources of toxic amounts are lead-based paint (discarded paint cans or peeling paint), used motor oil, discarded oil filters, storage batteries, and certain types of grease and linoleum (Allcroft, 1950; National Research Council, 1972). Lead-based paint is the most common source (Allcroft, 1950).

General acute lead-toxicity symptoms include dullness, inappetence, and abdominal pain with constipation sometimes followed by diarrhea. In advanced stages, which may occur 2 to 3 days after a lethal dose, symptoms may include: bellowing, staggering, snapping of eyelids, muscular twitching, frothing mouth, and convulsive seizures (Allcroft and Blaxter, 1950; Merck Veterinary Manual, 1973).

Lead ingested in the form of phosphate, oxide, basic carbonate, or wet paint is equally toxic when similar quantities are given (Allcroft, 1950). Calves up to 4 months old given single oral doses of these lead sources at the rate of 200–400 mg lead per kilogram body weight died 4–6 days later (Allcroft, 1951). Older cattle could tolerate about twice this amount.

Although data are sparse, chronic lead toxicity is unlikely to occur under most practical conditions of cattle management (Allcroft and Blaxter, 1950). This does not preclude the possibility of borderline toxicity arising when cattle graze near lead mines or smelters (Allcroft and Blaxter, 1950). However, these sources of lead generally are poorly absorbed. A dose of 6 mg lead (as acetate or carbonate) per kilogram body weight per day (equivalent to 250 ppm dietary lead) was tolerated by cattle for 3 years without obvious ill effects (Allcroft and Blaxter, 1950).

The diagnosis of lead poisoning in cattle is best made by simultaneously considering the clinical symptoms, the presence of a lead source, the lead content of blood and feces if the animal survives, or, if death occurs, lead content of soft tissues, especially kidney cortex (Allcroft and Blaxter, 1950; Neathery and Miller, 1975). High blood and fecal lead may only indicate recent exposure and not be responsible for death. Blood levels may remain above normal (0.13 ppm Pb) for many weeks following a single oral dose (Allcroft, 1950). Kidney cortex values of 50 mg lead per kilogram fresh tissue and liver lead content of 20 mg per kilogram indicate death from lead poisoning (Allcroft and Blaxter, 1950).

Apparent intestinal absorption of inorganic lead is relatively low in most species (Blaxter, 1950b; National Research Council, 1972). Absorption is increased on low-calcium and phosphorus diets (Shields and Mitchell, 1941) and in young animals (Kostial *et al.*, 1971).

Most ingested lead is deposited in bone with appreciable amounts in liver and kidney (Blaxter, 1950a). Few adverse effects are seen when most of the lead is in bone; however, when it is distributed throughout the system, especially in kidney, liver, and central nervous system, severe symptoms occur (Blaxter, 1950a).

Cadmium

Cadmium is of interest in animal agriculture because of its toxicity; there is no evidence for its essentiality. Cadmium toxicity may occur when animals inhale cadmium-containing dust or fumes or consume cadmium-contaminated feeds. Although naturally occurring toxicity has been reported in humans (Japanese), clinical symptoms of cadmium toxicity in cattle have not been reported under practical conditions (Friberg *et al.*, 1971; Neathery and Miller, 1975a,b). With current dairy cattle feeding and management conditions, cadmium toxicity is relatively unimportant, because most feeds and forages contain little cadmium and only a very small amount of ingested cadmium is absorbed. However, this does not preclude the possibility of borderline toxicity arising from cattle ingesting feeds containing recycled waste materials, such as sewage sludge, in which cadmium may be concentrated (Boswell, 1975). Ingested cadmium is poorly absorbed (less than 1 percent in cattle studies), but that which is absorbed may be retained in the body for a considerable time (Friberg *et al.*, 1971; Miller, 1973; Miller *et al.*, 1969). Cadmium concentrates mostly in kidney and liver, which may contain as much as 75 percent of the total body burden (Miller *et al.*, 1969). Very little of the retained cadmium is found in muscle or secreted into milk (Miller *et al.*, 1967, 1969; Neathery and Miller, 1975a,b; Neathery *et al.*, 1974).

Only limited research data are available on experimental cadmium toxicity in cattle. Four calves given a diet containing 2,560 ppm cadmium died 2, 3, 5, and 8 weeks later (Powell *et al.*, 1964). A reduction in growth, feed intake, and water consumption occurred in calves fed 160 ppm cadmium, but there was no significant effect with 40 ppm (Powell *et al.*, 1964). Three grams of cadmium as $CdCl_2$ given in gelatin capsules to lactating cows for 14 days resulted in a drastic reduction in milk production (Miller *et al.*, 1967).

Other general clinical symptoms of cadmium toxicity in cattle include anemia, retarded testicular development or degeneration, enlarged joints, scaly skin, liver and kidney damage, reduced growth, and increased mortality (Powell *et al.*, 1964). Some of these symptoms are similar to those in zinc-deficient calves (Miller, 1971; Powell *et al.*, 1964). In other species some of the toxic effects of cadmium can be diminished or prevented by zinc, cobalt, selenium, and thio compounds (Flick *et al.*, 1971; Gunn and Gould, 1967).

Mercury

Mercury poisoning is rather uncommon in cattle because of their lack of exposure to mercury-containing substances (Neathery and Miller, 1975). Toxicity occurs sporadically from accidental overdosing of mercury-containing medicines and from excessive absorption of liberally applied mercury skin ointments. Seed grain, which has been treated with an organic mercury fungicide, appears to be the most common source (Blood and Henderson, 1968).

Toxicity and metabolism of mercury are greatly affected by chemical form. In cattle (Ansari *et al.*, 1973; Potter *et al.*, 1972; Sell and Davison, 1973), as well as other species (Clarkson, 1971; Ellis and Fang, 1967; Miller *et al.*, 1967), the organic mercury compounds (especially methyl mercury) are more toxic than the inorganic compounds. This greater toxicity is due to a higher absorption (Ansari *et al.*, 1973; Friberg and Vostal, 1972; Miller *et al.*, 1967), greater body retention (Ansari *et al.*, 1973; Friberg and Vostal, 1972), and to a slower turnover rate in the body (Friberg and Vostal, 1972). Kidney and liver are the main deposition sites of both chemical forms; however, appreciable amounts of methyl mercury are found in muscle and brain (Ansari *et al.*, 1973; Friberg and Vostal, 1972; Neathery *et al.*, 1974).

Because organic mercury generally is much more toxic than the inorganic, there is considerable interest in the biotransformation. In the rumen, conversion of inorganic mercury to methyl mercury does not occur or is very minute (Ansari *et al.*, 1973).

Limited data with ruminants indicate that relatively small amounts of organic and inorganic mercury are secreted into milk (Neathery *et al.*, 1974; Potter *et al.*, 1972; Sell and Davison, 1973).

Different toxicity symptoms are produced from ingestion of organic and inorganic mercury forms (Neathery and Miller, 1975). Inorganic mercury compounds are very caustic. Their caustic action on the mucosal membranes of the alimentary tract results in a rapid development of gastroenteritis. Chronic mercurealism, in which small amounts of inorganic mercury are ingested over a long period, is manifested in cattle by depression, anorexia, emaciation, and a stiff, stilted gait that may progress to paresis. Alopecia, scabby lesions around the anus and vulva, pruritus, tenderness of gums and teeth, shedding of teeth, and chronic diarrhea are common symptoms in later development stages (Blood and Henderson, 1968).

The alkyl mercuries (organic compounds) primarily affect the nervous system. Clinical symptoms of chronic methyl mercury toxicity in calves are similar to those produced by polioencephalomalacia (PEM) in calves (Herigstad *et al.*, 1972). However, with methyl mercury toxicity calves do not respond to thiamine therapy as PEM calves do (Davis *et al.*, 1965). Calves may appear normal for several days during daily administration of methyl mercury, then there is a sudden and rapid onset of clinical symptoms, including ataxia, neuromuscular incoordination, headpressing, twitching of eyelids, tetanuslike spasms on stimulation, excessive salivation, recumbency, and inability to eat or drink. These are followed by tonic–clonic convulsions with opisthotonos and death (Herigstad *et al.*, 1972; Oliver and Platonow, 1960).

There is a dearth of data pertaining to the toxic dose of mercury to calves. Blood and Henderson (1968) reported that a single 8-g dose of mercuric chloride or mercury biniodide was toxic to cattle. Toxicity and death were produced in milk-fed calves whose total diet was supplemented with 10 or 28 ppm mercury (dry basis) from a methyl mercury product for 36–81 days. Calves receiving diets containing 2 or 4 ppm mercury remained clinically normal during a 96-day experimental period (Herigstad *et al.*, 1972).

VITAMINS

Ruminants are fortunate in having their needs for most vitamins met under normal conditions by natural feeds, rumen synthesis, and tissue synthesis. Vitamins A, D, and E are usually present in significant amounts in high-quality forage. Members of the B-vitamin group and vitamin K are synthesized in the rumen and vitamin C is synthesized in the tissues (McElroy and Goss, 1940; Wiese *et al.*, 1947). However, there are certain conditions where the natural supply may be limiting, such as when forage is fed in limited amounts or is low in quality, when sun-cured hay or exposure of animals to sunlight is limited, or when milk replacers are used extensively for young calves. Under these conditions, the needs can be furnished with commercially prepared feed supplements. Intramuscular injection of the fat-soluble vitamins can also be used, but usually should be limited to special short time conditions. A recent field study (Hartman *et al.*, 1976) found no advantage for routine injection of vitamins A, D, and E at the time of drying off for cows fed normal rations.

Vitamin A

Vitamin A deficiency is characterized by stratified keratinization of epithelial tissue. In cattle there is degeneration of the mucosa of the respiratory tract, mouth, salivary glands, eyes, tear glands, intestinal tract, urethra, kidneys, and vagina. Structures thus affected are highly susceptible to infection, and colds and pneumonia often occur. Diarrhea, loss of appetite, and emaciation are commonly observed at this stage of deficiency. In later stages, characteristic changes in the eye may take place: excessive lacrimation, keratitis, softening of the cornea, xerophthalmia, cloudiness of the cornea, and sometimes permanent blindness resulting from infection. As vitamin A deficiency develops, dark adaptation is reduced and night blindness occurs, which is readily detected when animals are driven among obstacles in dim light. Staggering gait, convulsive seizures, and papilledema, resulting from elevated cerebrospinal fluid pressure, may appear in advanced stages. The first signs of vitamin A deficiency in pregnant cows are shortened gestation periods; a high incidence of retained placentas; and birth of dead, incoordinated, or blind calves. Blindness in this case is generally permanent and is due to constriction of the optic nerves caused by stenosis of the optic foramen. Blindness or night blindness also may be the first noticeable symptom of vitamin A deficiency in rapidly growing cattle on high-concentrate diets.

One of the most sensitive indicators of vitamin A deficiency in growing calves is elevation of cerebrospinal fluid pressure. Early studies (Moore *et al.*, 1948) suggested that values above 120 mm saline were abnormal. More recent studies (Eaton *et al.*, 1964, 1972) suggested that a more accurate measure of requirement would be the point at which cerebrospinal fluid pressure began to be elevated, determined by regression formulas. Plasma vitamin A concentrations of less than 20 μg/100 ml are suggestive of the presence of a deficiency in growing Holstein calves fed fixed intakes of carotene or vitamin A (Eaton *et al.*, 1970). Blood plasma levels below 10 μg/100 ml indicate a more advanced stage of deficiency, since by then liver stores have been decreased to critical levels, less than 1 μg per gram. Cattle fed corn-silage-based high-energy diets may have low liver stores of vitamin A and show deficiency symptoms (Jordan *et al.*, 1963; Miller *et al.*, 1967).

Requirements generally have been expressed in terms of the provitamin A, carotene, since this is the most common dietary source for cattle. While, on the basis of rat growth, 1 mg beta-carotene is equivalent to 1,667 IU of vitamin A, the relative efficiency for cattle is much lower and is influenced by inheritance, previous vitamin A status, level of intake, and source of carotene. For a number of years, 1 mg of carotene has been considered equivalent to only 400 IU of vitamin A for cattle (24 percent of the rat value). This ratio (1 mg carotene = 400 IU vitamin A) can be used in conversions needed for using Tables 1, 2, 3, and 4.

In earlier reports, the suggested minimum carotene requirement for maintenance has been as low as 3.5 mg per 100 kg of body weight, a level that would prevent gross clinical symptoms. Up to twice as much was needed for normal growth (Guilbert *et al.*, 1940). However, using the most sensitive criterion (maintenance of normal cerebrospinal fluid pressure), Eaton *et al.* (1964) estimated the minimum requirement to be 10.6 mg of carotene per 100 kg of live weight for growing Holstein calves. Ronning *et al.* (1959) have shown that an intake of 19 mg of carotene per 100 kg of live weight resulted in successful reproduction for extended periods for Guernsey cows. Therefore, this level has been used as the requirement for the last 2 months of gestation for maintenance and pregnancy. Swanson *et al.* (1968) showed that levels of carotene adequate for reproduction seemed more than adequate for lactation, so this figure has also been used in estimating the ration content in Table 3. Higher levels will affect the vitamin A potency of the milk, although a rather high threshold for the secretion of the vitamin and its precursor into milk has been demonstrated (Rusoff *et al.*, 1942). While vitamin A deficiency reduces fertility in bulls, there have been no indications for a requirement above that for normal maintenance (Bratton *et al.*, 1948).

Eaton *et al.* (1972), using the function of log cerebrospinal fluid pressure on log vitamin A requirement for the estimation, suggested a requirement of 29 μg (96.7 IU) of vitamin A per kilogram of body weight daily for growing Holstein bull calves. This is approximately double a previous estimate of 14.1 μg (47 IU) of vitamin A per kilogram of body weight daily using a cerebrospinal fluid pressure of 120 mm saline as the criterion (Rousseau *et al.*, 1954). Use of this new value would approximately double the vitamin A requirements used in the previous publication. The subcommittee is basing the vitamin A requirements on the same data used in the last publication, with minor adjustments in interpretation. These previous values were 10.6 mg carotene per 100 kg body weight for growing animals and 19 mg per 100 kg for reproduction as well as lactation. These levels were used in the last two publications, and no evidence of problems under field conditions have come to the attention of the subcommittee. If additional evidence for a higher vitamin A requirement is forthcoming, the vitamin A requirement should be raised. The present requirements for the last 2 months of gestation and during lactation approach the higher levels on a body weight basis.

The special conditions where vitamin A supplementation may be indicated include feeding: (1) poor-quality forage or low levels of forage, (2) only limited amounts of colostrum or whole milk to calves, (3) primarily corn silage and a low-carotene concentrate mixture. It should be emphasized that the vitamin A requirements listed are adequate under most practical conditions but should be increased if certain stressful conditions exist, such as low environmental temperature or exposure to infective bacteria (Eaton *et al.*, 1972).

Vitamin D

Some of the first signs of vitamin-D-deficiency rickets are decreases in the blood plasma concentration of calcium or inorganic phosphorus, or both, and increases in serum phosphatase. These blood changes are associated with characteristic alterations in bones, including markedly retarded calcification of the cartilaginous matrix. There is accumulation of osteoid tissue, as indicated by a beading of the ends of the ribs, and the bone ash is reduced. Bones are susceptible to breakage (Bechtel *et al.*, 1936; Rupel *et al.*, 1933; Thomas and Moore, 1951).

Clinical signs begin with thickening and swelling of the metacarpal or metatarsal bones. As the disease progresses, the forelegs bend forward or sideways. The joints (particularly the knee and hock) become swollen and stiff, the pastern straight, and the back humped. In more severe cases synovial fluid accumulates in the joints. Posterior paralysis may occur as the result of fractured vertebrae. Structural weakness of the bones appears to be related to poor mineralization. The advanced stages are marked by stiffness of gait, dragging of the hind feet, irritability, tetany, labored and fast breathing, weakness, anorexia, and retardation of growth. Prolonged deficiency lowers retention of calcium, phosphorus, and nitrogen and increases the metabolic rate (Colovos *et al.*, 1951).

Recent studies (DeLuca, 1973, 1974) have shown that vitamin D must be metabolized to active forms before it can produce its well-known physiologic effects of curing rickets, initiating calcium absorption, and influencing the mobilization of calcium from bones. The first metabolite was identified as 25-hydroxy-vitamin-D_3, produced primarily in the liver and approximately four times more active than D_3 in cure of rickets in rats. The second metabolite identified was 1,25-dihydroxy-vitamin-D_3, produced in the kidney and about five times more active than the first metabolite. There is evidence for feedback regulation of the first metabolite when liver level is elevated. Further hydroxylation of the first metabolite by the kidney results in $1,25(OH)_2D_3$ or $24,25(OH)_2D_3$, depending upon physiological circumstances. It has been suggested that $1,25(OH)_2D_3$ be classified as a hormone involved in calcium absorption from the intestine and mobilization from bone, as well as phosphate transport in the intestine. Synthesis is regulated through plasma calcium level and the parathyroid hormone (low calcium–high parathyroid result in increased synthesis), as well as plasma inorganic phosphate level. Low phosphate increases synthesis even if calcium is above normal. These studies were done on weanling rats or chicks and need to be tested in ruminants.

Information on which to base vitamin D requirements for dairy animals is limited. The recommendation for calves of 660 IU per 100 kg of live weight is well supported (Bechdel *et al.*, 1938). Supplementation of calf rations is indicated when there is minimum exposure to sunlight. Wallis (1944) demonstrated the essentiality of vitamin D for maintenance, reproduction, and lactation, but quantitative requirements are not well defined. About 5,000 to 6,000 IU per cow per day appeared to prevent the symptoms he described.

It has generally been concluded that supplemental vitamin D is unnecessary when animals receive sun-cured forage or are exposed to ultraviolet light or sunlight. Green forage, barn-cured hay, and silage also have significant vitamin D activity (Thomas and Moore, 1951). More recent work (Dobson and Ward, 1974) has suggested some possible advantages of vitamin D supplementation of normal rations, but specific requirements are not elucidated. Ward *et al.* (1971) found that first postpartum estrus occurred 16 days earlier in cows given 300,000 IU of D_3 by capsule weekly than in those fed a similar alfalfa hay-concentrate ration without the supplement. There was no difference in milk production or services per pregnancy. Ward *et al.* (1972) also demonstrated improved utilization of calcium by dairy cows receiving 300,000 IU of supplemental D_3 weekly in addition to that in the natural ration of alfalfa hay and grain. In cows consuming adequate calcium, vitamin D supplementation permitted a positive calcium balance earlier in lactation. In the absence of definitive evidence of additional requirements beyond those listed in the 1971 bulletin, no changes have been made in listed requirements.

The value of vitamin D in the control of parturient paresis has received considerable attention. Hibbs and Conrad (1966) showed that the feeding of massive doses (20 million units of vitamin D per day), starting 3–5 days before expected calving date and continuing through the first day postpartum, with a maximum dosage period of 7 days, reduced the incidence of milk fever. Massive doses for longer periods produced toxicity symptoms. Continuous year-round feeding of 70,000 IU per kilogram of concentrate caused some reduction in milk fever incidence in cows with a previous history of the disease. The vitamin D metabolite, 25-OH-D_3, can be used at lower dosages without the dangers of accumulation and toxicity. Preliminary results, using 1 mg orally every other day prior to calving or 4 mg intramuscularly 4–7 days prior to calving, showed a reduced incidence of milk fever (Jorgensen, 1974). Variable field results appear to be related to phosphorus levels fed immediately prepartum (Frank *et al.*, 1977) and body condition. Recommendations on the use of vitamin D metabolites for milk fever control should await results of further study.

Vitamin E

Experimental vitamin E deficiencies have been produced in calves. They showed essentially the same signs as calves with white muscle disease that developed under field conditions (Safford *et al.*, 1954). The deficiency disease is characterized by generalized muscular dystrophic lesions. The first signs include a weakening of leg muscles, so that the calves walk with a typical crossing of the hind legs. There may be a relaxation of the pastern and splaying of the toes. The musculature of the tongue is affected, impairing the calf's ability to suckle. In advanced stages, the animal may be unable to hold up its head and soon is unable to stand. In one study, 148 mg of alpha-tocopherol acetate prevented development of the disease, but this cannot be taken as a requirement, since other levels were not tested. Supplementation of a skimmed milk diet with as little as 50 mg of alpha-tocopherol acetate protected calves when arachis oil was fed but not when cod liver oil was fed (Blaxter *et al.*, 1952).

Similar signs developed in calves fed filled milks containing high levels of polyunsaturated oils, but not when these oils were hydrogenated (Adams *et al.*, 1959). The feeding of 500 mg *dl*-alpha-tocopherol prevented the problem, but no other levels were tested. Michel *et al.* (1972) showed that there was a greater incidence and severity of degenerative muscle lesions indistinguishable from vitamin E deficiency when calves were fed rations with protein supplied by fish protein concentrate compared to rations with dried skim milk, despite supplementation of all diets with 46 mg vitamin E per kilogram of dry ration. Additional experiments with supplementation of 46 mg or 92 mg vitamin E per kilogram of dry ration showed no muscle lesions in either group but greater weight gain at the higher level when the fish protein was fed. The fish protein supplement contained 1.43 percent polyunsaturated fat.

Gullickson *et al.* (1949) fed four generations of cattle on special diets very low in vitamin E and incapable of supporting reproduction in rats. There were no apparent effects on growth, reproduction, or lactation. However, several animals ranging in age from 21 months to 5 years died suddenly from heart failure. Salisbury (1944) found no benefit from vitamin E supplements for fertility in bulls.

It is apparent that the metabolic role of selenium is linked to that of vitamin E (National Research Council, 1971; Hoekstra, 1975). Some diseases associated with low concentrations of selenium (less than 0.1 ppm) are analogous to those of vitamin E deficiency. In some instances syndromes have responded fully to administration of E. In others, selenium was substantially more effective or induced a further response. It appears that white muscle disease in calves can be caused by a deficiency of selenium or vitamin E, or both, and that it is accentuated by high levels of polyunsaturated oils in the diet.

The feeding of high levels of vitamin E (400–1,000 mg per cow per day) has been helpful in reducing the incidence of oxidized flavor in milk, but the cost is high because the efficiency of transfer into milk is less than 2 percent (King, 1968).

Under most conditions, natural feedstuffs appear to supply adequate quantities of vitamin E for adult cattle. Vitamin E decreases during prolonged storage, and cows fed such feeds may produce milk susceptible to oxidized flavor.

Vitamins K_1 and K_2

Vitamins K_1 and K_2 are fat-soluble, and either of the two is necessary in the blood-clotting mechanism. Green, leafy materials of any kind, fresh or dry, are good sources of vitamin K_1. Vitamin K_2 is normally synthesized in large amounts in the rumen and no need for dietary supplementation has been established (McElroy and Goss, 1940). When moldy sweetclover hay high in dicoumarol is fed, signs of inadequacy may appear. There is reduced clotting time of blood and generalized hemorrhaging. This syndrome is commonly called sweetclover poisoning. It can be treated effectively with vitamin K. No other reports on this vitamin that relate to practical nutrition problems with cattle have been observed.

B Vitamins

B vitamins are synthesized by microflora in the rumen and are relatively abundant in ordinary feeds. Therefore, there is no evidence of a need for B-vitamin supplementation for older animals with a functional rumen (more than about 6 weeks of age) (Clifford *et al.*, 1967). Needs are apparently also met in the young calf receiving milk. However, in the case of young calves fed milk replacers, it is advisable to verify the adequacy of vitamin intakes, and supplementation may be indicated until their rumens are functional. Table 3 gives the minimum quantities of B-complex vitamins suggested for milk replacers.

Benevenga and Ronning (1965) reported a nutritional defect that responded to B-vitamin therapy in calves fed a diet composed of nonfat milk solids and dextrose as the main energy source. Single B-vitamin deficiency syndromes have been identified in young calves fed purified and semipurified diets. However, specific requirements have not been established, and the best recommendations that can be made are based on levels of intake under which deficiencies have not developed.

Thiamine Deficiency of thiamine is characterized by polyneuritis. In the calf, an apparent weakness is usually first exhibited by poor coordination of the legs, especially of the forelimbs, and by the inability to rise and stand. The head is frequently retracted along the shoulder when the calf lies down after exertion. The heart may develop arrhythmia. The specific signs are usually accompanied by anorexia and severe diarrhea, followed by dehydration and death.

On a deficient diet, urinary excretion of thiamine drops to very low levels in 20 to 25 days, and increased pyruvate excretion follows. Blood pyruvate and lactate levels increase suddenly to 400 and 500 percent of normal as the deficiency develops. If the condition is not too advanced, all deficiency signs disappear rapidly after thiamine therapy.

Clinical signs in calves weighing less than 50 kg were prevented with 0.65 mg thiamine-HCl per kilogram of liquid diet fed at 10 percent of live weight (65 μg per kilogram of live weight) (Johnson *et al.*, 1948). Benevenga *et al.* (1966) observed a decrease in urinary excretion at this level of intake in calves.

Clinical reports (Edwin and Lewis, 1971; Sapienza and Brent, 1974) have suggested that under high-concentrate feeding systems of beef cattle and lambs, a thiaminase may become active in the rumen and cause a possible thiamine deficiency in animals with functional rumens. It was suggested that this may accompany lactic acid acidosis and may explain the appearance of polioencephalomalacia (PEM) in grain-fed cattle. The latter condition has been shown to respond to intravenous administration of thiamine (2.2 mg per kilogram of body weight). No reports of problems in adult dairy cattle due to increased thiaminase activity have been observed.

Riboflavin Deficiency of riboflavin in the calf is characterized by hyperemia of the mucosa of the mouth, lesions in the corners of the mouth and along the edge of the lips, and loss of hair, especially on the abdomen. There is copious salivation and lacrimation. Less-specific signs are anorexia, diarrhea, and arrested growth. Urinary excretion of riboflavin drops rapidly on a deficient diet and is essentially nil when gross signs are apparent.

Wiese *et al.* (1947) alleviated signs of the deficiency in calves weighing less than 50 kg with daily oral administration of 5 mg of riboflavin. No deficiency signs appeared when the basal diet contained 0.65 mg per kilogram of liquid fed at 10 percent of live weight (65 μg per kilogram of live weight). Warner and Sutton (1948) suggested that the requirement was less than 75 μg per kilogram of live weight.

Pyridoxine Pyridoxine deficiency has been described in calves on a synthetic diet; gross signs were preceded by anorexia and cessation of growth at 3½ to 10 weeks. In some cases, after 3 months or more, there were epileptoid fits, with thrashing of the legs and head, and grinding of the teeth. These acute signs were not demonstrated by all calves, perhaps because of secondary involvements developing during the relatively long period of deterioration. Pathological studies indicated some demyelination of peripheral nerves, hemorrhages in the epicardium, and evidence of proliferation of Schwann cells. Urinary excretion of pyridoxine and its metabolites decreased markedly. Calves responded to pyridoxal, pyridoxamine, or pyridoxine therapy if initiated before complications developed. Calves on diets furnishing 65 μg per kilogram of live weight apparently were normal (Johnson *et al.*, 1950).

Pantothenic Acid The most characteristic sign of pantothenic acid deficiency in the calf is scaly dermatitis around the eyes and muzzle. Anorexia and diarrhea follow after 11–20 weeks on a deficient diet, and calves become weak and unable to stand and may develop convulsions. They are susceptible to mucosal infection, especially in the respiratory tract. Postmortem studies have revealed some proliferation of Schwann cells and moderate demyelination of the sciatic and peripheral nerves. Some edema in the facial plane of muscular tissue has been indicated. Intramuscular injections of 0.5 g of pantothenic acid the first day, followed by 0.1 g daily thereafter, cured the deficiency in cases not too far advanced. No pantothenic acid deficiency signs were observed with 1.30 mg of Ca pantothenate per kilogram of liquid diet (130 μg per kilogram of live weight) (Sheppard and Johnson, 1957).

Biotin Wiese *et al.* (1946) produced a deficiency of biotin characterized by paralysis of the hind quarters and accompanied by decreased urinary excretion of biotin. In acute cases, single injections of 100 μg of biotin subcutaneously or 1 mg intravenously reversed the signs. No symptoms developed when synthetic milk was supplemented with 10 μg of biotin per kilogram of feed and fed at 10 percent of live weight (1 μg per kilogram of live weight).

Nicotinic Acid A diet free of nicotinic acid and low in tryptophan produced deficiency signs of sudden anorexia, severe diarrhea, and dehydration followed by sudden death. Supplementation with 2.6 mg of nicotinic acid per liter of milk offered *ad libitum* twice daily prevented the deficiency (Hopper and Johnson, 1955). Calves did not require this vitamin when fed a synthetic diet containing considerable tryptophan.

Large doses of nicotinic acid cause an initial inhibition of lipolysis, followed by a rebound with accelerated lipid mobilization in fasted or ketotic ruminants (Waterman and Schultz, 1973). High levels also elevate circulating insulin and reduce glucose tolerance in ruminants (Thornton and Schultz, 1975). Whether there are any benefits of these actions under special conditions has not been established.

Vitamin B_{12} Lassiter *et al.* (1953) demonstrated vitamin B_{12} deficiency in calves less than 6 weeks old that were fed a diet containing no animal protein. Signs characterizing the deficiency included poor appetite and growth, muscular weakness, and poor general condition. However, this may have been complicated by other nutritional defects associated with the quality of protein in the diet. It was suggested that the requirement of vitamin B_{12} is between 0.34 and 0.68 μg per kilogram of live weight.

Walker and Elliot (1972) demonstrated that roughage restriction in dairy cows resulted in lower liver and milk and higher urine vitamin B_{12} activity. Although serum B_{12} was higher, it was suggested that this might be due to vitamin B_{12} analogues that were bound in the serum and excreted in urine but not taken up by liver or secreted in milk.

Folic Acid Folic acid deficiency has not been described in the calf but has been produced in lambs fed certain synthetic-milk diets (Draper and Johnson, 1952). The disease was characterized by leukopenia, followed by diarrhea, pneumonia, and death. Folic acid therapy promoted regeneration of white cells, and 0.39 mg per liter in the diets of control animals prevented development of the disease. There was no indication of this deficiency disease in calves fed a synthetic milk containing 52 μg of folic acid per kilogram of liquid feed fed at 10 percent of live weight (Wiese *et al.*, 1947).

Choline An apparent choline-deficiency syndrome has been produced with a synthetic diet containing 15 percent casein. Within 6–8 days calves developed extreme weakness and labored breathing and were unable to stand. Supplementation of the diet with 260 mg of choline per liter of synthetic milk prevented development of these signs (Johnson *et al.*, 1951).

WATER

Dairy cattle suffer more quickly and severely from a lack of water than from a deficiency of any other nutrient. Of all farm animals, dairy cows in milk require the greatest amount of water in proportion to their size because water constitutes 85–87 percent of the milk they yield. In addition, the bodies of most cows contain 55–65 percent of water; very fat cows may have less than 50 percent, and very thin cows may have as much as 70 percent of water (Reid *et al.*, 1955). In a hot, dry climate, cattle wholly deprived of water lost their appetites almost completely by the fourth day of dehydration (Weeth *et al.*, 1967). The weight loss was equivalent to 16 percent of the body weight.

A restricted intake of water lowers the feed intake (Utley *et al.*, 1970), the retention of nitrogen, and the loss of nitrogen in the feces; but it results in an increased excretion of urea in the urine (Thornton and Yates, 1969). Cattle that are gaining weight require more water than those that are losing weight (Leitch and Thomson, 1944).

Many conditions determine the amount of fluid water that cattle will consume. These are: the amount of dry matter and salt ingested, ambient temperature, humidity, breed, body size, milk yield, and the amount of water and protein in the feed. The intake of water by cows increases with increasing intakes of dry matter (Kamal *et al.*, 1962; Owen *et al.*, 1968; Paquay *et al.*, 1970; Ragsdale *et al.*, 1950, 1951; Utley *et al.*, 1970; Winchester and Morris, 1956) and increasing temperature of the air (Kamal *et al.*, 1962; Ragsdale *et al.*, 1950, 1951; Winchester and Morris, 1956). The ingestion of feeds high in water reduces the cow's voluntary consumption of fluid water (Paquay *et al.*, 1970; Sykes, 1955; Winchester and Morris, 1956). Increasing the wind velocity up to 10 miles per hour resulted in a slightly lower consumption of water by cows of European breeds at air temperatures of 10°C to 26.7°C; at a temperature of 35°C, water consumption was about the same at velocities of 0.4 and 10 miles per hour (Brody *et al.*, 1954). Under conditions of high humidity, cows consume less water than they do at low levels of humidity, and the difference becomes more marked as the ambient temperature increases (Ragsdale *et al.*, 1953). Presumably, this effect reflects in part the lower intake of feed and in part the reduced vaporization of moisture at high humidities.

At the same ambient temperature, cattle of the European breeds (*Bos taurus*) consume considerably more water than do Indian cattle (*Bos indicus*) on the basis of both per unit of body weight and per unit of dry matter ingested (Ragsdale *et al.*, 1950, 1951; Winchester and Morris, 1956). The difference in water intake between the European and Indian cattle becomes decidedly greater as the temperature of the air increases.

For each kilogram of dry matter ingested, dairy cattle of European origin consume about 3.1 kg of water within the ambient temperature range, −12°C to 4.4°C; as the air temperature increases from 4.4°C, to 26.7°C, water intake increases almost linearly from 3.1 to 5.2 kg per 1 kg of dry matter consumed; and as the temperature increases from 26.7°C to 37.8°C, the ratio of water to dry matter increases at an increasing rate from 5.2 to 15.6 (Winchester and Morris, 1956). These values represent those of nonlactating cattle. Since the dry matter intake of large cows is greater than that of small cows, the absolute volume of water consumed increases with increasing body size.

Lactating cows will consume the following amounts (in kilograms) of water at certain ambient temperatures for each kilogram of milk produced: 4.4°C, 2.08; 10°C, 2.17; 15.6°C, 2.42; 21.1°C, 2.67; 26.7°C, 2.92; and 32.2°C, 3.83. These needs are in addition to the intake of water for maintenance. A nonpregnant cow weighing 635 kg and producing 36 kg of milk per day will consume about 102 kg of water daily when the ambient temperature is 4.4°C, and 174 kg of water per day when the air temperature is 32.2°C, according to Winchester and Morris (1956). Additional water will be consumed during the last 3 months of pregnancy.

Water intake is markedly affected by the nature of the diet. Diets high in salt or protein are associated with higher water intakes than are those low in these substances (Sykes, 1955; Weeth and Haverland, 1961). The teleologically unexpected observation was made recently (Whitlock *et al.*, 1975) that salt(sodium)-deficient dairy cows exhibit signs of extreme thirst and polyuria. Diets high in pentosans and crude fiber result in increased losses of water in the feces and, therefore, in increased water intakes (Paquay *et al.*, 1970).

The characteristics of the water also influence its consumption. Growing cattle tolerate concentrations of NaCl in water up to 1 percent; higher levels are toxic (Weeth and Haverland, 1961). As the concentration of salt is increased to 1.2 percent, the intake of water increases; higher concentrations reduce the water intake.

No difference in the performance of lactating cows was observed when they drank hard (33 ppm of calcium plus magnesium) or soft (1 ppm) water (Blosser and Soni, 1957). Other elements, such as iron, aluminum, zinc, manganese, and strontium, can contribute to the hardness of water. Although hardness per se does not affect the performance of cattle, some of the elements causing water hardness could be toxic when present in unusually high concentrations.

Most natural waters range in pH from 6 to 9. Water from some springs sometimes has a pH above 9, and circumstances resulting in sulfur oxidation reactions can result in a pH lower than 6, e.g., drainage from mines. Apparently, water within a pH range of 6–9 is satisfactory for cattle (National Research Council, 1974).

It long has been known that cattle are sometimes poisoned when they drink lake water invaded by blue-green algae. Since at least six species have been identified as potential causes of toxicity (Gorham, 1964), cattle should be prevented from drinking water with a heavy algal growth.

The temperature of the water affects the amounts of water consumed and the performance of cattle. In cold weather cows will drink more water if it is warmed somewhat above the ambient temperature (Cannon *et al.*, 1932); however, the main benefit of warming the water is the prevention of its freezing. Under high environmental temperatures (29°C–30°C), cooling the temperature of the drinking water from 31.1°C to 18.3°C resulted in a reduction in water consumption of 3.6 to 4.5 kg per day, in a 10–12 percent reduction in the respiration rate, and in a 36 percent increase in the rate of body gain of beef cattle (Ittner *et al.*, 1951). It needs to be determined whether milking cows in high-temperature regions would benefit sufficiently from the cooling of water to justify the energy expense of cooling.

SPECIAL ASPECTS OF DAIRY CATTLE NUTRITION

Fat

The newborn dairy calf requires some fat in the diet until the rumen becomes functional (Cunningham and Loosli, 1954), but the adult ruminant may not require dietary lipids for normal rumen function or for growth (Oltjen and Williams, 1974). Ruminal microorganisms apparently can suffice as a source of lipid constituents for the host animal. Forages are low in lipid, usually less than 3 percent, and the grain portion of most rations is about 3–4 percent lipid. However, there is a need for concern about supplying adequate fat only in the case of the young calf. A level of 10 percent fat in milk replacers appears to be sufficient to supply essential fatty acids, carry fat-soluble vitamins, and supply adequate energy for normal gains. Higher levels accelerate gains in veal calves (Radostitts and Bell, 1970). A minimum of 2 percent ether extract in diets for older animals is being suggested under practical conditions (Table 3).

Because of the increased caloric density provided by fat and improved physical characteristics of processed feeds due to reduced dust and feed wastage, limited additions of fat or oils to ruminant rations are sometimes made. Cost is usually a limiting factor. In addition, there are other limitations in the feeding of fats or oils to dairy animals (Oltjen, 1975). Levels of added fats or oils above about 5 percent of the ration can have adverse effects on animal performance. There is usually a decrease in the digestibility of cellulose. Feed intake may be reduced. Fecal soaps are increased, although the true digestion coefficient of the added fat is still about 95 percent after correction for fecal soaps. When added fat is fed to milking cows, milk production is usually not altered, but milk fat content and composition may be changed. Saturated fats tend to cause a slight temporary increase in milk fat percentage, while the unsaturated oils, even in amounts as low as 250 ml daily, depress milk fat percentage. Oils containing high levels of 18:2 or more highly unsaturated fatty acids have the greatest milk-fat-depressing effect. There is a partial hydrogenation in the rumen, with 18:1 fatty acids being increased to the greatest extent in milk. Dividing the same amount into several daily feedings or feeding the oil as a component of the original seed, such as ground whole soybeans, reduces or eliminates the effect. Placing the oils in the abomasum or protecting them from rumen action also prevents the fat depression. Under these conditions unsaturation of milk fat is increased, but the oxidative stability of the milk is decreased (Schultz, 1974).

Recent Ohio studies (Palmquist, 1976) suggest that in early lactation adding fat to the grain mix may aid in maintaining milk fat test by allowing substitution of forage for grain, thus increasing fiber content while maintaining energy intake. The energetic efficiency and economic aspects of such fat additives will determine their practicality (Palmquist, 1976).

Roughage

Roughage in the proper quantity and physical form is necessary in dairy rations to maintain normal milk fat percentage (Chalupa *et al.*, 1970; Van Soest, 1963), to prevent displaced abomasum (Coppock, 1974), and possibly to aid in control of other postcalving disorders. A number of thumb rules have been developed suggesting, for example, that at least one-third of the total ration dry matter should be long hay or its dry matter equivalent in silage or other coarse roughage, that each cow should receive a minimum of 1.5 percent of her body weight daily as hay equivalent, or that the total ration should contain a certain amount of fiber. Lofgren and Warner (1970) suggested that, of the fiber fractions analyzed, acid-detergent fiber and crude fiber were the best indices of the ability of a diet to increase a depressed fat percentage. A level of 19.4 percent acid-detergent fiber and 17.3 percent crude fiber in the diet (dry matter) maintained fat percentage at essentially normal levels. Acid-detergent fiber was the preferred analysis, showing the highest correlation with fat test change.

There are obvious problems with the thumb rules because of difficulties in determining the "hay equivalent" of different feeds and the fact that physical form is not taken into account in the fiber determination. Grinding, with or without pelleting, or fine chopping reduces the effectiveness of the roughage. O'Dell *et al.* (1968) found that milk fat was depressed by feeding hay processed through a 0.64-cm screen, but not with that through a 0.95-cm screen. McCoy *et al.* (1966) found that hay fed at a level of 30 percent of the ration and chopped through a 2.54-cm screen maintained a normal test, as did corncobs at the same level ground through a 1.59-cm screen. Balch (1971) and Sudweeks and Holmes (1975) have suggested use of a "roughage value index" based on chewing time (both eating and cud chewing) per kilogram of dietary dry matter. This or other systems should prove useful in establishing specific animal requirements for roughage in the future, but are not adequately developed to include in this revision. Therefore, minimum crude fiber levels of 15 percent of ration dry matter for heifers and bulls, and 17 percent for lactating and dry cows, are being suggested (Table 3). In establishing this level, it is assumed that physical form is coarse enough to prevent any adverse influences of this factor. Adequate coarse roughage before and after calving appears to be important in preventing displaced abomasum, which occurs most often in early lactation.

In this discussion "roughage" has been used as an all-inclusive term for the more fibrous feeds, in contrast to "concentrates." The term "forage" is sometimes used interchangeably with "roughage."

Metabolic Disorders

Several metabolic disorders that may be related to nutrition occur in dairy cattle. Most of these occur at or shortly after parturition and represent a failure of the cow to adjust to the rapid onset and stress of high production.

Udder edema, characterized by excessive accumulation of fluid in the intercellular spaces of the udder and forward of it and usually occurring at calving time, sometimes develops to a serious magnitude before calving. The cause is not well understood, but a reduction of blood proteins at calving time and increased blood flow without compensatory lymph removal have been suggested. Most studies (Emery *et al.*, 1969; Schmidt and Schultz, 1959) show little relationship of the condition to level of grain feeding before calving except in the former experiment in the case of heifers self-fed grain before calving. Randall *et al.* (1974) have suggested that high intakes of sodium chloride or potassium chloride (227 g per day) increase the severity of udder edema and that restriction of salt intake could reduce the severity. It was suggested that the increase in edema observed in heifers in the study of Emery *et al.* (1969) was due to the inclusion of high levels of salt in the grain mix rather than increased concentrate feeding.

Milk fever is characterized by low blood calcium and paralysis, usually within 48 hours postcalving, in cows beyond first lactation. Incidence is accentuated by high calcium intake during the dry period and reduced by limiting calcium intake before calving but increasing it at calving time. A discussion of control procedures appears in the calcium section.

Ketosis or acetonemia is usually characterized by inappetence and dullness and most often occurs during the first 6 weeks following calving, with peak incidence at about 3 weeks. Occasionally, the animals are highly excitable. Blood glucose is depressed and ketones and free fatty acids are elevated. Current evidence suggests that the major causative factor is an inadequate supply of glucose precursors to maintain an adequate blood glucose level. Control involves liberal concentrate feeding after calving, but with palatable, balanced rations that meet minimum roughage requirements. Feeding of propylene glycol at levels of 125–250 gm daily during the ketosis-susceptible period to problem cows may be helpful (Schultz, 1971).

The "fat cow syndrome" is a poorly defined condition characterized by inappetence and rapid fatty liver development following calving in cows that are excessively fat and have disease or stress complications at calving. Treatment is not very effective. Control involves care to avoid overconditioning while dry, and feeding of adequate roughage at calving time (Morrow, 1976).

Nonnutritive Additives

Antibiotics are widely used in feeds for dairy calves. Young calves, particularly those exposed to adverse conditions of sanitation, housing, and disease, respond favorably to the oral administration of some of the antibiotics, such as chlortetracycline and oxytetracycline (Lassiter, 1955). The greatest benefits from antibiotic feeding accrue when calves are started on the antibiotic as soon as possible after birth (Bartley *et al.*, 1954). Benefit is seldom obtained from feeding antibiotics beyond 4 months of age. Most of the benefit occurs during the milk or replacer feeding period. Response to the antibiotic feeding involves mainly increased growth due to improved appetite and feed consumption, along with prevention of diarrhea. Under most circumstances antibiotic levels of 20–40 ppm in milk replacer on a dry basis or equivalent amount of whole milk and 10–20 ppm in starter appear to be adequate for promoting growth. Higher levels (50–100 ppm in milk replacer or 25–50 ppm in starter) are required for prevention or reduction of diarrhea.

Low-level feeding of antibiotics to calves needs to be re-examined to ensure that this practice is of value in present-day formulations and that drug-resistant organisms are not induced.

Although some studies have reported slight increases in milk production with low-level feeding of antibiotics to dairy cows, this practice is not recommended. The disadvantages, such as the possibility of drug-resistance and antibiotics in the milk, appear to outweigh any advantages.

Detailed information on current legal requirements regarding use of antibiotics may be found in the *Feed*

Additive Compendium, published each year by the Miller Publishing Company, 2501 Wayzata Boulevard, Minneapolis, Minn. 55440. For official information concerning Food and Drug Administration approval of antibiotics and other animal drugs, the *Code of Federal Regulations* (CFR) should be consulted. The CFR is kept up to date by the individual issues of the *Federal Register*.

The inclusion in dairy cattle rations of materials with hormone activity for the purpose of increasing milk production has received periodic attention for many years. Current evidence does not warrant recommending the use of such materials. Feeding of thyroprotein after 50 days postpartum resulted in initial increases in production but less production from the twenty-second to forty-second week of lactation. Differences in total lactation milk yield, fat test, and milk protein were not statistically significant (Schmidt *et al.*, 1971). Although there is some evidence that feeding low levels of estrogens can stimulate milk production, legal limitations preclude such use.

Special feed additives classified as "buffers" have received attention for the prevention or correction of low milk fat percentage observed on high-concentrate rations. Grain additives that have been partially effective are sodium bicarbonate, with or without magnesium oxide, and sodium bentonite. Thomas and Emery (1969) suggested 1 percent sodium bicarbonate and 0.5 percent magnesium oxide in the grain mixture as a practical level for the purpose of controlling milk fat depression. Fat test was maintained at about 90 percent of normal with approximately this level compared to 75 percent of normal without the additives. Grain intake was reduced somewhat. Rindsig and Schultz (1969) fed sodium bentonite at a level of 5 percent of the grain mix in a fat-depressing ration. Fat percentage was maintained at 87 percent of normal compared to 60 percent of normal without the additive. Grain intake was not altered. Further studies (Rindsig and Schultz, 1970) showed small reductions in phosphorus and magnesium balance in bentonite-fed animals. Sodium bicarbonate elevated rumen pH and increased the acetate:propionate ratio. Bentonite caused similar changes in rumen acids without altering pH. It is apparent that these materials are not completely effective in restoring fat test and may have certain other disadvantages, such as adverse effects on feed intake or mineral balance. There is no evidence that they will increase milk fat percentage of cows fed normal rations. Therefore, except for special situations, the method of choice for control of milk fat depression is the inclusion of adequate roughage in the ration.

USING TABLES OF NUTRIENT REQUIREMENTS

The nutrient requirements presented in Tables 1 and 2 can be used to calculate feeding programs for all classes of dairy cattle. Recommended concentrations of nutrients in the ration dry matter for all classes of dairy cattle are listed in Table 3. Table 1 has been revised from previous editions by listing several daily growth rates at each body weight. The different growth rate requirements can be used for calculating feed if gains different than those designated as normal for large-breed (L) or small-breed (S) cattle are desired. Feed dry matter (DM) listed for each class is based on nearly maximum forage intakes under practical conditions. It is presented only as a guide to expected feed intake and may be conservative in ideal conditions of health, housing, and management. Feed requirements in Table 1 were computed from daily NE_g and NE_m requirements to determine the concentration of net energy required in feeds to equal the expected dry matter consumption. Crude protein computation was made factorially (see pp. 5–6) on the basis of animal size, rate of gain, feed intake, and feed digestibility. Maintenance for lactating cows and lactation requirements in Table 2 are based upon a feed concentration of 1.52 Mcal NE_l per kilogram DM (67 to 68 percent TDN). Maintenance for dry, pregnant cows is based upon a feed concentration of 1.42 Mcal NE_l per kilogram (63 percent TDN). Requirements in Table 2 are presented as guides for average use. Tables 1, 2, and 3 are in the metric system. Tables 1A, 2A, and 3A are equivalent to Tables 1, 2, and 3, but weights are entirely in pounds.

Using Table 3: Recommended Nutrient Content of Rations for Dairy Cattle

Table 3 contains recommended nutrient concentrations in the ration dry matter for lactating cows, dry cows, mature bulls, growing heifers and bulls, calf starter concentrate mixes, and calf milk replacers. Recommended levels for many of the nutrients, particularly the minor mineral elements, are based on very limited data. Also, many feeds vary widely in their mineral content, and values for some of the trace elements are unavailable on many feeds (Table 4).

Recommended nutrient concentrations in Table 3 include safety factors to ensure that requirements are fulfilled under a wide variety of practical conditions. Therefore, they should be considered as practical allowances rather than minimum requirements.

The last column of Table 3 lists maximum concentrations of mineral elements to avoid toxicity. Many of these maximum values are based on very limited data and may be modified as additional data become available.

Ration formulation can be based on amounts of nutrients required daily as listed in Tables 1 and 2, or based on concentrations of nutrients shown in Table 3. The example in Table 5 illustrates the formulation of a ration based on Table 2 data. However, data are inadequate to express requirements in this manner for many nutrients, particularly mineral elements. Furthermore, there is a trend toward group-feeding of complete rations (roughages and concentrates mixed together) to cows with similar nutrient requirements. Under these conditions, the ration is based on concentrations of nutrients recommended for the range of cow weights and levels of milk production in the group, rather than the requirement of an individual cow. The ration is fed to the group essentially *ad libitum*, but amounts are varied according to the appetites of the cows such that there is minimum carry-over from one feeding to the next. Nutrient concentrations listed in Table 3 are essential for formulation of rations under these conditions.

Concentrate mixes formulated by feed companies often are based on nutrient concentrations, depending on the types and amounts of roughages that they are designed to supplement. Nutrient concentrations also are essential for computer formulation of least-cost rations and for rations that maximize income above feed cost. Thus, the data in Table 3 can be very valuable for a wide variety of practical dairy cattle feeding situations.

Use of Table 3 for Lactating Cow Rations

Nutrient concentrations are listed for cows ranging in body weight from 400 to 700 kg. For cows weighing less than 400 kg, use the recommendations for the 400-kg cows; for cows above 700 kg, use the 700-kg values. For each body weight, there are nutrient concentrations recommended for four ranges in milk production.

Example What should be the concentration of crude protein, NE_l, crude fiber, calcium, and phosphorus in the ration dry matter for a group of cows with a mean body weight of 600 kg and a mean milk production of 25 kg per day?

In Table 3, under "Lactating Cow Rations," find the row for a "Cow Wt" of 600 kg. Read across that row to the third column under "Daily Milk Yield (kg)," which lists the range "21–29." Read down that column for the recommended nutrient concentrations in the ration dry matter. These would be 15 percent crude protein, 1.62 Mcal/kg NE_l, 17 percent crude fiber, 0.54 percent calcium, and 0.38 percent phosphorus.

TABLE 1 Daily Nutrient Requirements of Dairy Cattle

				Feed Energy					Total Crude	Minerals		Vitamins	
Body Weight (kg)	Breed Size, Age (wk)	Daily Gain (g)	Feed DM (kg)	NE_m (Mcal)	NE_g (Mcal)	ME (Mcal)	DE (Mcal)	TDN (kg)	Protein (g)	Ca (g)	P (g)	A (1,000 IU)	D (IU)
Growing Dairy Heifer and Bull Calves Fed Only Milk													
25	S-1[a,b]	300	0.45	0.85	0.53	2.14	2.38	0.54	111	6	4	1.1	165
30	S-3	350	0.52	0.95	0.63	2.49	2.77	0.63	128	7	4	1.3	200
42	L-1	400	0.63	1.25	0.70	2.98	3.31	0.75	148	8	5	1.8	280
50	L-3	500	0.76	1.40	0.90	3.61	4.01	0.91	180	9	6	2.1	330
Growing Dairy Heifer and Bull Calves Fed Mixed Diets													
50		300	1.31	1.45	0.57	3.91	4.45	1.01	150	9	6	2.1	330
50	S-10	400	1.40	1.45	0.76	4.36	4.94	1.12	176	9	6	2.1	330
50	L-3	500	1.45	1.45	0.96	4.82	5.42	1.23	198	10	6	2.1	330
50		600	1.45	1.45	1.16	5.01	5.69	1.29	221	11	7	2.1	330
50		700	1.45	1.45	1.35	5.36	5.95	1.35	243	12	7	2.1	330
75		300	2.10	1.96	0.58	5.17	6.05	1.37	232	11	7	3.2	495
75		400	2.10	1.96	0.77	5.56	6.53	1.46	254	12	7	3.2	495
75	S-19	500	2.10	1.96	0.98	5.96	6.94	1.55	275	13	7	3.2	495
75		600	2.10	1.96	1.17	6.36	7.31	1.64	296	14	8	3.2	495
75	L-10	700	2.10	1.96	1.37	6.71	7.67	1.72	318	15	8	3.2	495
75		800	2.10	1.96	1.56	7.08	7.94	1.80	341	16	8	3.2	495
Growing Dairy Heifers													
100		300	2.80	2.43	0.60	6.27	7.45	1.69	317	14	7	4.2	660
100		400	2.80	2.43	0.84	6.78	7.96	1.81	336	15	8	4.2	660
100	S-26	500	2.80	2.43	1.05	7.17	8.35	1.89	360	16	8	4.2	660
100		600	2.80	2.43	1.26	7.64	8.81	2.00	380	17	9	4.2	660
100	L-16	700	2.80	2.43	1.47	8.09	9.26	2.10	402	18	9	4.2	660
100		800	2.80	2.43	1.68	8.47	9.63	2.18	426	19	10	4.2	660
150		300	4.00	3.30	0.72	8.44	10.14	2.30	433	16	10	6.4	990
150		400	4.00	3.30	0.96	8.90	10.59	2.40	455	17	11	6.4	990
150	S-40	500	4.00	3.30	1.20	9.42	11.11	2.52	474	17	11	6.4	990
150		600	4.00	3.30	1.44	9.97	11.65	2.64	491	18	11	6.4	990
150	L-26	700	4.00	3.30	1.68	10.49	12.17	2.76	510	19	12	6.4	990
150		800	4.00	3.30	1.92	11.03	12.70	2.88	528	20	12	6.4	990
200		300	5.00	4.10	0.84	10.44	12.57	2.85	533	18	12	8.5	1320
200		400	5.20	4.10	1.12	11.20	13.41	3.04	571	19	13	8.5	1320
200	S-54	500	5.20	4.10	1.40	11.86	14.06	3.19	586	20	13	8.5	1320
200		600	5.20	4.10	1.68	12.39	14.59	3.31	604	21	14	8.5	1320
200	L-36	700	5.20	4.10	1.96	13.01	15.20	3.45	620	21	14	8.5	1320
200		800	5.20	4.10	2.24	13.52	15.70	3.56	640	22	15	8.5	1320
250		300	5.89	4.84	0.93	12.05	14.55	3.30	610	20	15	10.6	1650
250		400	6.30	4.84	1.24	13.15	15.83	3.59	665	21	15	10.6	1650
250	S-69	500	6.30	4.84	1.55	13.81	16.49	3.74	678	22	16	10.6	1650
250		600	6.30	4.84	1.86	14.57	17.24	3.91	689	22	16	10.6	1650
250	L-47	700	6.30	4.84	2.17	15.20	17.86	4.05	704	23	17	10.6	1650
250		800	6.30	4.84	2.48	15.82	18.47	4.19	719	23	17	10.6	1650
300		300	6.67	5.55	1.02	13.64	16.47	3.74	671	20	15	12.7	1980
300		400	7.00	5.55	1.36	14.80	17.77	4.03	713	22	17	12.7	1980
300	S-83	500	7.20	5.55	1.70	15.69	18.74	4.25	746	23	17	12.7	1980
300		600	7.20	5.55	2.04	16.49	19.53	4.43	755	23	17	12.7	1980
300	L-57	700	7.20	5.55	2.38	17.07	20.11	4.56	771	24	18	12.7	1980
300		800	7.20	5.55	2.72	17.83	20.86	4.73	782	24	18	12.7	1980
350		300	7.23	6.24	1.08	15.27	18.34	4.16	701	22	16	14.8	2310
350	S-97	400	7.42	6.24	1.44	15.99	19.14	4.34	738	23	17	14.8	2310
350		500	8.00	6.24	1.80	17.42	20.81	4.72	804	25	18	14.8	2310
350		600	8.00	6.24	2.16	18.21	21.60	4.90	812	25	19	14.8	2310
350	L-67	700	8.00	6.24	2.52	18.88	22.26	5.05	826	25	19	14.8	2310
350		800	8.00	6.24	2.88	19.56	22.93	5.20	841	26	19	14.8	2310

TABLE 1 Daily Nutrient Requirements of Dairy Cattle—Continued

				Feed Energy					Total	Minerals		Vitamins	
Body Weight (kg)	Breed Size, Age (wk)	Daily Gain (g)	Feed DM (kg)	NE_m (Mcal)	NE_g (Mcal)	ME (Mcal)	DE (Mcal)	TDN (kg)	Crude Protein (g)	Ca (g)	P (g)	A (1,000 IU)	D (IU)
400	S-115	200	7.26	6.89	0.76	14.85	17.94	4.07	692	21	16	17.0	2640
400		400	8.50	6.89	1.52	17.76	21.38	4.85	833	24	19	17.0	2640
400		600	8.60	6.89	2.28	19.61	23.24	5.27	856	25	20	17.0	2640
400	L-77	700	8.60	6.89	2.66	20.40	24.03	5.45	864	25	20	17.0	2640
400		800	8.60	6.89	3.04	21.11	24.73	5.61	876	26	21	17.0	2640
450		200	7.87	7.52	0.80	16.09	19.44	4.41	749	23	18	19.1	2970
450		400	9.00	7.52	1.60	19.02	22.84	5.18	867	26	20	19.1	2970
450		600	9.10	7.52	2.40	21.03	24.87	5.64	883	27	21	19.1	2970
450	L-87	700	9.10	7.52	2.80	21.82	25.66	5.82	892	27	21	19.1	2970
450		800	9.10	7.52	3.20	22.67	26.50	6.01	898	28	21	19.1	2970
500		200	8.46	8.14	0.84	17.30	20.90	4.74	788	24	19	21.2	3300
500		400	9.50	8.14	1.68	20.26	24.29	5.51	900	27	21	21.2	3300
500	L-98	600	9.50	8.14	2.52	22.26	26.28	5.96	903	27	21	21.2	3300
500		800	9.50	8.14	3.36	24.00	28.00	6.35	916	28	21	21.2	3300
550		200	9.05	8.75	0.88	18.50	22.34	5.07	835	25	19	23.3	3630
550	L-109	400	9.80	8.75	1.76	21.33	25.48	5.78	913	27	20	23.3	3630
550		600	9.80	8.75	2.64	23.38	27.51	6.24	914	27	20	23.3	3630
550		800	9.80	8.75	3.52	25.08	29.19	6.62	928	28	21	23.3	3630
600	L-127	200	9.58	9.33	0.90	19.60	23.68	5.37	879	25	18	25.4	3960
600		300	9.72	9.33	1.35	20.78	24.87	5.64	895	25	18	25.4	3960
600		400	10.00	9.33	1.80	22.22	26.45	6.00	918	26	19	25.4	3960
600		500	10.00	9.33	2.25	23.34	27.56	6.25	916	26	19	25.4	3960
Growing Dairy Bulls													
100		500	2.80	2.43	1.05	7.17	8.35	1.89	361	16	8	4.2	660
100	S-26	600	2.80	2.43	1.26	7.64	8.81	2.00	381	17	9	4.2	660
100		700	2.80	2.43	1.47	8.09	9.26	2.10	403	18	9	4.2	660
100	L-15	800	2.80	2.43	1.68	8.47	9.63	2.18	427	19	10	4.2	660
100		900	2.80	2.43	1.89	8.84	10.00	2.27	450	20	10	4.2	660
150		500	4.00	3.30	1.15	9.42	11.11	2.52	476	18	11	6.4	990
150		600	4.00	3.30	1.38	9.91	11.59	2.63	497	19	11	6.4	990
150	S-38	700	4.00	3.30	1.61	10.30	11.98	2.72	520	20	12	6.4	990
150		800	4.00	3.30	1.84	10.84	12.52	2.84	539	21	12	6.4	990
150		900	4.00	3.30	2.07	11.47	13.14	2.98	555	21	13	6.4	990
150	L-24	1000	4.00	3.30	2.30	11.73	13.40	3.04	583	22	13	6.4	990
200		500	5.20	4.10	1.25	11.46	13.66	3.10	602	20	13	8.5	1320
200		600	5.20	4.10	1.50	12.01	14.21	3.22	622	21	14	8.5	1320
200	S-48	700	5.20	4.10	1.75	12.59	14.78	3.35	640	21	14	8.5	1320
200		800	5.20	4.10	2.00	13.07	15.26	3.46	660	22	15	8.5	1320
200		900	5.20	4.10	2.25	13.52	15.70	3.56	688	23	16	8.5	1320
200	L-31	1000	5.20	4.10	2.50	14.05	16.23	3.68	702	23	16	8.5	1320
250		500	6.30	4.84	1.35	13.44	16.11	3.65	684	22	16	10.6	1650
250		600	6.30	4.84	1.62	14.00	16.67	3.78	702	23	16	10.6	1650
250	S-58	700	6.30	4.84	1.89	14.62	17.28	3.92	718	23	17	10.6	1650
250		800	6.30	4.84	2.16	15.20	17.86	4.05	736	24	17	10.6	1650
250		900	6.30	4.84	2.43	15.78	18.43	4.18	753	25	17	10.6	1650
250	L-38	1000	6.30	4.84	2.70	16.13	18.78	4.26	778	25	18	10.6	1650
300		500	7.33	5.69	1.48	15.45	18.56	4.21	777	24	18	12.7	1980
300		600	7.40	5.69	1.77	16.13	19.27	4.37	800	25	19	12.7	1980
300	S-68	700	7.40	5.69	2.07	16.89	20.02	4.54	811	26	19	12.7	1980
300		800	7.40	5.69	2.36	17.51	20.63	4.68	827	26	19	12.7	1980
300		900	7.40	5.69	2.66	18.09	21.21	4.81	845	27	19	12.7	1980
300	L-45	1000	7.40	5.69	2.95	18.67	21.78	4.94	862	27	20	12.7	1980
350		500	8.10	6.54	1.60	17.27	20.71	4.70	828	25	19	14.8	2310
350		600	8.30	6.54	1.92	18.13	21.65	4.91	863	26	20	14.8	2310
350	S-79	700	8.30	6.54	2.24	18.93	22.44	5.09	873	27	20	14.8	2310
350		800	8.30	6.54	2.56	19.60	23.10	5.24	887	27	20	14.8	2310

TABLE 1 Daily Nutrient Requirements of Dairy Cattle—Continued

Body Weight (kg)	Breed Size, Age (wk)	Daily Gain (g)	Feed DM (kg)	Feed Energy: NE_m (Mcal)	NE_g (Mcal)	ME (Mcal)	DE (Mcal)	TDN (kg)	Total Crude Protein (g)	Minerals: Ca (g)	P (g)	Vitamins: A (1,000 IU)	D (IU)
350		900	8.30	6.54	2.88	20.22	23.72	5.38	903	28	20	14.8	2310
350	L-52	1000	8.30	6.54	3.20	20.89	24.38	5.53	917	28	21	14.8	2310
400		500	9.00	7.41	1.75	19.24	23.06	5.23	891	27	21	17.0	2640
400		600	9.00	7.41	2.10	20.00	23.81	5.40	902	27	21	17.0	2640
400	S-89	700	9.00	7.41	2.45	20.84	24.64	5.59	910	28	22	17.0	2640
400		800	9.00	7.41	2.80	21.60	25.40	5.76	921	28	22	17.0	2640
400		900	9.00	7.41	3.15	22.36	26.15	5.93	932	28	22	17.0	2640
400	L-60	1000	9.00	7.41	3.50	22.93	26.72	6.06	947	29	23	17.0	2640
450		200	8.41	8.27	0.76	17.20	20.77	4.71	762	23	19	19.1	2970
450		400	9.33	8.27	1.52	19.90	23.86	5.41	868	27	21	19.1	2970
450	S-90	600	9.50	8.27	2.28	21.83	25.84	5.86	898	28	22	19.1	2970
450		800	9.50	8.27	3.04	23.52	27.52	6.24	914	28	22	19.1	2970
450	L-67	1000	9.50	8.27	3.80	25.08	29.07	6.59	934	29	23	19.1	2970
500		100	8.26	8.95	0.40	16.90	20.41	4.63	740	22	18	21.2	3300
500		300	9.30	8.95	1.20	19.83	23.77	5.39	855	25	21	21.2	3300
500	S-111	500	10.00	8.95	2.00	22.22	26.45	6.00	941	28	23	21.2	3300
500		700	10.00	8.95	2.80	23.60	27.82	6.31	967	29	23	21.2	3300
500	L-74	900	10.00	8.95	3.60	25.56	29.76	6.75	973	29	23	21.2	3300
550		100	8.86	9.62	0.42	18.11	21.87	4.96	789	24	18	23.3	3630
550	S-125	300	10.20	9.62	1.25	21.29	25.62	5.81	935	28	22	23.3	3630
550		500	10.50	9.62	2.08	23.56	28.00	6.35	967	29	22	23.3	3630
550	L-82	700	10.50	9.62	2.91	25.51	29.94	6.79	976	29	22	23.3	3630
550		900	10.50	9.62	3.74	27.16	31.57	7.16	994	30	23	23.3	3630
600	S-149	100	9.42	10.27	0.43	19.27	23.28	5.28	833	25	19	25.4	3960
600		300	10.52	10.27	1.29	22.44	26.90	6.10	947	28	22	25.4	3960
600		500	10.80	10.27	2.15	24.72	29.28	6.64	980	29	23	25.4	3960
600	L-92	700	10.80	10.27	3.01	26.58	31.13	7.06	988	29	23	25.4	3960
650		100	9.96	10.90	0.44	20.37	24.60	5.58	875	26	20	27.6	4290
650		300	10.69	10.90	1.32	23.29	27.82	6.31	947	28	22	27.6	4290
650	L-102	500	11.10	10.90	2.20	25.75	30.44	6.90	992	29	23	27.6	4290
650		700	11.10	10.90	3.08	27.78	32.45	7.36	995	29	23	27.6	4290
700		100	10.51	11.53	0.45	21.50	25.97	5.89	918	27	21	29.7	4620
700		300	11.40	11.53	1.35	24.61	29.45	6.68	1005	29	23	29.7	4620
700	L-117	500	11.40	11.53	2.25	26.94	31.75	7.20	998	30	23	29.7	4620
700		700	11.40	11.53	3.15	28.99	33.78	7.66	1001	30	23	29.7	4620
750		100	11.02	12.14	0.45	22.53	27.21	6.17	960	28	22	31.8	4950
750	L-131	300	11.70	12.14	1.35	25.48	30.44	6.90	1024	30	23	31.8	4950
750		500	11.70	12.14	2.25	27.86	32.80	7.44	1014	30	23	31.8	4950
800		100	11.52	12.74	0.45	23.55	28.44	6.45	999	29	23	33.9	5280
800		300	12.00	12.74	1.35	26.35	31.44	7.13	1040	30	23	33.9	5280
800		500	12.00	12.74	2.25	28.62	33.68	7.64	1035	30	23	33.9	5280
Growing Veal Calves Fed Only Milk													
35	—	500	0.67	0.98	0.90	3.17	3.52	0.80	173	7	4	1.5	231
45	L-1.0	800	1.06	1.36	1.52	5.04	5.60	1.27	259	8	5	1.9	297
55	L-2.8	900	1.20	1.55	1.73	5.74	6.38	1.45	292	11	7	2.3	363
65	L-4.4	1000	1.36	1.76	1.95	6.48	7.20	1.63	324	13	8	2.8	429
75	L-5.8	1050	1.48	1.96	2.10	7.05	7.83	1.78	334	15	9	3.2	495
100	L-9.2	1100	1.69	2.43	2.31	8.05	8.94	2.03	357	17	10	4.2	660
125	L-12.4	1200	1.95	2.88	2.64	9.30	10.33	2.34	392	19	11	5.3	825
150	L-15.4	1300	2.22	3.30	2.99	10.58	11.75	2.66	428	20	12	6.4	990
Maintenance of Mature Breeding Bulls													
500	—	—	7.80	9.36	—	15.95	19.27	4.37	673	20	15	21	—
600	—	—	8.95	10.74	—	18.29	22.09	5.01	766	23	17	25	—
700	—	—	10.04	12.05	—	20.52	24.78	5.62	852	26	19	30	—
800	—	—	11.10	13.32	—	22.52	27.20	6.17	942	29	21	34	—
900	—	—	12.13	14.55	—	24.79	29.94	6.79	1017	31	23	38	—
1000	—	—	13.12	15.75	—	26.83	32.41	7.35	1093	34	25	42	—

TABLE 1 Daily Nutrient Requirements of Dairy Cattle—Continued

Body Weight (kg)	Breed Size, Age (wk)	Daily Gain (g)	Feed DM (kg)	Feed Energy: NE_m (Mcal)	NE_g (Mcal)	ME (Mcal)	DE (Mcal)	TDN (kg)	Total Crude Protein (g)	Minerals: Ca (g)	P (g)	Vitamins: A (1,000 IU)	D (IU)
1100	—	—	14.10	16.91	—	28.84	34.83	7.90	1169	36	27	47	—
1200	—	—	15.05	18.05	—	30.77	37.17	8.43	1244	39	29	51	—
1300	—	—	15.98	19.17	—	32.67	39.46	8.95	1316	41	31	55	—
1400	—	—	16.88	20.27	—	34.49	41.66	9.45	1386	43	33	59	—

[a] Breed size: S for small breeds (e.g., Jersey); L is for large breeds (e.g., Holstein).
[b] Age in weeks indicates probable age of S or L animals when they reach the weight indicated.

TABLE 2 Daily Nutrient Requirements of Lactating and Pregnant Cows

Body Weight (kg)	Feed Energy: NE_l (Mcal)	ME (Mcal)	DE (Mcal)	TDN (kg)	Total Crude Protein (g)	Calcium (g)	Phosphorus (g)	Vitamin A (1,000 IU)
Maintenance of Mature Lactating Cows[a]								
350	6.47	10.76	12.54	2.85	341	14	11	27
400	7.16	11.90	13.86	3.15	373	15	13	30
450	7.82	12.99	15.14	3.44	403	17	14	34
500	8.46	14.06	16.39	3.72	432	18	15	38
550	9.09	15.11	17.60	4.00	461	20	16	42
600	9.70	16.12	18.79	4.27	489	21	17	46
650	10.30	17.12	19.95	4.53	515	22	18	50
700	10.89	18.10	21.09	4.79	542	24	19	53
750	11.47	19.06	22.21	5.04	567	25	20	57
800	12.03	20.01	23.32	5.29	592	27	21	61
Maintenance Plus Last 2 Months of Gestation of Mature Dry Cows								
350	8.42	14.00	16.26	3.71	642	23	16	27
400	9.30	15.47	17.98	4.10	702	26	18	30
450	10.16	16.90	19.64	4.47	763	29	20	34
500	11.00	18.29	21.25	4.84	821	31	22	38
550	11.81	19.65	22.83	5.20	877	34	24	42
600	12.61	20.97	24.37	5.55	931	37	26	46
650	13.39	22.27	25.87	5.90	984	39	28	50
700	14.15	23.54	27.35	6.23	1035	42	30	53
750	14.90	24.79	28.81	6.56	1086	45	32	57
800	15.64	26.02	30.24	6.89	1136	47	34	61
Milk Production—Nutrients Per Kg Milk of Different Fat Percentages								
(% Fat)								
2.5	0.59	0.99	1.15	0.260	72	2.40	1.65	
3.0	0.64	1.07	1.24	0.282	77	2.50	1.70	
3.5	0.69	1.16	1.34	0.304	82	2.60	1.75	
4.0	0.74	1.24	1.44	0.326	87	2.70	1.80	
4.5	0.78	1.31	1.52	0.344	92	2.80	1.85	
5.0	0.83	1.39	1.61	0.365	98	2.90	1.90	
5.5	0.88	1.48	1.71	0.387	103	3.00	2.00	
6.0	0.93	1.56	1.81	0.410	108	3.10	2.05	
Body Weight Change During Lactation—Nutrients Per Kg Weight Change								
Weight loss	−4.92	−8.25	−9.55	−2.17	−320			
Weight gain	5.12	8.55	9.96	2.26	500			

[a] To allow for growth of young lactating cows, increase the maintenance allowances for all nutrients except vitamin A by 20 percent during the first lactation and 10 percent during the second lactation.

TABLE 3 Recommended Nutrient Content of Rations for Dairy Cattle

Nutrients (Concentration in the Feed Dry Matter)	Lactating Cow Rations: Cow Wt (kg)	Daily Milk Yields (kg)				Nonlactating Cattle Rations: Dry Pregnant Cows	Mature Bulls	Growing Heifers and Bulls	Calf Starter Concentrate Mix	Calf Milk Replacer	Maximum Concentrations (All Classes)
	≤400	< 8	8–13	13–18	>18						
	500	<11	11–17	17–23	>23						
	600	<14	14–21	21–29	>29						
	≥700	<18	18–26	26–35	>35						
Ration No.		I	II	III	IV	V	VI	VII	VIII	IX	Max.
Crude Protein, %		13.0	14.0	15.0	16.0	11.0	8.5	12.0	16.0	22.0	—
Energy											
NE_l, Mcal/kg		1.42	1.52	1.62	1.72	1.35	—	—	—	—	—
NE_m, Mcal/kg		—	—	—	—	—	1.20	1.26	1.90	2.40	—
NE_g, Mcal/kg		—	—	—	—	—	—	0.60	1.20	1.55	—
ME, Mcal/kg		2.36	2.53	2.71	2.89	2.23	2.04	2.23	3.12	3.78	—
DE, Mcal/kg		2.78	2.95	3.13	3.31	2.65	2.47	2.65	3.53	4.19	—
TDN, %		63	67	71	75	60	56	60	80	95	—
Crude Fiber, %		17	17	17	17[a]	17	15	15	—	—	—
Acid Detergent Fiber, %		21	21	21	21	21	19	19	—	—	—
Ether Extract, %		2	2	2	2	2	2	2	2	10	—
Minerals[b]											
Calcium, %		0.43	0.48	0.54	0.60	0.37	0.24	0.40	0.60	0.70	—
Phosphorus, %		0.31	0.34	0.38	0.40	0.26	0.18	0.26	0.42	0.50	—
Magnesium, %[c]		0.20	0.20	0.20	0.20	0.16	0.16	0.16	0.07	0.07	—
Potassium, %		0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	—
Sodium, %		0.18	0.18	0.18	0.18	0.10	0.10	0.10	0.10	0.10	—
Sodium chloride, %[d]		0.46	0.46	0.46	0.46	0.25	0.25	0.25	0.25	0.25	5
Sulfur, %[d]		0.20	0.20	0.20	0.20	0.17	0.11	0.16	0.21	0.29	0.35
Iron, ppm[d,e]		50	50	50	50	50	50	50	100	100	1,000
Cobalt, ppm		0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	10
Copper, ppm[d,f]		10	10	10	10	10	10	10	10	10	80
Manganese, ppm[d]		40	40	40	40	40	40	40	40	40	1,000
Zinc, ppm[d,g]		40	40	40	40	40	40	40	40	40	500
Iodine, ppm[h]		0.50	0.50	0.50	0.50	0.50	0.25	0.25	0.25	0.25	50
Molybdenum, ppm[i,j]		—	—	—	—	—	—	—	—	—	6
Selenium, ppm		0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	5
Fluorine, ppm[j]		—	—	—	—	—	—	—	—	—	30
Vitamins[k]											
Vit A, IU/kg		3,200	3,200	3,200	3,200	3,200	3,200	2,200	2,200	3,800	—
Vit D, IU/kg		300	300	300	300	300	300	300	300	600	—
Vit E, ppm		—	—	—	—	—	—	—	—	300	—

[a] It is difficult to formulate high-energy rations with a minimum of 17 percent crude fiber. However, fat percentage depression may occur when rations with less than 17 percent crude fiber or 21 percent ADF are fed to lactating cows.

[b] The mineral values presented in this table are intended as guidelines for use of professionals in ration formulation. Because of many factors affecting such values, they are not intended and should not be used as a legal or regulatory base.

[c] Under conditions conducive to grass tetany (see text), should be increased to 0.25 or higher.

[d] The maximum safe levels for many of the mineral elements are not well defined; estimates given here, especially for sulfur, sodium chloride, iron, copper, zinc, and manganese, are based on very limited data; safe levels may be substantially affected by specific feeding conditions.

[e] The maximum safe level of supplemental iron in some forms is materially lower than 1,000 ppm. As little as 400 ppm added iron as ferrous sulfate has reduced weight gains (Standish *et al.*, 1969).

[f] High copper may increase the susceptibility of milk to oxidized flavor (see text).

[g] Maximum safe level of zinc for mature dairy cattle is 1,000 ppm.

[h] If diet contains as much as 25 percent strongly goitrogenic feed on dry basis, iodine provided should be increased two times or more.

[i] If diet contains sufficient copper, dairy cattle tolerate substantially more than 6 ppm molybdenum (see text).

[j] Maximum safe level of fluorine for growing heifers and bulls is lower than for other dairy cattle. Somewhat higher levels are tolerated when the fluorine is from less-available sources such as phosphates (see text). Minimum requirement for molybdenum and fluorine not yet established.

[k] The following minimum quantities of B-complex vitamins are suggested per unit of milk replacer: niacin, 2.6 ppm; pantothenic acid, 13 ppm; riboflavin, 6.5 ppm; pyridoxine, 6.5 ppm; thiamine, 6.5 ppm; folic acid, 0.5 ppm; biotin, 0.1 ppm; vitamin B_{12}, 0.07 ppm; choline, 0.26 percent. It appears that adequate amounts of these vitamins are furnished when calves have functional rumens (usually at 6 weeks of age) by a combination of rumen synthesis and natural feedstuffs.

COMPOSITION OF FEEDS

Table 4 gives the composition of feeds commonly used in dairy cattle rations. Although some of the names have been shortened from those proposed by Harris *et al.* (1968), the feed reference numbers have been retained so that a complete description of the feed may be obtained if necessary.

The values in the table represent the best judgment of this subcommittee, and while many remained unchanged from the previous report, considerable latitude has been exercised in incorporating such effects as stage of maturity on digestibility. Consideration has been given to values in the previous publication, new data provided by the International Feedstuffs Institute, Utah State University, Logan, and suggestions or data from many individuals in both industry and public institutions. The values in Table 4 do not necessarily represent the average of all data for a particular feed attribute but are recommended values for the average feeding situation. The composition of many feeds varies with differences in climate, soil conditions, maturity, variety, and many management factors. Because of this normal variation in feed composition, Table 4 should be considered a guide to ration formulation rather than a precise statement of nutrient composition. The composition of grazed forages is based on data available for fresh forages and the feed reference numbers listed for those feeds are those of the corresponding fresh forages.

The details of computation of DE, ME, and NE_l content of feeds are presented in the energy section of the text.

The cell wall and acid detergent fiber content of feeds as measured by the procedures of Goering and Van Soest (1970) have been included because of the increasing use of these methods.

The carotene content of feeds has been converted to IU of potential vitamin A activity for cattle on the basis that 1 mg of carotene will provide 400 IU of vitamin A activity.

TABLE 4 Composition of Feeds Commonly Used in Dairy Cattle Rations

				On a Dry Basis (Moisture Free)								
						Growing Dairy Cattle		Lactating Cows				
Line No.	Feedstuff	Reference Number	Dry Matter (%)	DE (Mcal/kg)	ME (Mcal/kg)	NE_m (Mcal/kg)	NE_g (Mcal/kg)	NE_l (Mcal/kg)	TDN (%)	Crude Protein (%)	Cellulose (%)	Crude Fiber (%)
001	ALFALFA. *Medicago sativa*											
002	—dehy grnd, 15% protein	1-00-022	93	2.69	2.27	1.31	0.69	1.37	61	16.3	29	33
003	—dehy grnd, 17% protein	1-00-023	93	2.73	2.31	1.33	0.73	1.40	62	19.7	24	27
004	—fresh	2-00-196	27	2.69	2.27	1.31	0.61	1.37	61	19	26	28
005	—hay, s-c, early vegetative, 1st cutting	1-00-048	89	3.00	2.58	1.49	0.92	1.54	68	23.4	22	21
006	—hay, s-c, early vegetative	1-00-050	89	2.87	2.44	1.41	0.82	1.47	65	21.7	23	24
007	—hay, s-c, late vegetative	1-00-054	90	2.73	2.31	1.33	0.73	1.40	62	19.9	24	27
008	—hay, s-c, early bloom	1-00-059	90	2.56	2.13	1.24	0.59	1.30	58	17.2	28	31
009	—hay, s-c, mid-bloom	1-00-063	89	2.47	2.04	1.19	0.51	1.25	56	16	29	33
010	—hay, s-c, full bloom	1-00-068	88	2.38	1.95	1.15	0.44	1.20	54	15	30	35
011	—hay, s-c, mature	1-00-071	91	2.29	1.87	1.11	0.36	1.15	52	13.5	32	37
012	—silage, wilted, 25–40% moisture (energy value on dry basis is the same as alfalfa hay of same maturity)											
013	ALMOND. *Prunus amygdalus*											
014	—almond hulls	4-00-359	91	2.51	2.09	1.22	0.56	1.27	57	4.4	10	15
015	APPLE. *Melus* spp.											
016	—pomace, dehy	4-00-423	89	3.04	2.62	1.52	0.95	1.57	69	4.9	—	17
017	BAHIAGRASS. *Paspalum notatum*											
018	—grazed	2-00-464	30	2.29	1.87	1.11	0.36	1.15	52	7.9	—	32
019	BAKERY WASTE	4-00-466	92	3.92	3.51	2.19	1.44	2.06	89	11.9	—	1
020	BARLEY. *Hordeum vulgare*											
021	—grain	4-00-549	89	3.65	3.24	1.96	1.31	1.91	83	13.9	—	6
022	—grain, Pacific Coast	4-07-939	89	3.61	3.19	1.93	1.29	1.89	82	10.7	—	7
023	—grain screenings	4-00-542	89	3.52	3.10	1.85	1.23	1.84	80	13.5	—	9
024	—hay, s-c	1-00-495	87	2.51	2.09	1.23	0.55	1.27	57	8.9	—	26
025	—straw	1-00-498	88	2.16	1.72	1.05	0.24	1.08	49	4.1	37	42
026	BEAN. *Phaseolus* spp.											
027	—navy, seeds	5-00-623	90	3.65	3.24	1.96	1.31	1.91	83	25.4	—	5
028	BEET, MANGELS. *Beta vulgaris, macroriza*											
029	—roots	4-00-637	11	3.43	3.02	1.80	1.20	1.79	78	11.4	—	8
030	BEET, SUGAR. *Beta vulgaris, saccharifera*											
031	—aerial part w crowns, silage	3-00-660	21	2.38	1.95	1.14	0.44	1.20	54	12.7	—	13
032	—molasses—see MOLASSES											
033	—pulp, dehy (dried beet pulp)	4-00-669	91	3.44	3.02	1.79	1.19	1.79	78	8	—	22
034	—pulp, wet	4-00-671	10	3.44	3.02	1.79	1.19	1.79	78	9	—	20
035	—pulp w molasses, dehy	4-00-672	92	3.44	3.02	1.79	1.19	1.79	78	9.9	—	17
036	BERMUDAGRASS, COASTAL. *Cynodon dactylon*											
037	—hay, s-c, late vegetative	1-20-900	91	2.33	1.91	1.13	0.40	1.18	53	9.5	—	31
038	—hay, s-c	1-00-716	91	2.11	1.68	1.03	0.19	1.05	48	6	—	34
039	BIRDSFOOT TREFOIL—see TREFOIL, BIRDSFOOT											
040	BLUEGRASS, CANADA. *Poa compressa*											
041	—grazed	2-00-764	31	3.08	2.67	1.54	0.97	1.59	70	17	—	26
042	—grazed, early vegetative	2-00-763	26	3.12	2.71	1.57	1.00	1.62	71	18.7	—	26
043	—hay, s-c	1-00-762	93	2.86	2.44	1.41	0.82	1.47	65	11.6	—	29
044	—hay, s-c, early vegetative	1-20-889	97	3.12	2.71	1.57	1.00	1.62	71	17.3	—	26
045	BLUEGRASS, KENTUCKY. *Poa pratensis*											
046	—grazed, early vegetative	2-00-777	30	3.17	2.76	1.60	1.03	1.64	72	17.3	20	25
047	—grazed, early bloom	2-00-779	36	3.04	2.62	1.52	0.95	1.57	69	14.8	28	28
048	BONE CHARCOAL (bone black, bone char)	6-00-402	90	—	—	—	—	—	—	9.7	—	—
049	BONE MEAL, feeding (more than 10% P)	6-00-397	94	—	—	—	—	—	—	24.5	—	—
050	BONE MEAL, steamed	6-00-400	95	0.70	0.26	0.57	—	0.27	16	12.7	—	2

Line No.	Lignin (%)	Acid Deter-gent Fiber (%)	Cell Walls (%)	Cal-cium (%)	Chlo-rine (%)	Cobalt (ppm)	Copper (ppm)	Iron (ppm)	Mag-nesium (%)	Mangan-ese (ppm)	Phos-phorus (%)	Potas-sium (%)	So-dium (%)	Sul-fur (%)	Zinc (ppm)	Vita-min A (1,000 IU/kg)	Vita-min E (ppm)
	On a Dry Basis (Moisture Free)																
001																	
002	12	41	51	1.32	0.48	0.190	11.2	330	0.31	31	0.24	2.50	0.08	—	22	27	—
003	10.6	35	45	1.43	0.52	0.390	10.6	490	0.39	31	0.26	2.68	0.10	—	17	48	—
004	9	35	45	1.72	0.47	0.090	9.9	300	0.27	50	0.31	2.03	0.20	0.39	18	97	152
005	6.4	28	38	—	—	—	—	—	—	—	—	—	—	—	—	75	—
006	7.6	31	41	2.12	0.34	0.090	13.4	200	0.26	39	0.30	2.26	0.22	0.63	17	75	—
007	8.6	34	44	2.45	0.34	—	—	250	0.25	34	0.30	2.75	0.22	0.29	—	72	—
008	10.1	38	48	1.25	0.38	0.090	21.7	200	0.30	32	0.23	2.08	0.15	0.30	17	34	26
009	10.8	40	50	1.35	—	0.360	13	180	0.29	29	0.22	1.69	0.14	0.27	20	10	—
010	11.6	42	52	1.28	—	0.560	11.7	170	0.31	34	0.20	1.86	0.14	0.26	24	10	—
011	12.4	44	55	1.17	—	0.090	13.4	200	0.35	33	0.17	1.97	0.15	0.20	17	3	—
012																	
013																	
014	6	28	31	0.23	—	—	—	—	—	—	0.11	—	—	—	—	0	—
015																	
016	—	—	—	0.13	—	—	—	300	0.07	8	0.12	0.49	0.14	0.02	—	0	—
017																	
018	—	—	—	0.45	—	—	—	—	0.25	—	0.19	1.45	—	—	—	73	—
019	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—
020																	
021	—	7	19	0.05	0.20	0.110	9.1	90	0.15	19	0.37	0.45	0.03	0.18	17	0	11
022	—	9	21	0.05	0.17	0.100	9.1	60	0.14	18	0.36	0.60	0.02	—	16	0	—
023	—	—	—	0.46	—	—	—	60	0.14	—	0.32	1.38	0.02	0.15	—	0	—
024	—	—	—	0.21	—	0.060	4.1	300	0.19	39	0.30	1.49	0.14	0.17	—	21	—
025	11	59	80	0.24	0.68	0.070	10.1	300	0.19	17	0.09	2.28	0.14	0.17	—	—	—
026																	
027	—	—	—	0.15	0.04	—	11.2	110	0.19	24	0.63	1.89	0.06	0.26	—	0	—
028																	
029	—	—	—	0.19	1.23	—	—	190	0.19	—	0.19	1.98	0.66	0.19	—	0	—
030																	
031	—	—	—	2.32	—	—	—	—	1.07	—	0.20	5.79	0.54	0.57	—	—	—
032																	
033	5	34	59	0.75	0.04	0.100	13.7	330	0.30	38	0.11	0.23	0.19	0.22	10	0	—
034	—	—	—	0.90	—	—	—	—	0.14	—	0.10	0.20	—	—	10	0	—
035	—	—	—	0.61	—	0.230	16	210	0.14	26	0.11	1.78	0.40	0.42	10	0	—
036																	
037	9	33	75	—	—	—	—	—	—	—	—	—	—	—	—	51	—
038	12	35	80	0.46	—	—	—	—	0.17	—	0.18	1.57	0.44	—	20	25	—
039																	
040																	
041	—	—	—	0.39	—	—	—	—	0.16	79	0.38	2.04	—	—	—	153	—
042	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	160	—
043	—	—	—	0.30	—	—	—	—	0.33	93	0.29	1.59	0.11	0.13	—	99	—
044	—	—	—	0.30	—	—	—	—	0.33	—	0.29	1.59	0.11	0.13	—	135	—
045																	
046	3.8	—	—	0.56	—	—	—	—	—	—	0.47	2.27	—	—	—	179	156
047	4.6	—	—	0.46	—	—	—	—	0.11	—	0.39	2.01	—	—	—	112	—
048	—	—	—	30.11	—	—	—	—	0.59	—	14.14	0.16	—	—	—	0	—
049	—	—	—	26.81	0.10	—	20	470	0.37	9	11.91	0.19	0.79	0.13	400	0	—
050	—	—	—	30.51	0.01	0.100	17.2	880	0.67	32	14.31	0.19	0.48	0.13	400	0	—

TABLE 4 Composition of Feeds Commonly Used in Dairy Cattle Rations—Continued

Line No.	Feedstuff	Reference Number	Dry Matter (%)	On a Dry Basis (Moisture Free): DE (Mcal/kg)	ME (Mcal/kg)	Growing Dairy Cattle: NE_m (Mcal/kg)	Growing Dairy Cattle: NE_g (Mcal/kg)	Lactating Cows: NE_l (Mcal/kg)	TDN (%)	Crude Protein (%)	Cellulose (%)	Crude Fiber (%)
051	BREWERS DRIED GRAINS	5-02-141	92	2.90	2.49	1.44	0.86	1.50	66	26	—	16
052	BREWERS GRAINS, WET	5-02-142	24	2.95	2.53	1.46	0.89	1.52	67	26	—	16
053	BREWERS DRIED YEAST—see YEAST, brewers											
054	BROME. *Bromus* spp.											
055	—grazed, early vegetative	2-00-892	32	3.00	2.58	1.49	0.92	1.54	68	14.6	27	24
056	—grazed, mature	2-00-898	56	2.87	2.44	1.41	0.82	1.47	65	9	34	33
057	—hay, s-c, late vegetative	1-00-887	88	2.73	2.31	1.33	0.73	1.40	62	10.5	—	33
058	—hay, s-c, late bloom	1-00-888	90	2.38	1.95	1.15	0.44	1.20	54	7.4	—	40
059	CARROT. *Daucus* spp											
060	—roots, fresh	4-01-145	12	3.62	3.19	1.93	1.29	1.89	82	10.1	—	9
061	CITRUS. *Citrus* spp.											
062	—pulp silage	3-01-234	20	3.65	3.24	1.96	1.31	1.91	83	7.3	—	16
063	—pulp, wo fines, dehy (dried citrus pulp)	4-01-237	90	3.40	2.98	1.76	1.16	1.76	77	6.9	—	14
064	CLOVER, ALSIKE. *Trifolium hybridum*											
065	—grazed, early vegetative	2-01-314	19	2.86	2.44	1.41	0.82	1.47	65	24.1	—	17
066	—hay, s-c	1-01-313	88	2.65	2.22	1.29	0.66	1.35	60	14.7	—	29
067	CLOVER, CRIMSON. *Trifolium incarnatum*											
068	—grazed, early vegetative	2-20-890	18	2.77	2.36	1.36	0.76	1.42	63	17	—	28
069	—hay, s-c	1-01-328	87	2.65	2.22	1.29	0.66	1.35	60	16.9	—	32
070	CLOVER, LADINO. *Trifolium repens*											
071	—grazed, early vegetative	2-01-380	21	3.08	2.67	1.54	0.97	1.59	70	24.7	—	14
072	—hay, s-c	1-01-378	91	2.69	2.27	1.31	0.69	1.37	61	23	—	19
073	CLOVER, RED. *Trifolium pratense*											
074	—fresh, early bloom	2-01-428	20	2.99	2.58	1.49	0.92	1.54	68	21.1	—	19
075	—fresh, full bloom	2-01-429	28	2.82	2.40	1.39	0.80	1.45	64	14.9	—	30
076	—fresh, cut 2	2-01-432	27	2.82	2.40	1.39	0.80	1.45	64	17.3	—	25
077	—hay, s-c	1-01-415	88	2.60	2.18	1.26	0.62	1.32	59	14.9	26	30
078	COCONUT. *Cocos nucifera*											
079	—meats, meal mech-extd (copra meal)	5-01-572	93	3.57	3.16	1.89	1.26	1.86	81	21.9	—	13
080	—meats, meal solv-extd (copra meal)	5-01-573	92	3.26	2.85	1.66	1.08	1.69	74	23.1	—	16
081	CORN. *Zea mays*											
082	—aerial part, s-c (corn fodder)	1-02-775	82	2.86	2.44	1.41	0.82	1.47	65	8.9	28	26
083	—aerial part wo ears wo husks, s-c, mature (corn stover)	1-02-776	87	2.60	2.18	1.26	0.62	1.32	59	5.9	25	34
084	—aerial part wo ears wo husks, silage	3-02-836	27	2.55	2.13	1.24	0.59	1.30	58	7.2	25	32
085	Corn stover silage											
086	—cobs, grnd	1-02-782	90	2.07	1.64	1.01	0.15	1.03	47	2.8	28	35
087	—distillers grain, dehy	5-02-842	92	3.70	3.29	1.99	1.33	1.94	84	29.5	—	13
088	—distillers grains w solubles, dehy	5-02-843	92	3.88	3.47	2.16	1.42	2.03	88	29.8	—	10
089	—distillers solubles, dehy	5-02-844	93	3.88	3.47	2.15	1.42	2.03	88	28.9	—	4
090	—ears w husks, silage	3-02-839	43	3.17	2.76	1.60	1.03	1.64	72	8.8	—	12
091	—ears, grnd (ground ear corn)	4-02-849	87	3.53	3.11	1.86	1.24	1.84	80	9.3	—	9
092	—gluten, meal, mn 60% protein	5-02-318	91	3.70	3.29	1.99	1.33	1.94	84	65.9	—	3
093	—gluten w bran (corn gluten feed)	5-02-903	90	3.61	3.19	1.93	1.29	1.89	82	25	—	9
094	—grain, cracked, dent yellow	4-21-017	89	3.53	3.11	1.86	1.24	1.84	80	10	—	2
095	—grain, grnd, dent yellow	4-21-018	89	3.88	3.47	2.15	1.42	2.03	88	10	—	2
096	—hominy feed	4-02-887	91	4.05	3.65	2.32	1.50	2.13	92	11.8	—	6
097	—silage, well-eared	3-02-823	35	3.08	2.67	1.54	0.97	1.59	70	8	—	24
098	—silage, not well-eared	3-08-600	35	2.86	2.44	1.41	0.82	1.47	65	8.4	—	32
099	CORN, SWEET. *Zea mays saccharata*											
100	—cannery residue, fresh	2-02-975	77	3.08	2.67	1.54	0.97	1.59	70	8.8	—	22
101	—cannery residue, ensiled	3-07-955	29	3.17	2.76	1.60	1.03	1.64	72	8.8	—	27
102	COTTON. *Gossypium* spp.											
103	—seed hulls	1-01-599	90	1.68	1.24	0.86	0	0.81	38	4.3	60	50
104	—seeds, whole	5-13-749	93	4.31	3.91	2.59	1.61	2.28	98	24.9	—	18

On a Dry Basis (Moisture Free)

Line No.	Lignin (%)	Acid Detergent Fiber (%)	Cell Walls (%)	Calcium (%)	Chlorine (%)	Cobalt (ppm)	Copper (ppm)	Iron (ppm)	Magnesium (%)	Manganese (ppm)	Phosphorus (%)	Potassium (%)	Sodium (%)	Sulfur (%)	Zinc (ppm)	Vitamin A (1,000 IU/kg)	Vitamin E (ppm)
051	5	23	42	0.29	0.13	0.100	22.2	270	0.15	41	0.54	0.09	0.28	0.34	106	0	25
052	5	23	42	0.29	0.13	0.100	22.2	270	0.15	41	0.54	0.09	0.28	0.34	106	0	25
053																	
054																	
055	3.0	31	60	0.59	—	—	—	—	0.18	—	—	—	—	—	—	184	—
056	4.5	38	67	0.30	—	—	—	—	0.18	—	—	—	—	—	—	33	—
057	4.7	40	68	0.30	—	—	—	—	0.09	—	0.35	2.32	0.02	0.20	—	26	—
058	7.5	44	72	0.30	—	—	—	—	0.09	—	0.35	2.32	0.02	0.20	—	15	—
059																	
060	—	—	—	0.37	0.50	—	11.1	110	0.17	31	0.34	2.50	1.00	0.17	—	356	—
061																	
062	—	—	—	2.04	—	—	—	160	0.16	—	0.15	0.62	—	—	16	—	—
063	—	23	23	2.07	—	0.16	6.3	170	0.16	7	0.13	0.77	0.10	0.07	16	—	—
064																	
065	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	154	—
066	—	—	—	1.31	0.78	—	6.0	460	0.32	117	0.25	2.54	0.46	0.17	—	15	—
067																	
068	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	95	—
069	—	—	—	1.42	0.63	—	—	700	0.27	171.3	0.18	1.54	0.39	0.28	—	9	—
070																	
071	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	141	—
072	6.6	32	36	1.38	0.63	0.150	8.8	600	0.29	208.7	0.24	2.82	0.39	0.28	17	25	—
073																	
074	—	—	—	2.26	—	—	—	300	0.51	—	0.38	2.49	0.20	0.17	—	99	—
075	—	—	—	1.01	—	—	—	300	0.51	—	0.27	1.96	0.20	0.17	—	83	—
076	—	—	—	1.64	—	—	—	300	0.51	—	0.36	2.44	0.20	0.17	—	74	—
077	10	41	56	1.49	0.32	0.150	11.2	210	0.45	73.3	0.25	1.66	0.18	0.17	17	13	1,912
078																	
079	—	—	—	0.23	—	0.140	15.2	1,420	0.23	70.6	0.66	1.65	0.04	0.37	—	0	—
080	—	—	—	0.18	0.03	0.140	10.36	750	0.39	71.8	0.66	1.32	0.04	0.37	—	0	—
081																	
082	3	33	55	0.43	0.19	—	7.7	100	0.29	68.1	0.23	0.95	0.03	0.14	—	2	—
083	11	39	67	0.60	—	—	5.1	200	0.45	—	0.09	0.92	0.07	0.17	—	2	—
084	12	40	68	0.38	—	—	—	—	0.31	—	0.42	1.65	0.03	—	—	6	—
085																	
086	7	35	89	0.12	—	0.130	7.3	230	0.07	6.2	0.04	0.84	—	0.47	—	0	—
087	—	—	43	0.10	0.08	0.080	48.6	200	0.07	20	0.40	0.20	0.10	0.46	35	1	—
088	6.5	—	—	0.16	0.18	0.330	48.6	200	0.07	20	0.79	0.50	0.98	0.32	86	2	40
089	2.2	—	—	0.38	0.28	—	88.9	590	0.69	79	1.47	1.87	0.59	0.40	92	0	55
090	—	—	—	0.06	—	—	—	—	—	—	0.27	—	—	—	—	3	—
091	—	—	—	0.05	—	0.300	8.8	80	0.17	28	0.26	0.56	0.05	0.22	18	3	—
092	—	—	—	0.18	0.12	0.050	31	1,480	0.05	8	0.51	0.03	1	0.44	29	7	20
093	—	—	—	0.33	0.24	0.230	53	600	0.32	26	0.86	0.67	1.06	0.24	52	4	15
094	—	3	9	0.03	0.05	0.040	3.6	30	0.13	6	0.31	0.35	0.01	0.14	21	1	—
095	—	3	9	0.03	0.05	0.040	3.6	30	0.13	6	0.31	0.35	0.01	0.14	21	1	25
096	—	12	—	0.06	0.06	0.066	16.1	70	0.26	16	0.58	0.59	0.09	0.03	—	3	—
097	—	31	51	0.27	—	0.060	13.2	640	0.28	34	0.20	1.05	0.01	0.08	21	18	—
098	—	—	—	0.34	—	—	—	—	—	—	—	—	—	—	—	5	—
099																	
100	—	—	—	—	—	—	7	—	—	—	0.63	—	—	0.15	—	5	—
101	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	—
102																	
103	23	71	90	0.16	0.02	0.020	54.6	150	0.35	10	0.73	1.20	0.31	0.26	22	0	—
104	—	29	39	0.15	—	—	54.6	150	0.35	10	0.73	1.20	0.31	0.26	—	0	—

TABLE 4 Composition of Feeds Commonly Used in Dairy Cattle Rations—Continued

				On a Dry Basis (Moisture Free)								
						Growing Dairy Cattle		Lactating Cows				
Line No.	Feedstuff	Reference Number	Dry Matter (%)	DE (Mcal/kg)	ME (Mcal/kg)	NE_m (Mcal/kg)	NE_g (Mcal/kg)	NE_l (Mcal/kg)	TDN (%)	Crude Protein (%)	Cellulose (%)	Crude Fiber (%)
105	—seeds, meal mech-extd, 36% protein	5-01-625	93	3.26	2.85	1.66	1.08	1.69	74	39	—	17
106	—seeds, meal mech-extd, 41% protein	5-01-617	93	3.39	2.98	1.76	1.16	1.76	77	44	—	13
107	—seeds, meal solv-extd, 41% protein	5-01-621	93	3.30	2.89	1.69	1.11	1.72	75	44.8	—	13
108	—seeds, meal, wo hulls, pre-press solv-extd, 50% protein	5-07-874	93	3.30	2.89	1.69	1.11	1.72	75	54	—	9
109	COWPEA. *Vigna* spp.											
110	—hay, s-c	1-01-645	90	2.77	2.36	1.36	0.76	1.42	63	18.4	—	27
111	DEFLUORINATED PHOSPHATE—see PHOSPHATE ROCK, defluorinated											
112	DICALCIUM PHOSPHATE	6-01-080	96	—	—	—	—	—	—	—	—	—
113	DISTILLERS GRAINS—see CORN; see SORGHUM, GRAIN VARIETY											
114	FATS AND OILS											
115	—animal fat (not exceeding 3% of ration)	4-00-409	99	8.00	7.50	5.25	2.62	5.25	182	—	—	—
116	FESCUE, MEADOW. *Festuca elatior*											
117	—grazed	2-01-920	28	2.73	2.31	1.33	0.73	1.40	62	12.4	—	29
118	—hay, s-c (fescue hay, tall)	1-01-912	88	2.42	2	1.17	0.48	1.23	55	10.5	38	33
119	FISH, MENHADEN. *Brevoortia tyrannus*											
120	—meal, mech extd	5-02-009	92	3.26	2.85	1.66	1.08	1.69	74	66.6	—	1
121	FLAX. *Linum usitatissimum*											
122	—seed screenings	4-02-056	91	2.82	2.40	1.38	0.79	1.45	64	17.4	—	14
123	—seeds, meal mech-extd (linseed meal)	5-02-045	91	3.56	3.15	1.90	1.27	1.86	81	38.8	—	10
124	—seeds, meal solv-extd (linseed meal)	5-02-048	91	3.34	2.93	1.73	1.14	1.74	76	38.6	—	10
125	GRAIN SCREENINGS—see also BARLEY; WHEAT											
126	—screenings, refuse	4-02-151	90	2.24	1.82	1.09	0.32	1.13	51	16	—	32
127	—screenings, uncleaned	4-02-153	92	2.86	2.44	1.41	0.82	1.47	65	15.6	—	18
128	GRAPE. *Vitis* spp.											
129	—pomace, dried	1-02-208	91	1.32	0.89	0.74	0	0.61	30	12.7	—	30
130	GROUNDNUT—see PEANUT											
131	HOMINY FEED—see CORN, hominy feed											
132	JOHNSONGRASS—see SORGHUM, JOHNSONGRASS											
133	KENTUCKY BLUEGRASS—see BLUEGRASS, KENTUCKY											
134	LESPEDEZA. Kobe, *Lespedeza striata kobe*, or Korean, *Lespedeza stipulacea*											
135	—grazed, late vegetative	2-21-023	32	2.60	2.18	1.26	0.62	1.32	59	16.4	—	32
136	—grazed, early bloom	2-20-885	25	2.42	2	1.17	0.48	1.23	55	16.4	—	32
137	—hay, s-c, late vegetative	1-21-019	92	2.60	2.18	1.26	0.62	1.32	59	17.8	—	24
138	—hay, s-c, early bloom	1-21-020	93	2.42	2	1.17	0.48	1.23	55	15.5	—	28
139	—hay, s-c, mid-bloom	1-21-021	93	2.20	1.78	1.07	0.28	1.10	50	14.5	—	30
140	—hay, s-c, full bloom	1-21-022	93	2.07	1.64	1.01	0.15	1.03	47	13.4	—	32
141	LESPEDEZA, SERICEA. *Lespedeza cuneata*											
142	—hay, s-c, late vegetative	1-09-172	93	1.98	1.56	0.97	0.06	0.98	45	18.6	—	22
143	LIMESTONE											
144	—grnd, mn 33% calcium	6-02-632	100	—	—	—	—	—	—	—	—	—
145	LINSEED MEAL—see FLAX											
146	MANGEL—see BEET, MANGELS											

	On a Dry Basis (Moisture Free)																
Line No.	Lignin (%)	Acid Detergent Fiber (%)	Cell Walls (%)	Calcium (%)	Chlorine (%)	Cobalt (ppm)	Copper (ppm)	Iron (ppm)	Magnesium (%)	Manganese (ppm)	Phosphorus (%)	Potassium (%)	Sodium (%)	Sulfur (%)	Zinc (ppm)	Vitamin A (1,000 IU/kg)	Vitamin E (ppm)
105	—	—	—	0.20	—	0.160	20.7	220	0.60	23	1.09	1.28	0.04	—	—	0	10
106	6	20	28	0.17	0.04	0.164	21.3	240	0.61	24	1.28	1.49	0.06	0.43	—	0	35
107	—	—	—	0.17	0.03	0.164	21.3	240	0.61	24	1.31	1.53	0.05	0.23	91	0	15
108	—	—	—	0.17	—	0.100	19.4	120	0.50	25	1.09	1.36	0.05	—	—	0	—
109																	
110	—	—	—	1.34	0.17	0.070	—	300	0.43	485	0.32	1.99	0.27	0.35	—	14	—
111																	
112	—	—	—	23.70	—	—	6.2	1,320	—	153	18.84	0.04	2.71	—	28	0	—
113																	
114																	
115	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	8
116																	
117	—	—	—	0.61	—	0.130	—	—	0.37	—	0.42	2.34	—	—	—	135	146
118	6.9	43	65	0.57	—	0.135	—	—	0.59	24	0.36	1.74	—	—	—	29	136
119																	
120	—	—	—	5.61	0.65	0.170	11.78	510	0.17	36	3.05	0.74	0.40	0.49	162	0	13
121																	
122	—	—	—	0.36	—	—	—	—	—	—	0.47	—	—	—	—	0	—
123	—	17	25	0.43	0.04	0.470	29	190	0.64	43	0.93	1.36	0.12	0.04	36	0	9
124	—	—	—	0.43	0.04	0.140	28.2	360	0.66	41	0.91	1.52	0.15	0.44	—	0	18
125																	
126	—	—	—	0.25	—	—	—	—	—	—	0.32	—	—	—	—	0	—
127	—	—	—	0.40	—	—	5.46	—	0.22	—	0.45	—	—	—	37	0	—
128																	
129	35.2	54	53	—	—	—	—	—	—	—	—	—	—	—	—	0	—
130																	
131																	
132																	
133																	
134																	
135	—	—	—	1.12	—	—	—	—	—	—	0.28	1.28	—	—	—	103	—
136	—	—	—	1.35	—	—	—	250	0.27	—	0.21	1.12	—	—	—	65	—
137	—	—	—	1.14	—	—	—	340	0.25	178	0.26	1.20	—	—	—	58	—
138	—	—	—	1.23	—	0.040	0.28	400	0.26	256	0.25	1	—	—	—	55	—
139	—	—	—	1.19	—	—	—	320	0.27	223	0.26	1.05	—	—	—	22	—
140	—	—	—	1.04	—	—	—	300	0.24	152	0.23	1.03	—	—	—	5	—
141																	
142	16	—	—	1.54	—	—	—	—	—	—	0.26	0.69	—	—	—	16	—
143																	
144	—	—	—	36.07	0.03	—	—	3,500	2.05	280	0.02	0.12	0.05	0.04	—	0	—
145																	
146																	

TABLE 4 Composition of Feeds Commonly Used in Dairy Cattle Rations—Continued

				On a Dry Basis (Moisture Free)								
						Growing Dairy Cattle		Lactating Cows				
Line No.	Feedstuff	Reference Number	Dry Matter (%)	DE (Mcal/kg)	ME (Mcal/kg)	NE_m (Mcal/kg)	NE_g (Mcal/kg)	NE_l (Mcal/kg)	TDN (%)	Crude Protein (%)	Cellulose (%)	Crude Fiber (%)
147	MEAT MEAL	5-00-385	93	3.34	2.93	1.73	1.14	1.74	76	57.1	—	2
148	MEAT AND BONE MEAL	5-00-388	94	3.17	2.76	1.61	1.03	1.64	72	53.8	—	2
149	MILK											
150	—buttermilk, dehy	5-01-160	93	3.78	3.39	2.07	1.36	1.98	86	34.2	—	—
151	—milk, whole, dehy	5-01-167	94	5.73	5.16	3.61	2.01	—	130	26.9	—	—
152	—milk, fresh	5-01-168	12	5.73	5.16	3.61	2.01	—	130	25.8	—	—
153	—milk, skimmed	5-01-170	10	4.10	3.69	2.36	1.52	2.16	93	36	—	—
154	—milk, skimmed, dehy	5-01-175	94	3.78	3.39	2.07	1.37	1.98	86	36	—	—
155	MILLET, Foxtail. *Setaria italica*											
156	—grazed	2-03-101	28	2.82	2.40	1.38	0.79	1.45	64	9.5	—	32
157	—hay, s-c	1-03-099	86	2.51	2.09	1.22	0.55	1.27	57	8.6	—	30
158	MOLASSES											
159	—beet, sugar, molasses, mn 79.0 deg. brix	4-00-668	77	3.30	2.89	1.69	1.11	1.72	75	8.7	—	—
160	—citrus, molasses	4-01-241	65	3.40	2.98	1.76	1.16	1.76	77	10.9	—	—
161	—sugarcane, molasses, dehy	4-04-695	96	2.99	2.58	1.49	0.92	1.54	68	10.7	—	5
162	—sugarcane, molasses, mn 79.5 deg. brix	4-04-696	75	3.17	2.76	1.60	1.03	1.64	72	4.3	—	—
163	MONOSODIUM PHOSPHATE—see SODIUM PHOSPHATE, monobasic											
164	NAPIERGRASS. *Pennisetum purpureum*											
165	—grazed, late vegetative	2-03-158	15	2.78	2.36	1.36	0.76	1.42	63	11	33	31
166	—grazed, late bloom	2-03-162	23	2.29	1.87	1.10	0.35	1.15	52	7.8	35	39
167	OATS. *Avena sativa*											
168	—cereal by-product (feeding oat meal)	4-03-303	91	4.05	3.65	2.32	1.50	2.13	92	16.2	—	5
169	—grain	4-03-309	89	3.34	2.93	1.73	1.14	1.74	76	13.6	18	12
170	—grain, Pacific Coast	4-07-999	91	3.39	2.98	1.76	1.16	1.76	77	10.1	—	12
171	—groats (hulled oats)	4-03-331	91	4.10	3.69	2.36	1.52	2.16	93	17.5	—	3
172	—hay, s-c	1-03-280	88	2.68	2.27	1.31	0.70	1.37	61	9.2	—	31
173	—straw	1-03-283	90	2.12	1.69	1.03	0.19	1.05	48	4.4	40	41
174	—silage, late vegetative stage	3-20-898	30	2.73	2.31	1.33	0.73	1.40	62	12.8	—	30
175	—silage, dough stage	3-03-296	32	2.60	2.18	1.27	0.62	1.32	59	9.7	—	34
176	ORANGE. *Citrus sinensis*											
177	—pulp, dried	4-01-254	88	3.44	3.02	1.79	1.19	1.79	78	8.5	—	10
178	ORCHARDGRASS. *Dactylis glomerata*											
179	—grazed, early vegetative	2-03-439	24	2.95	2.53	1.46	0.89	1.52	67	18.4	—	27
180	—hay, s-c, early bloom	1-03-425	87	2.73	2.31	1.33	0.73	1.40	62	10.2	—	34
181	—hay, s-c, late bloom	1-03-428	88	2.20	1.78	1.07	0.28	1.10	50	8.4	—	37
182	OYSTER. *Crassostrea* spp., *Ostrea* spp.											
183	—shells, fine grnd, mn 33% calcium	6-03-481	100	—	—	—	—	—	—	1	—	—
184	PEA. *Pisum* spp.											
185	—seeds	5-03-600	90	3.66	3.25	1.96	1.31	1.91	83	26.5	—	6
186	—vine silage	3-03-596	24	2.46	2.04	1.20	0.51	1.25	56	13.1	34	30
187	PEANUT. *Arachis hypogaea*											
188	—hay, s-c	1-03-619	91	2.55	2.13	1.24	0.59	1.30	58	10.9	—	33
189	—kernels, mech-extd, mx 7% fiber (peanut meal)	5-03-649	92	3.65	3.24	1.96	1.31	1.91	83	49.8	—	9
190	—kernels, meal solv-extd, 45% protein (peanut meal)	5-03-650	92	3.39	2.98	1.76	1.16	1.76	77	54.2	—	11
191	PEARLMILLET. *Pennisetum glaucum*											
192	—grazed	2-03-115	21	2.73	2.31	1.33	0.73	1.40	62	10.1	—	31
193	—silage	3-20-903	30	2.60	2.18	1.26	0.62	1.32	59	6.9	—	32
194	PHOSPHATE ROCK.											
195	—defluorinated grnd, mx 1 part fluorine per 100 parts phosphorus	6-01-780	100	—	—	—	—	—	—	—	—	—
196	PINEAPPLE. *Ananas comosus*											
197	—pulp, dried (pineapple bran)	4-03-722	87	3.22	2.80	1.63	1.06	1.67	73	4.6	—	—

On a Dry Basis (Moisture Free)

Line No.	Lignin (%)	Acid Detergent Fiber (%)	Cell Walls (%)	Calcium (%)	Chlorine (%)	Cobalt (ppm)	Copper (ppm)	Iron (ppm)	Magnesium (%)	Manganese (ppm)	Phosphorus (%)	Potassium (%)	Sodium (%)	Sulfur (%)	Zinc (ppm)	Vitamin A (1,000 IU/kg)	Vitamin E (ppm)
147	—	—	—	8.49	1.40	0.137	10.4	470	0.29	10	4.31	0.59	1.41	0.53	112	0	1
148	—	—	—	10.29	0.80	0.195	1.6	530	1.20	14	5.39	1.38	0.78	0.28	102	0	1
149																	
150	—	—	—	1.07	0.38	—	1.1	<10	0.10	—	0.73	1.35	1.04	0.09	44	2	6
151	—	—	—	0.89	0.92	0.005	0.8	<10	0.08	—	0.72	1.16	0.34	—	23	14	—
152	—	—	—	0.89	0.92	0.005	0.8	<10	0.08	—	0.72	1.16	0.34	—	23	15	—
153	—	—	—	1.41	0.54	0.110	1	<10	0.12	—	1.17	1.90	0.54	—	51	0	—
154	—	—	—	1.25	0.54	0.117	1	<10	0.11	—	1.03	1.62	0.50	0.33	68	0	—
155																	
156	—	—	—	0.32	—	—	—	—	—	—	0.19	1.94	—	—	—	73	—
157	—	—	—	0.33	0.13	—	—	0.23	136	—	0.19	1.94	0.10	0.16	—	24	—
158																	
159	—	—	—	0.21	1.92	0.500	22.9	100	0.30	6	0.04	6.20	1.52	0.61	18	0	5
160	—	—	—	2.01	0.10	0.160	112	500	0.22	40	0.14	0.14	0.40	—	137	0	—
161	—	—	—	0.87	—	1.210	72.8	240	0.43	52	0.29	3.68	0.19	0.46	33	0	6
162	—	—	—	1.19	—	—	7.94	250	0.47	56	0.11	3.17	—	—	—	0	—
163																	
164																	
165	10	45	70	0.60	—	—	—	—	0.26	—	0.41	1.31	0.01	0.10	—	—	—
166	14	47	75	0.35	—	—	—	—	0.26	—	0.30	1.31	0.01	0.10	—	—	—
167																	
168	—	—	—	0.08	0.05	0.050	4.81	330	0.18	48	0.48	0.59	0.01	0.29	154	0	26
169	3.4	17	31	0.07	0.12	0.070	6.6	80	0.19	43	0.39	0.42	0.18	0.38	33	0	37
170	—	—	—	0.10	0.13	—	—	—	—	42	0.36	0.41	—	0.23	—	0	22
171	—	—	—	0.08	0.10	—	7	90	0.10	52	0.47	0.40	0.06	0.22	—	0	16
172	6	36	66	0.26	0.52	0.070	4.4	500	0.75	120	0.24	1.23	0.17	0.30	—	21	—
173	14	47	70	0.26	0.78	—	10.1	200	0.18	39	0.07	2.37	0.42	0.23	—	4	—
174	—	—	—	—	—	—	—	—	—	—	0.10	2.44	0.37	0.24	—	65	—
175	—	—	—	0.47	—	—	—	—	—	—	0.33	—	—	—	—	24	—
176																	
177	—	—	—	0.71	—	—	—	—	—	—	0.11	—	—	—	—	—	—
178																	
179	3	31	55	0.58	0.08	—	7	—	0.10	31	0.55	3.88	—	—	—	135	—
180	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	15	—
181	6	39	69	—	—	—	—	—	—	—	—	—	—	—	—	8	—
182																	
183	—	—	—	38.22	0.01	—	—	2,900	0.30	133	0.07	0.10	0.21	—	—	0	—
184																	
185	—	—	—	0.13	—	—	—	60	—	—	0.47	1.14	0.05	—	—	—	—
186	9	49	59	1.31	—	—	—	—	0.39	—	0.24	1.40	0.01	0.25	—	75	—
187																	
188	—	—	—	1.23	—	0.08	—	—	0.49	—	0.17	1.38	—	0.23	—	20	—
189	—	—	—	0.18	0.03	—	—	—	—	—	0.62	1.25	—	0.32	—	0	—
190	—	—	—	0.22	0.03	0.12	16.6	290	0.04	32	0.71	1.29	0.45	—	36	0	3
191																	
192	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	73	—
193	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10	—
194																	
195	—	—	—	31.65	—	—	66.2	7,090	0.27	696	13.7	0.16	0.19	0.13	—	0	—
196																	
197	—	—	—	0.24	—	—	—	560	—	—	0.12	—	—	—	—	0	—

TABLE 4 Composition of Feeds Commonly Used in Dairy Cattle Rations—Continued

				On a Dry Basis (Moisture Free)								
						Growing Dairy Cattle		Lactating Cows				
Line No.	Feedstuff	Reference Number	Dry Matter (%)	DE (Mcal/kg)	ME (Mcal/kg)	NE_m (Mcal/kg)	NE_g (Mcal/kg)	NE_l (Mcal/kg)	TDN (%)	Crude Protein (%)	Cellulose (%)	Crude Fiber (%)
198	POTATO. *Solanum tuberosum*											
199	—tubers, dried	4-07-850	—	3.39	2.98	1.76	1.16	1.76	77	8.7	—	2
200	—tubers, silage	3-03-768	25	3.48	3.07	1.82	1.21	1.81	79	8.2	—	4
201	—tubers, fresh	4-03-787	25	3.48	3.07	1.82	1.21	1.81	79	9.6	—	2
202	RAPE. *Brassica* spp.											
203	—grazed, early vegetative	2-03-865	18	3.08	2.67	1.54	0.97	1.59	70	16.4	—	13
204	—seeds, meal mech-extd	5-03-870	94	3.26	2.85	1.67	1.09	1.69	74	39.6	—	13
205	—seeds, meal solv-extd	5-03-871	90	3.04	2.62	1.51	0.94	1.57	69	43.6	—	13
206	REDTOP. *Agrostis alba*											
207	—fresh, full bloom	2-03-891	26	2.73	2.31	1.33	0.73	1.40	62	10	—	27
208	—hay, s-c, mid-bloom	1-03-886	93	2.65	2.22	1.28	0.66	1.35	60	12	—	25
209	RICE. *Oryza sativa*											
210	—bran w germ	4-03-928	91	2.91	2.49	1.44	0.86	1.50	66	14	—	12
211	—groats, polished (white polished rice)	4-03-942	89	3.70	3.29	2	1.33	1.94	84	8.2	—	1
212	—hulls	1-08-075	92	0.48	0.34	0.52	0	0.15	11	3.1	33	44
213	RYE. *Secale cereale*											
214	—grain	4-04-047	88	3.52	3.10	1.86	1.24	1.84	80	13.8	—	3
215	—grazed, early vegetative	2-04-013	16	3.04	2.62	1.52	0.95	1.57	69	28	—	—
216	—silage	3-04-020	28	2.33	1.91	1.13	0.40	1.18	53	12.6	—	34
217	RYEGRASS, ITALIAN. *Lolium multiflorum*											
218	—grazed, early vegetative	2-04-070	24	2.90	2.49	1.44	0.86	1.50	66	24.2	—	19
219	—hay, s-c, late vegetative	1-04-065	89	2.73	2.31	1.33	0.73	1.40	62	10.3	—	24
220	RYEGRASS, PERENNIAL. *Lolium perenne*											
221	—hay, s-c, early bloom	1-04-075	84	2.73	2.31	1.33	0.73	1.40	62	6	—	35
222	SAFFLOWER. *Carthamus tinctorius*											
223	—seeds	4-07-958	93	3.92	3.51	2.20	1.44	2.06	89	19.5	—	31
224	—seeds, meal mech-extd	5-04-109	91	2.51	2.09	1.22	0.56	1.27	57	22.8	—	36
225	—seeds, meal solv-extd	5-04-110	92	2.42	2	1.17	0.48	1.23	55	23.9	—	34
226	—seeds wo hulls, meal solv-extd	5-07-959	90	3.34	2.93	1.73	1.14	1.74	76	46.5	—	17
227	SCREENINGS—see BARLEY; GRAINS; WHEAT											
228	SESAME. *Sesamum indicum*											
229	—seeds, meal mech-extd	5-04-220	93	3.31	2.89	1.69	1.11	1.72	75	51.5	—	5
230	SODIUM PHOSPHATE											
231	—monobasic, $NaH_2PO_4 \cdot H_2O$ (monosodium phosphate)	6-04-228	87	—	—	—	—	—	—	—	—	—
232	SODIUM TRIPOLYPHOSPHATE	6-08-076	96	—	—	—	—	—	—	—	—	—
233	SORGHUM, GRAIN VARIETY. *Sorghum vulgare*											
234	—distillers grains, dehy	5-04-374	94	3.61	3.19	1.93	1.29	1.89	82	33.2	—	13
235	—grain, mn 6% mx 9% protein	4-08-138	88	3.56	3.16	1.89	1.26	1.86	81	7.9	—	2
236	—grain, mn 9% mx 12% protein	4-08-139	88	3.52	3.10	1.86	1.24	1.84	80	11.7	—	2
237	—grain, mn 12% mx 15% protein	4-08-140	88	3.48	3.07	1.82	1.21	1.81	79	13	—	2
238	—s-c (grain sorghum fodder)	1-07-960	90	2.55	2.13	1.24	0.58	1.30	58	7.4	—	28
239	—wo heads, s-c (grain sorghum stover)	1-04-302	85	2.11	1.68	1.03	0.19	1.05	48	4.9	—	33
240	—silage w heads (grain sorghum silage)	3-04-323	29	2.42	2	1.17	0.48	1.23	55	8.3	—	26
241	SORGHUM, JOHNSONGRASS. *Sorghum halepense*											
242	—hay, s-c	1-04-407	91	2.46	2.01	1.19	0.51	1.25	56	9.6	—	33
243	SORGHUM, SORGO. *Sorghum vulgare saccharatum*											
244	—silage	3-04-468	26	2.55	2.13	1.25	0.59	1.30	58	6.2	—	29
245	SORGHUM, SUDANGRASS. *Sorghum vulgare sudanense*											
246	—grazed, early vegetative	2-04-484	18	3.08	2.67	1.54	0.97	1.59	70	16.8	—	31
247	—grazed, mid-bloom	2-04-485	23	2.77	2.36	1.37	0.77	1.42	63	8.7	—	36

Line No.	Lignin (%)	Acid Detergent Fiber (%)	Cell Walls (%)	Calcium (%)	Chlorine (%)	Cobalt (ppm)	Copper (ppm)	Iron (ppm)	Magnesium (%)	Manganese (ppm)	Phosphorus (%)	Potassium (%)	Sodium (%)	Sulfur (%)	Zinc (ppm)	Vitamin A (1,000 IU/kg)	Vitamin E (ppm)
	On a Dry Basis (Moisture Free)																
198																	
199	—	—	—	0.07	0.40	—	—	—	—	2	0.21	2.19	—	—	2	0	—
200	—	—	—	0.04	—	—	—	—	—	—	0.23	2.13	0.09	0.09	—	0	—
201	—	—	—	0.04	0.28	—	28.4	90	0.13	42	0.22	2.18	0.09	0.09	—	0	—
202																	
203	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	62	—
204	—	—	—	0.69	—	—	7.4	190	0.54	65	1.04	0.9	0.5	—	47	0	20
205	—	—	—	0.67	—	—	—	—	—	—	1	—	—	—	—	0	—
206																	
207	8	40	64	—	—	—	—	200	0.25	—	0.37	2.35	0.05	0.16	—	61	—
208	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—
209																	
210	4.3	16	24	0.07	0.08	—	14.3	210	1.04	459	1.62	1.91	0.03	0.20	3	0	66
211	—	—	—	0.03	0.04	—	3.3	20	0.02	12	0.12	0.11	0.02	0.09	2	0	4
212	16	72	82	0.09	—	—	—	—	—	333	0.08	0.34	—	—	—	0	—
213																	
214	—	—	—	0.07	0.03	—	7.7	70	0.14	62	0.36	0.52	0.03	0.17	36	0	17
215	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	224	—
216	—	—	—	0.39	—	—	—	—	—	—	0.32	—	—	—	—	23	—
217																	
218	—	—	—	0.62	—	—	—	320	—	—	0.34	1.56	—	—	—	160	—
219	—	—	—	0.62	—	—	—	320	—	—	0.34	1.56	—	—	—	116	—
220																	
221	—	—	—	0.65	—	—	—	—	—	—	0.37	1.92	—	—	—	48	—
222																	
223	—	—	—	0.25	—	—	10.7	500	0.36	20	0.67	0.79	0.06	0.06	43	0	1
224	—	41	59	0.28	—	—	10.7	530	0.36	20	0.78	0.79	0.05	0.06	44	0	1
225	—	—	—	0.37	—	—	10.8	560	0.37	20	0.80	0.79	0.06	—	44	0	1
226	—	—	—	0.44	0.18	2.22	97.4	1,100	1.33	44	1.41	1.33	0.04	0.06	—	0	1
227																	
228																	
229	—	—	—	2.18	0.06	—	—	—	0.86	52	1.39	1.29	0.17	0.46	107	0	—
230																	
231	—	—	—	—	—	—	—	—	—	—	25.80	—	19.15	—	—	0	—
232	—	—	—	—	—	—	—	40	—	—	25.98	—	31.25	—	—	0	—
233																	
234	—	—	—	0.16	—	—	—	—	—	—	0.76	—	—	—	—	0	—
235	—	—	—	0.04	0.10	0.29	10.8	500	0.19	17	0.33	0.38	0.03	0.18	16	0	12
236	1.3	9	18	0.03	0.10	0.29	10.8	500	0.19	17	0.33	0.38	0.03	0.18	16	0	12
237	—	—	—	0.03	0.10	0.29	10.8	500	0.19	17	0.33	0.38	0.03	0.18	16	0	12
238	—	—	—	0.47	—	—	—	—	—	—	0.19	1.39	0.02	—	—	21	—
239	—	—	—	0.48	—	—	—	2,000	—	—	0.11	1.20	0.02	—	—	2	—
240	—	—	—	0.32	0.13	0.30	34.9	270	0.30	48	0.18	1.54	0.02	0.10	—	5	—
241																	
242	—	—	—	0.71	—	—	—	600	0.35	—	0.31	1.35	0.01	0.10	—	17	—
243																	
244	—	—	—	0.35	0.06	—	31.1	200	0.27	61	0.20	1.22	0.15	0.10	—	10	—
245																	
246	—	—	—	0.43	—	—	—	200	0.35	—	0.41	2.14	0.01	0.11	—	79	—
247	—	—	—	0.43	—	—	—	200	0.35	—	0.41	2.14	0.01	0.11	—	73	—

TABLE 4 Composition of Feeds Commonly Used in Dairy Cattle Rations—Continued

				On a Dry Basis (Moisture Free)								
						Growing Dairy Cattle		Lactating Cows				
Line No.	Feedstuff	Reference Number	Dry Matter (%)	DE (Mcal/kg)	ME (Mcal/kg)	NE_m (Mcal/kg)	NE_g (Mcal/kg)	NE_l (Mcal/kg)	TDN (%)	Crude Protein (%)	Cellulose (%)	Crude Fiber (%)
248	—hay, s-c	1-04-480	89	2.60	2.18	1.26	0.62	1.32	59	11	32	29
249	—silage	3-04-499	23	2.60	2.18	1.26	0.64	1.32	59	11.1	—	34
250	SOYBEAN. *Glycine max*											
251	—hay, s-c, mid-bloom	1-04-538	94	2.46	2.04	1.19	0.51	1.25	56	17.8	—	30
252	—hay, s-c, dough stage	1-04-542	88	2.64	2.22	1.28	0.66	1.35	60	16.8	—	28
253	—hulls (soybran flakes)	1-04-560	91	3.43	3.02	1.79	1.19	1.79	78	12	44	39
254	—straw	1-04-567	88	1.94	1.51	0.96	0.01	0.96	44	5.2	38	44
255	—silage	3-04-581	28	2.38	1.95	1.16	0.45	1.20	54	17.7	—	28
256	—seeds	5-04-610	90	4.14	3.74	2.41	1.53	2.18	94	41.7	—	6
257	—seeds, meal solv-extd, mn 44% protein (soybean meal)	5-04-604	89	3.56	3.15	1.89	1.26	1.86	81	49.6	8	7
258	—seeds, meal solv-extd, mn 46% protein	5-21-119	89	3.56	3.15	1.89	1.26	1.86	81	51.8	—	5
259	—seeds, meal solv-extd, dehulled, mn 48% protein	5-04-612	89	3.56	3.15	1.89	1.26	1.86	81	54	—	3
260	SUDANGRASS—see SORGHUM											
261	SUGARCANE. *Saccharum officinarum*											
262	—bagasse, dehy	1-04-686	92	1.24	0.80	0.71	0	0.57	28	1.8	—	48
263	SUNFLOWER. *Helianthus* spp.											
264	—seeds wo hulls, meal mech-extd	5-04-738	93	3.08	2.67	1.54	0.97	1.59	70	44.1	21	13
265	—seeds wo hulls, meal solv-extd	5-04-739	93	2.86	2.44	1.41	0.83	1.47	65	50.3	—	12
266	SWEETCLOVER. *Melilotus* spp.											
267	—hay, s-c	1-04-754	87	2.51	2.09	1.22	0.55	1.27	57	14	—	36
268	TIMOTHY. *Phleum pratense*											
269	—grazed, late vegetative	2-04-903	28	2.99	2.58	1.49	0.92	1.54	68	9.6	—	31
270	—grazed, mid-bloom	2-04-905	28	2.73	2.31	1.33	0.73	1.40	62	9.1	31	34
271	—hay, s-c, late vegetative	1-04-881	88	2.99	2.58	1.49	0.92	1.54	68	11.4	—	31
272	—hay, s-c, early bloom	1-04-882	88	2.73	2.31	1.33	0.73	1.40	62	10	31	32
273	—hay, s-c, mid-bloom	1-04-883	88	2.55	2.13	1.23	0.59	1.30	58	9.5	—	32
274	—hay, s-c, late bloom	1-04-885	88	2.42	2	1.17	0.48	1.23	55	7.7	—	33
275	—hay, s-c, seed stage	1-04-886	88	2.24	1.82	1.09	0.32	1.13	51	6	—	35
276	—silage, 25–40% dry matter (energy value on dry basis is same as timothy hay of same maturity)											
277	TOMATO. *Lycopersicon esculentum*											
278	—pomace, dehy	5-05-041	92	2.56	2.13	1.24	0.59	1.30	58	23.9	—	26
279	TORULA DRIED YEAST—see YEAST, *Torulopsis*											
280	TREFOIL, BIRDSFOOT. *Lotus corniculatus*											
281	—hay, s-c	1-05-044	91	2.68	2.27	1.31	0.69	1.37	61	15.6	24	30
282	—grazed	2-20-786	20	3.30	2.89	1.68	1.10	1.72	75	18.2	—	25
283	TURNIP. *Brassica rapa*											
284	—roots, fresh	4-05-067	9	3.70	3.29	2	1.33	1.94	84	11.3	—	11
285	VETCH. *Vicia* spp.											
286	—hay, s-c	1-05-106	88	2.73	2.31	1.33	0.73	1.40	62	19	—	31
287	WHEAT. *Triticum* spp.											
288	—bran	4-05-190	89	3.08	2.67	1.53	0.96	1.59	70	18	8	11
289	—germ, meal	5-05-218	90	4.18	3.78	2.44	1.55	2.20	95	28.1	—	4
290	—grain, Durum	4-05-224	89	3.88	3.47	2.15	1.42	2.03	88	14.3	—	3
291	—grain, hard red winter	4-05-268	89	3.88	3.47	2.15	1.42	2.03	88	14.4	—	3
292	—grain, soft white winter	4-05-337	86	3.88	3.47	2.15	1.42	2.03	88	11.5	—	3
293	—grain screenings	4-05-216	89	3.40	2.98	1.76	1.17	1.76	77	16	6	8
294	—grazed, early vegetative	2-05-176	21	3.21	2.80	1.64	1.07	1.67	73	28.6	—	17
295	—hay, s-c	1-05-172	86	2.56	2.13	1.24	0.59	1.30	58	8.7	—	28
296	—middlings	4-05-205	90	3.52	3.10	1.86	1.24	1.84	80	18.7	—	8
297	—mill run	4-05-206	90	3.26	2.85	1.6	1.09	1.69	74	17	—	9
298	—shorts	4-05-201	90	3.65	3.24	1.96	1.31	1.91	83	18.6	—	7
299	—silage, early vegetative	3-05-184	26	2.73	2.31	1.33	0.73	1.40	62	11.9	—	27
300	—straw	1-05-175	90	2.02	1.60	0.99	0.10	1.01	46	4.2	39	42

	On a Dry Basis (Moisture Free)																
Line No.	Lignin (%)	Acid Detergent Fiber (%)	Cell Walls (%)	Calcium (%)	Chlorine (%)	Cobalt (ppm)	Copper (ppm)	Iron (ppm)	Magnesium (%)	Manganese (ppm)	Phosphorus (%)	Potassium (%)	Sodium (%)	Sulfur (%)	Zinc (ppm)	Vitamin A (1,000 IU/kg)	Vitamin E (ppm)
248	5	42	72	0.56	—	0.13	36.8	200	0.40	93	0.31	1.54	0.02	0.06	—	24	—
249	—	—	—	0.48	—	0.27	36.6	140	0.49	99	0.19	2.56	0.02	0.06	—	10	—
250																	
251	—	—	—	1.29	—	—	—	300	0.79	—	0.33	0.97	0.12 '	0.26	—	14	—
252	—	—	—	1.29	—	—	—	300	0.79	—	0.33	0.97	0.12	0.26	—	13	—
253	2	46	67	0.45	—	0.12	17.8	320	—	14	0.17	1.03	0.05	—	24	0	—
254	13	54	70	1.59	—	—	—	—	0.92	51	0.06	0.53	—	—	—	0	—
255	—	—	—	1.25	—	—	9.3	400	0.38	114	0.49	0.93	0.09	0.30	—	31	—
256	—	—	—	0.28	0.03	—	17.6	90	0.31	33	0.66	1.79	0.13	0.24	18	0	37
257	—	10	14	0.36	0.03	0.100	40.8	130	0.30	31	0.75	2.21	0.31	0.49	48	0	2
258	—	—	—	0.36	0.03	0.100	40.8	130	0.30	31	0.75	2.21	0.31	0.49	48	0	2
259	—	—	—	0.36	0.03	0.100	40.8	130	0.30	31	0.75	2.21	0.31	0.49	48	0	2
260																	
261																	
262	—	—	—	0.90	—	—	—	100	0.10	—	0.29	0.50	0.20	0.10	—	0	—
263																	
264	12	33	40	0.46	0.20	—	3.8	40	0.79	25	1.12	1.16	1.31	—	—	0	—
265	—	—	—	0.40	0.11	—	3.8	40	0.81	25	1.10	1.07	1.30	—	—	0	12
266																	
267	—	—	—	1.27	0.37	—	10.1	150	0.49	103	0.26	1.34	0.10	0.49	—	40	—
268																	
269	—	—	—	0.28	—	—	—	200	0.15	—	0.28	2.40	0.19	0.13	—	94	—
270	4	37	64	0.25	0.63	—	11.2	200	0.15	—	0.25	1.71	0.19	0.13	—	78	—
271	3.1	33	63	0.66	—	—	—	200	0.14	—	0.34	—	—	—	—	50	—
272	4	37	64	0.53	—	—	—	200	0.14	—	0.26	0.92	—	—	—	21	13
273	5.5	40	66	0.41	—	—	—	140	0.16	46	0.19	1.59	0.18	0.13	—	21	—
274	7	43	68	0.38	—	—	—	160	0.17	—	0.18	1.63	—	—	—	18	—
275	11	45	70	0.28	—	—	—	—	0.12	—	0.18	1	0.01	—	—	11	—
276																	
277																	
278	11.4	50	55	—	—	—	—	—	—	—	—	—	—	—	—	0	—
279																	
280																	
281	8.8	36	47	1.75	—	0.11	9.3	230	0.51	15	0.22	1.80	0.88	77.2	—	57	—
282	—	—	—	2.20	—	0.21	—	—	—	—	0.25	1.83	—	—	—	—	—
283																	
284	10	34	44	0.56	—	—	21.33	110	0.22	43	0.22	2.99	1.05	0.43	—	0	—
285																	
286	11	43	58	1.18	—	0.350	9.9	380	0.27	73	0.34	2.12	0.52	0.15	—	154	—
287																	
288	3	12	45	0.12	0.07	0.011	13.8	190	0.58	130	1.32	1.39	0.07	0.25	124	1	3
289	—	—	—	0.06	0.09	0.190	9.8	60	0.28	150	1.16	0.98	0.03	0.27	136	0	159
290	—	—	—	0.06	—	0.09	8.1	60	0.18	55	0.41	0.58	—	—	—	0	—
291	—	—	—	0.05	0.06	0.160	5.4	40	0.12	44	0.45	0.48	0.02	0.17	43	0	12
292	—	4	14	0.06	0.09	0.150	7.8	40	0.11	40	0.41	0.46	0.02	0.13	30	0	34
293	7.9	—	—	0.17	—	—	—	60	0.18	16	0.40	0.58	0.10	0.22	—	0	—
294	3.9	30	52	0.42	—	—	—	—	0.21	—	0.40	3.50	0.07	0.19	—	208	—
295	7.3	41	68	0.14	—	—	—	200	0.12	—	0.18	1	0.28	0.24	—	45	—
296	—	—	—	0.12	0.03	0.100	19.6	100	0.41	132	1.01	1.08	0.19	0.18	146	0	40
297	—	—	—	0.10	—	0.200	20.8	100	0.57	114	1.13	1.42	0.24	0.22	—	0	—
298	—	—	—	0.12	0.08	0.100	10.3	110	0.29	116	0.84	0.94	0.02	0.26	—	0	32
299	—	—	—	0.27	0.07	0.044	13.8	190	0.62	130	0.27	1.39	0.07	0.24	—	103	3
300	13.7	54	85	0.21	0.30	0.040	3.3	200	0.12	40	0.08	1.11	0.14	0.19	—	1	—

TABLE 4 Composition of Feeds Commonly Used in Dairy Cattle Rations—Continued

				On a Dry Basis (Moisture Free)								
						Growing Dairy Cattle		Lactating Cows				
Line No.	Feedstuff	Reference Number	Dry Matter (%)	DE (Mcal/kg)	ME (Mcal/kg)	NE_m (Mcal/kg)	NE_g (Mcal/kg)	NE_l (Mcal/kg)	TDN (%)	Crude Protein (%)	Cellu-lose (%)	Crude Fiber (%)
301	WHEY, dehy	4-01-182	93	3.43	3.02	1.79	1.19	1.79	78	14	—	0
302	YEAST. *Saccharomyces cerevisiae*											
303	—brewers dried yeast	7-05-527	93	3.43	3.02	1.79	1.19	1.79	78	48.3	—	3
304	YEAST. *Torulopsis utilis*											
305	—dehy (torula dried yeast)	7-05-534	93	3.52	3.10	1.86	1.24	1.84	80	51.5	—	3

On a Dry Basis (Moisture Free)

Line No.	Lignin (%)	Acid Detergent Fiber (%)	Cell Walls (%)	Calcium (%)	Chlorine (%)	Cobalt (ppm)	Copper (ppm)	Iron (ppm)	Magnesium (%)	Manganese (ppm)	Phosphorus (%)	Potassium (%)	Sodium (%)	Sulfur (%)	Zinc (ppm)	Vitamin A (1,000 IU/kg)	Vitamin E (ppm)
301	—	—	—	0.98	0.08	0.116	51.4	140	0.14	5	0.81	0.92	1.10	1.12	3	1	0
302																	
303	—	—	—	0.14	0.13	0.200	35.5	100	0.25	6	1.54	1.85	0.08	0.41	42	0	2
304																	
305	—	—	—	0.63	0.02	—	14.4	100	0.14	14	1.81	2.02	0.01	0.37	107	0	—

FORMULATING RATIONS

The first step in formulating a ration is to calculate the nutrient requirements for the cow, or group of cows, to be fed the ration. This will vary with the size and age of the cow, amount of activity, and amount and fat content of the milk produced. Required amounts of energy, protein, calcium, and phosphorus for maintenance of mature lactating cows and for milk production appear in Table 2. For a 650-kg cow in a large dry lot dairy producing 27 kg of milk with 3.5 percent fat, the requirements are as follows:

	NE_l (Mcal)	Total Protein (kg)	Ca (kg)	P (kg)
Maintenance, 650-kg cow	10.30	0.515	0.0220	0.0180
Activity allowance (5%)	0.52	—	—	—
27-kg milk (3.5% fat)	18.63	2.214	0.0702	0.0472
TOTAL	29.45	2.729	0.0922	0.0652

The activity allowance of 5 percent of the NE_l for maintenance is an arbitrary decision, based on the statement in the narrative section on energy (p. 2): "Although these values should provide adequate energy for maintenance under most management systems, there may be instances where cows are required to move unusually long distances. In this situation the maintenance allowance should be increased by 3 percent for each additional kilometer walked." A 5 percent activity allowance was added in this case because the cow is in a large drylot dairy where considerable walking to and from the milking parlor is required.

The requirements listed above can be fulfilled with many different combinations of feed ingredients. In order to simplify this example, the ingredients will be restricted to alfalfa hay (early bloom); corn silage (well-eared); corn grain; meal (dent yellow); 46 percent protein soybean meal (solvent extracted); and dicalcium phosphate. Other feedstuffs and mineral mixtures could be used to fulfill the requirements. Local availability and relative prices usually determine which ingredients actually are used.

Begin with the roughage because, in most cases, forages are the least expensive source of nutrients, and available supplies of roughages usually must be fed on the farm where they are produced. See section on voluntary feed intake for estimating forage intake beginning on p. 54. In this case, the dairyman's forage supplies are such that he will feed 6 kg of alfalfa hay dry matter and 7 kg of corn silage dry matter per cow daily. With alfalfa hay and corn silage at 90 percent and 35 percent dry matter, respectively, this amounts to 6.67 kg of alfalfa hay and 20 kg of corn silage on an "as-fed" basis.

The nutrients provided by the alfalfa hay and corn silage can be calculated from Table 4, "Composition of Feeds," as shown in Table 5. The difference between the amounts of nutrients required by the cow and the amounts provided by the roughage must be fulfilled by the concentrate mix, as shown below:

	NE_l (Mcal)	Total Protein (kg)	Ca (kg)	P (kg)
Requirements	29.45	2.729	0.0922	0.0652
Provided by roughage (Table 5)	18.93	1.592	0.0939	0.0278
Needed in concentrate mix	10.52	1.137	0	0.0374

The roughage alone provides more than enough calcium in this example. Simultaneous equations can be used to determine the amounts of corn grain and soybean meal needed to fulfill the requirements for energy and protein. The requirement for phosphorus will be fulfilled later by addition of a high-phosphorus supplement, such as dicalcium phosphate.

In Table 4, corn grain, ground, dent yellow, contains 2.03 Mcal/kg of NE_l and 10 percent total protein. Values for 46 percent soybean meal, solvent extracted, are 1.86 Mcal/kg NE_l and 51.8 percent total protein. If X = the kg of corn dry matter to feed, and Y = the kg of soybean meal dry matter to feed, the calculations are as follows:

$$2.03X + 1.86Y = 10.52 \quad (NE_l) \quad (1)$$
$$0.10X + 0.518Y = 1.137 \quad (\text{Protein}) \quad (2)$$

Multiply Eq. (2) by the dividend obtained by dividing the coefficient for X in Eq. (1) by the coefficient for X in Eq. (2). In this case it would be 20.3 ($2.03 \div 0.10 = 20.3$). Multiplying Eq. (2) by 20.3 and subtracting it from Eq. (1) makes it possible to solve for Y:

$$2.03X + 1.86Y = 10.52 \quad (1)$$
$$-(2.03X + 10.5154Y = 23.0811) \quad (2)$$
$$-8.6554Y = -12.5611$$
$$Y = 1.4512 = \text{kg soybean meal DM to feed}$$

Substituting the value for Y in Eq. (1) makes it possible to solve for X:

$$2.03X + (1.86)(1.4512) = 10.52$$
$$2.03X = 10.52 - (1.86)(1.4512) = 7.8208$$
$$X = 3.853 = \text{kg corn grain DM to feed}$$

When the nutrients in 3.853 kg corn and 1.451 kg soybean meal are added to the nutrients provided by the roughage, requirements for energy and protein are satisfied (Table 5). However, there is still a deficit of 0.0146 kg of phosphorus. The amount of dicalcium phosphate needed to fulfill the phosphorus requirement can be calculated as follows:

$$\frac{\text{Kg phosphorus needed}}{\text{\% phosphorus in dicalcium phosphate}} \times 100 = \text{kg dicalcium phosphate to feed}$$

$$\frac{0.0146}{18.84} \times 100 = 0.078 \text{ kg dicalcium phosphate dry matter}$$

When the phosphorus in 0.078 kg dicalcium phosphate is added to the ration, the phosphorus requirement is fulfilled (Table 5).

The calculations in Table 5 are on a dry-matter basis. However, the amounts of ingredients fed, percentage composition of the total ration, and of the concentrate mix are also shown in Table 5 on an "as-fed" basis. This is calculated by dividing the kilograms of dry matter of each ingredient by its dry-matter content to put each ingredient on an "as-fed" basis. Dividing the kilograms of each ingredient as fed by the kilograms of total ration as fed, or

TABLE 5 Example Ration Formulated for a 650-kg Cow Producing 27 kg of Milk (3.5% Fat)

	Dry Matter Basis							As-Fed Basis			
	Amount Fed (kg)	NE_l (Mcal)	Total Protein (kg)	Calcium (kg)	Phosphorus (kg)	Crude Fiber (kg)	Acid Detergent Fiber (kg)	Dry Matter[a] (%)	Amount Fed (kg)	Total Ration (%)	Concentrate Mix (%)
Alfalfa hay (early bloom)	6.000	7.80[b]	1.032	0.0750	0.0138	1.86	2.28	90	6.67[c]	20.4[d]	
Corn silage (well-eared)	7.000	11.13	0.560	0.0189	0.0140	1.68	2.17	35	20.00	61.2	
Roughage subtotal	13.000	18.93	1.592	0.0939	0.0278	3.54	4.45		26.67	81.6	
Corn grain, meal (dent yellow)	3.853	7.82	0.385	0.0012	0.0119	0.08	0.12	89	4.33	13.2	71.7[e]
Soybean meal (solv-extd)	1.451	2.70	0.752	0.0052	0.0109	0.07	0.15	89	1.63	5.0	27.0
Dicalcium phosphate	0.078	—	—	0.0185	0.0147	—	—	96	0.08	0.2	1.3
Concentrate subtotal	5.382	10.52	1.137	0.0249	0.0375	0.15	0.27		6.04	18.4	100.0
Ration total	18.382	29.45	2.729	0.1188	0.0653	3.69	4.72		32.71	100.0	
Composition of DM		1.60[f]	14.8%	0.65%	0.36%	20.1%	25.7%				

[a] From Table 4.

[b] Alfalfa hay (early bloom) contains 1.30 Mcal/kg NE_l (Table 4): 6 kg × 1.30 Mcal/kg = 7.80 Mcal.

[c] 6 kg DM ÷ 90% DM = 6.67 kg (as fed).

[d] $\frac{6.67 \text{ kg alfalfa hay}}{32.71 \text{ kg total ration}} \times 100 = 20.4\%$.

[e] $\frac{4.33 \text{ kg corn grain}}{6.04 \text{ kg concentrate mix}} \times 100 = 71.7\%$.

[f] $\frac{29.45 \text{ Mcal } NE_l}{18.382 \text{ kg DM fed}} = 1.60$ Mcal/kg.

kilograms of concentrate mix as fed, and multiplying the results by 100, gives the percentage composition of ingredients in the total ration, or in the concentrate mix on an "as-fed" basis. Composition of the ration dry matter, as shown in Table 5, is calculated by dividing the amount of each nutrient provided by the ration by the kilograms of dry matter fed.

OTHER NUTRIENTS AND CONSIDERATIONS

Required daily amounts of NE_l, DE, ME, TDN, total protein, Ca, P, and vitamin A are included in Table 2. Recommended concentrations of these nutrients in the dry matter of rations for various age groups of dairy cattle are shown in Table 3. It also contains recommended concentrations for other nutrients such as ether extract, crude fiber, acid detergent fiber, mineral elements, and vitamins A, D, and E.

Ration formulation as shown in Table 5 is based on the amounts of nutrients listed in Table 2 rather than concentrations of nutrients as shown in Table 3 (see p. 36 for use of Table 3 data in ration formulation). However, data are inadequate to express requirements in this manner, for many nutrients, especially the minor mineral elements. Fortunately, legume forages are good sources of most of the mineral elements needed by the cow. When high-quality legumes make up half or more of the roughage in a dairy ration, most of the mineral requirements will be met. Exceptions to this are phosphorus and sodium, with the possibility of a few others under rare conditions. The sodium requirement usually can be fulfilled by including 0.5 percent salt (sodium chloride) in the concentrate mix, or by providing it *ad libitum* as granular salt or a salt block.

When poor-quality legumes or nonlegume forages predominate in a ration, more extensive mineral supplementation is required, especially calcium, manganese, zinc, iodine, and cobalt. Forages should be tested for their mineral content because there is extreme variation in the content of some minerals, even within the same type of forage. If the forages are low in certain mineral elements, additional amounts of those minerals should be fed to bring the concentration in the total ration dry matter up to the recommended concentrations listed in Table 3.

The fiber level in lactating cow rations is important for the health of the cow, and for production of milk with normal fat content. The minimum level suggested in Table 3 is 17 percent crude fiber (CF), or 21 percent acid detergent fiber (ADF), in the total ration dry matter. Amounts of CF and ADF provided by the example ration are shown in Table 5. The amount of crude fiber provided, 3.69 kg, divided by the total ration dry matter, 18.382 kg, equals 20.1 percent. Similar calculations show the ration to have 25.7 percent ADF. If the minimum fiber level had not been provided by the example ration, other feeds with higher fiber levels should be included in the ration because of a potential fat-test depression problem.

VOLUNTARY FEED INTAKE

Maximum dry matter intake must be considered when formulating rations. There is considerable variation between cows, depending on cow size, level of milk production, and quality of feed ingredients, particularly forages. A dry matter intake range of 2 percent to 4 percent of body weight may be observed within a herd. Guidelines for estimating maximum dry matter intake for cows weighing between 400 and 800 kg, and producing from 10 to 45 kg of milk daily, are shown in Table 6.

When formulating a ration, the total dry matter to be fed should be checked against the guidelines in Table 6 to see if the ration conceivably can be consumed by the cow. In the previous example, the ration for the 650-kg cow contains 18.382 kg of feed dry matter. This amounts to 2.83 percent of body weight ($18.382 \div 650 = 2.83$ percent). From Table 6, a 650-kg cow producing 25 kg of 4 percent fat-corrected-milk would be expected to eat about 2.9 percent of her body weight (interpolate between 600- and 700-kg body weights). Therefore, it is likely that the ration could be consumed in adequate amounts to fulfill the requirements of the example cow.

The data in Table 6 also are useful in estimating forage intakes when they are fed *ad libitum*. For example, if the dairyman in our previous example was feeding 6 kg of alfalfa hay dry matter and corn silage *ad libitum* to appetite, maximum silage dry matter consumption can be calculated as follows:

From Table 3, a 650-kg cow producing 27 kg of milk daily should be fed a ration with approximately 1.62 NE_l. The NE_l values for alfalfa hay and corn silage in the example are 1.30 and 1.59 Mcal/kg, respectively. If about half of the forage dry matter comes from alfalfa hay, and half from corn silage, the NE_l of the forage will be 1.45 Mcal/kg. Corn grain and soybean meal have NE_l values of 2.03 and 1.86 Mcal/kg, respectively. If about 75 percent of the concentrate dry matter consists of corn grain and about 25 percent is soybean meal, the NE_l of the concentrate mix will be 1.99 Mcal/kg.

Letting r = roughage and $1 - r$ = concentrate, the proportion of roughage that can be included in the ration and still meet the recommended NE_l concentration in the ration dry matter is calculated as follows:

$$1.45r + 1.99(1 - r) = 1.62 \qquad (NE_l)$$
$$1.45r + 1.99 - 1.99r = 1.62$$
$$-0.54r = -0.37$$
$$r = 0.6852 = 69 \text{ percent roughage in ration dry matter}$$

The cow in the example weighed 650 kg and was producing 27 kg of 3.5 percent milk. Converting this to 4 percent fat-corrected-milk (FCM), it is equivalent to 24.975 kg FCM [$0.4 \times \text{milk} + 15 \times \text{fat} = (0.4)(27) + (15)(0.945) = 24.975$]. From Table 6, interpolating between 600 and 700 kg, a 650-kg cow producing 25 kg FCM will have a maximum dry matter intake of about 2.9 per-

TABLE 6 Maximum, Dry Matter Intake Guidelines.[a]

Body Wt (kg)	400	500	600	700	800
FCM (4% milk)	←		% of Body Wt		→
10	2.5	2.3	2.2	2.1	2.0
15	2.8	2.5	2.4	2.3	2.2
20	3.1	2.8	2.7	2.6	2.4
25	3.4	3.1	3.0	2.8	2.6
30	3.7	3.4	3.2	3.0	2.8
35	4.0	3.6	3.4	3.2	3.0
40	—	3.8	3.6	3.4	3.2
45	—	4.0	3.8	3.6	3.4

[a] Derived from:
(1) Chandler, P. T., and C. A. Brown. 1975. Adjusting nutrient concentrations according to season of year and make up of group or herd. Unpublished report at Dairy Feed Conference Board, University of Delaware.
(2) Smith, N.E. 1971. Feed efficiency in intensive milk production. Proc. 10th Annual Dairy Cattle Day, p. 40. Dep. Anim. Sci., Univ. Calif., Davis.
(3) Swanson, E. W., S. A. Hinton, and J. T. Miles. 1967. Full lactation response on restricted vs. *ad libitum* roughage diets with liberal concentrate feeding. J. Dairy Sci. 50:1147–1152.
(4) Trimberger, G. W., H. G. Gray, W. L. Johnson, M. J. Wright, D. Van Vleck, and C. R. Henderson. 1963. Forage appetite in dairy cattle. Proc. Cornell Nutr. Conf. Feed Manuf., pp. 33–43.
(5) Trimberger, G. W., H. F. Tyrrell, D. A. Morrow, J. T. Reid, M. J. Wright, W. F. Shipe, W. G. Merrill, J. K. Loosli, C. E. Coppock, L. A. Moore, and C. H. Gordon. 1972. Effects of liberal concentrate feeding on health, reproductive efficiency, economy of milk production, and other related responses of the dairy cow. N.Y. Food Life Serv. Bull. No. 8.

cent of body weight. From this, the maximum silage dry matter intake can be calculated as follows:

650 kg cow × 2.9% = 18.85 kg ration DM
18.85 kg × 69% roughage = 13 kg roughage DM
13 kg − 6 kg hay DM = 7 kg silage DM

Therefore, if the cow in the example consumes 6 kg hay DM daily and roughages compose 69 percent of the ration dry matter, *ad libitum* silage DM intake will be about 7 kg. This is the basis for the amounts of forages specified in the example ration illustrated in Table 5.

NONLACTATING DAIRY ANIMALS

When formulating rations for lactating cows and for dry cows between lactations, a single net energy value (NE_l) is used for maintenance, gain, pregnancy, and milk production. However, when formulating rations for young nonlactating dairy animals such as dairy heifers, bulls, and veal calves, there are two net energy values in Table 1 on requirements (NE_m for maintenance and NE_g for gain) and two net energy values in the feed composition table (Table 4). The following example shows how to use these values:

How much of a ration composed of 70 percent alfalfa hay and 30 percent corn silage (dry matter basis) is required to fulfill the energy requirements of a 400-kg heifer gaining 0.7 kg per day?

	NE_m (Mcal)	NE_g (Mcal)	Dry Matter (%)
400-kg heifer gaining 0.7 kg per day (Table 1)	6.89	2.66	—
Alfalfa hay, mid-bloom (Table 4), Mcal/kg	1.19	0.51	89
Corn silage, well-eared (Table 4), Mcal/kg	1.54	0.97	35
70% alfalfa hay—30% corn silage	1.30	0.65	—

$$\text{Amount of ration dry matter for } NE_m = \frac{6.89}{1.30} = 5.30 \text{ kg}$$

$$\text{Amount of ration dry matter for } NE_g = \frac{2.66}{0.65} = 4.09 \text{ kg}$$

Total amount of ration dry matter required = 5.30 + 4.09 = 9.39 kg

9.39 kg × 70% alfalfa hay = 6.57 kg alfalfa hay dry matter
9.39 kg × 30% corn silage = 2.82 kg corn silage dry matter

To put these amounts on an "as-fed" basis, divide the kilograms of dry matter by the dry matter percentage of each feed and multiply by 100.

$$\frac{6.57 \text{ kg alfalfa hay DM}}{89} \times 100 = 7.4 \text{ kg alfalfa hay (as fed)}$$

$$\frac{2.82 \text{ kg corn silage DM}}{35} \times 100 = 8.1 \text{ kg corn silage (as fed)}$$

Therefore, a ration of 7.4 kg of alfalfa hay and 8.1 kg of corn silage (both on an as-fed basis) will fulfill the energy requirements for a 400-kg dairy heifer gaining 0.7 kg per day. Further calculation shows that this ration also fulfills the requirements for protein, calcium, and phosphorus. Salt should be available *ad libitum* as granular or block salt.

	Total Protein (kg)	Ca (kg)	P (kg)
Requirements for a 400-kg heifer gaining 0.7 kg per day (Table 1)	0.864	0.025	0.020
Provided by 6.57 kg alfalfa hay dry matter (Table 4)	1.051	0.089	0.014
Provided by 2.82 kg corn silage dry matter (Table 4)	0.226	0.008	0.006
TOTAL	1.277	0.097	0.020

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ENERGY

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APPENDIX

TABLE 1A Daily Nutrient Requirements of Dairy Cattle

				Feed Energy					Total Crude Protein	Minerals		Vitamins	
Body Weight (lb)	Breed Size, Age (wk)	Daily Gain (lb)	Feed DM (lb)	NE_m (Mcal)	NE_g (Mcal)	ME (Mcal)	DE (Mcal)	TDN (lb)	(lb)	Ca (lb)	P (lb)	A (1,000 IU)	D (IU)
Growing Dairy Heifer and Bull Calves Fed Only Milk													
55	S-1[a,b]	0.7	1.00	0.85	0.53	2.14	2.38	1.20	0.25	0.013	0.009	1.0	165
65	S-3	0.8	1.15	0.94	0.63	2.47	2.74	1.38	0.28	0.014	0.010	1.2	200
93	L-1	0.9	1.38	1.25	0.70	2.98	3.31	1.66	0.33	0.018	0.011	1.8	280
106	L-3	1.1	1.65	1.36	0.90	3.51	3.90	1.98	0.40	0.020	0.013	1.9	300
Growing Dairy Heifer (F) and Bull (M) Calves Fed Mixed Diets													
100		0.6	2.7	1.35	0.52	3.65	4.16	2.08	0.31	0.018	0.013	1.9	300
100(F)	S-10	0.8	2.8	1.35	0.69	3.98	4.51	2.25	0.36	0.020	0.013	1.9	300
100(M)	S-10	1.0	2.8	1.35	0.87	4.32	4.84	2.42	0.40	0.022	0.014	1.9	300
100(F)	L-3	1.2	2.8	1.35	1.05	4.58	5.10	2.55	0.44	0.024	0.015	1.9	300
100(M)	L-3	1.4	2.8	1.35	1.22	4.80	5.33	2.67	0.48	0.027	0.015	1.9	300
100		1.6	2.8	1.35	1.40	5.04	5.60	2.80	0.58	0.028	0.016	1.9	300
150		0.8	4.0	1.82	0.70	5.02	5.78	2.89	0.49	0.024	0.015	2.9	450
150(F)	S-19	1.0	4.1	1.82	0.88	5.39	6.17	3.08	0.55	0.026	0.015	2.9	450
150(M)	S-18	1.2	4.1	1.82	1.06	5.76	6.54	3.27	0.59	0.028	0.016	2.9	450
150(F)	L-9	1.4	4.1	1.82	1.24	6.07	6.85	3.42	0.64	0.031	0.017	2.9	450
150(M)	L-8	1.6	4.1	1.82	1.42	6.39	7.16	3.58	0.68	0.033	0.018	2.9	450
150		1.8	4.1	1.82	1.59	6.63	7.40	3.70	0.73	0.034	0.018	2.9	450
200		0.8	5.3	2.26	0.73	6.04	7.05	3.53	0.65	0.031	0.017	3.8	600
200		1.0	5.4	2.26	0.92	6.50	7.53	3.76	0.71	0.032	0.018	3.8	600
200(F)	S-26	1.2	5.4	2.26	1.10	6.86	7.88	3.94	0.75	0.034	0.018	3.8	600
200(M)	S-24	1.4	5.4	2.26	1.29	7.22	8.24	4.12	0.80	0.036	0.019	3.8	600
200(F)	L-14	1.6	5.4	2.26	1.47	7.52	8.53	4.27	0.85	0.038	0.020	3.8	600
200(M)	L-12	1.8	5.4	2.26	1.66	7.89	8.90	4.45	0.90	0.040	0.021	3.8	600
200		2.0	5.4	2.26	1.84	8.27	9.28	4.64	0.94	0.041	0.022	3.8	600
Growing Dairy Heifers													
300		0.8	7.9	3.07	0.83	8.12	9.64	4.82	0.88	0.034	0.021	5.8	900
300	S-38	1.0	7.9	3.07	1.04	8.60	10.11	5.06	0.92	0.036	0.022	5.8	900
300		1.2	7.9	3.07	1.25	8.98	10.51	5.25	0.96	0.037	0.023	5.8	900
300		1.4	7.9	3.07	1.46	9.47	10.97	5.48	1.00	0.039	0.024	5.8	900
300	L-23	1.6	7.9	3.07	1.66	9.89	11.40	5.70	1.04	0.041	0.025	5.8	900
300		1.8	7.9	3.07	1.87	10.26	11.76	5.88	1.09	0.043	0.026	5.8	900
400		0.8	10.5	3.81	0.96	10.16	12.18	6.09	1.15	0.040	0.026	7.7	1200
400	S-52	1.0	10.5	3.81	1.20	10.69	12.70	6.35	1.19	0.042	0.028	7.7	1200
400		1.2	10.5	3.81	1.44	11.24	13.26	6.63	1.22	0.043	0.029	7.7	1200

TABLE 1A Daily Nutrient Requirements of Dairy Cattle—Continued

				Feed Energy					Total Crude Protein	Minerals		Vitamins	
Body Weight (lb)	Breed Size, Age (wk)	Daily Gain (lb)	Feed DM (lb)	NE_m (Mcal)	NE_g (Mcal)	ME (Mcal)	DE (Mcal)	TDN (lb)	(lb)	Ca (lb)	P (lb)	A (1,000 IU)	D (IU)
400		1.4	10.5	3.81	1.68	11.75	13.76	6.88	1.26	0.044	0.030	7.7	1200
400	L-32	1.6	10.5	3.81	1.92	12.17	14.18	7.09	1.30	0.045	0.030	7.7	1200
400		1.8	10.5	3.81	2.16	12.68	14.68	7.34	1.33	0.046	0.031	7.7	1200
500		0.8	12.7	4.50	1.08	11.93	14.38	7.19	1.35	0.046	0.032	9.6	1500
500	S-67	1.0	12.7	4.50	1.35	12.60	15.04	7.52	1.38	0.047	0.033	9.6	1500
500		1.2	12.7	4.50	1.62	13.21	15.65	7.82	1.41	0.048	0.034	9.6	1500
500		1.4	12.7	4.50	1.89	13.77	16.20	8.10	1.44	0.049	0.035	9.6	1500
500	L-41	1.6	12.7	4.50	2.16	14.34	16.76	8.38	1.47	0.050	0.036	9.6	1500
500		1.8	12.7	4.50	2.43	14.90	17.32	8.66	1.50	0.051	0.037	9.6	1500
600		0.8	14.7	5.16	1.18	13.63	16.46	8.23	1.52	0.049	0.034	11.5	1800
600	S-81	1.0	14.7	5.16	1.47	14.37	17.20	8.60	1.53	0.049	0.035	11.5	1800
600		1.2	14.7	5.16	1.76	14.97	17.79	8.89	1.56	0.050	0.036	11.5	1800
600		1.4	14.7	5.16	2.06	15.62	18.44	9.22	1.59	0.051	0.037	11.5	1800
600	L-50	1.6	14.7	5.16	2.35	16.31	19.12	9.56	1.61	0.052	0.038	11.5	1800
600		1.8	14.7	5.16	2.65	16.90	19.70	9.85	1.64	0.053	0.039	11.5	1800
700		0.8	16.2	5.79	1.26	15.02	18.14	9.07	1.64	0.050	0.036	13.5	2100
700	S-95	1.0	16.4	5.79	1.57	15.86	19.02	9.51	1.67	0.051	0.037	13.5	2100
700		1.2	16.4	5.79	1.88	16.53	19.68	9.84	1.69	0.052	0.038	13.5	2100
700		1.4	16.4	5.79	2.20	17.22	20.36	10.18	1.72	0.053	0.039	13.5	2100
700	L-59	1.6	16.4	5.79	2.51	17.86	21.00	10.50	1.74	0.054	0.040	13.5	2100
700		1.8	16.4	5.79	2.83	18.55	21.68	10.84	1.76	0.054	0.041	13.5	2100
800	S-109	0.6	16.2	6.40	1.00	15.02	18.14	9.07	1.58	0.048	0.036	15.4	2400
800		0.8	17.6	6.40	1.33	16.33	19.72	9.86	1.75	0.054	0.038	15.4	2400
800		1.0	18.0	6.40	1.66	17.34	20.80	10.40	1.80	0.055	0.039	15.4	2400
800		1.2	18.0	6.40	1.99	18.00	21.46	10.73	1.82	0.056	0.040	15.4	2400
800	L-68	1.4	18.0	6.40	2.32	18.79	22.24	11.12	1.83	0.056	0.041	15.4	2400
800		1.6	18.0	6.40	2.66	19.52	22.96	11.48	1.85	0.057	0.042	15.4	2400
900	S-133	0.4	15.9	6.99	0.70	14.74	17.80	8.90	1.51	0.045	0.035	17.3	2700
900		0.6	17.4	6.99	1.04	16.14	19.49	9.74	1.68	0.050	0.039	17.3	2700
900		1.0	19.2	6.99	1.74	18.58	22.28	11.14	1.88	0.056	0.042	17.3	2700
900		1.2	19.2	6.99	2.09	19.35	23.04	11.52	1.90	0.057	0.043	17.3	2700
900	L-78	1.4	19.2	6.99	2.44	20.20	23.88	11.94	1.90	0.057	0.044	17.3	2700
900		1.6	19.2	6.99	2.78	20.91	24.58	12.29	1.92	0.058	0.045	17.3	2700
1000		0.4	17.1	7.57	0.73	15.86	19.16	9.58	1.60	0.049	0.040	19.2	3000
1000		0.6	18.7	7.57	1.09	17.34	20.94	10.47	1.78	0.054	0.042	19.2	3000
1000		1.0	20.2	7.57	1.82	19.75	23.64	11.82	1.95	0.060	0.045	19.2	3000
1000		1.2	20.2	7.57	2.18	20.56	24.44	12.22	1.96	0.060	0.046	19.2	3000
1000	L-88	1.4	20.2	7.57	2.55	21.39	25.26	12.63	1.97	0.060	0.046	19.2	3000
1000		1.6	20.2	7.57	2.91	22.16	26.02	13.01	1.98	0.060	0.046	19.2	3000
1100		0.4	18.3	8.13	0.76	16.97	20.50	10.25	1.70	0.051	0.042	21.2	3300
1100		0.8	20.9	8.13	1.53	19.79	23.82	11.91	1.98	0.060	0.045	21.2	3300
1100	L-98	1.2	20.9	8.13	2.29	21.69	25.70	12.85	1.99	0.060	0.046	21.2	3300
1100		1.6	20.9	8.13	3.06	23.39	27.38	13.69	2.00	0.060	0.046	21.2	3300
1200		0.4	19.4	8.68	0.79	17.98	21.72	10.86	1.79	0.053	0.042	23.1	3600
1200	L-110	0.8	21.6	8.68	1.58	20.90	25.06	12.53	2.01	0.060	0.044	23.1	3600
1200		1.2	21.6	8.68	2.38	22.64	26.78	13.39	2.02	0.060	0.044	23.1	3600
1200		1.6	21.6	8.68	3.17	24.40	28.52	14.26	2.04	0.061	0.046	23.1	3600
1300		0.4	20.5	9.21	0.82	19.01	22.96	11.48	1.88	0.054	0.040	25.0	3900
1300		0.8	21.9	9.21	1.63	21.63	25.84	12.92	2.01	0.058	0.040	25.0	3900
1300		1.2	21.9	9.21	2.45	23.62	27.82	13.91	2.01	0.058	0.042	25.0	3900
1300		1.6	21.9	9.21	3.26	25.39	29.56	14.78	2.02	0.058	0.042	25.0	3900
Growing Dairy Bulls													
300		1.0	7.9	3.07	1.01	8.53	10.04	5.02	0.93	0.036	0.022	5.8	900
300	S-34	1.4	7.9	3.07	1.41	9.36	10.86	5.43	1.02	0.039	0.024	5.8	900
300		1.8	7.9	3.07	1.82	10.12	11.62	5.81	1.11	0.043	0.026	5.8	900

TABLE 1A Daily Nutrient Requirements of Dairy Cattle—Continued

				Feed Energy					Total Crude Protein	Minerals		Vitamins	
Body Weight (lb)	Breed Size, Age (wk)	Daily Gain (lb)	Feed DM (lb)	NE_m (Mcal)	NE_g (Mcal)	ME (Mcal)	DE (Mcal)	TDN (lb)	(lb)	Ca (lb)	P (lb)	A (1,000 IU)	D (IU)
300	L-20	2.0	7.9	3.07	2.02	10.51	12.00	6.00	1.15	0.045	0.027	5.8	900
300		2.2	7.9	3.07	2.22	10.89	12.38	6.19	1.20	0.047	0.028	5.8	900
400		1.0	10.5	3.81	1.10	10.58	12.60	6.30	1.20	0.041	0.027	7.7	1200
400	S-44	1.4	10.5	3.81	1.54	11.45	13.46	6.73	1.29	0.044	0.029	7.7	1200
400		1.8	10.5	3.81	1.98	12.34	14.34	7.17	1.37	0.047	0.031	7.7	1200
400		2.0	10.5	3.81	2.20	12.76	14.76	7.38	1.41	0.048	0.032	7.7	1200
400	L-28	2.2	10.5	3.81	2.42	13.19	15.18	7.59	1.46	0.050	0.033	7.7	1200
500		1.0	12.7	4.50	1.18	12.24	14.68	7.34	1.41	0.048	0.032	9.6	1500
500	S-55	1.4	12.7	4.50	1.65	13.27	15.70	7.85	1.49	0.051	0.033	9.6	1500
500		1.8	12.7	4.50	2.12	14.30	16.72	8.36	1.56	0.053	0.035	9.6	1500
500		2.0	12.7	4.50	2.36	14.72	17.14	8.57	1.60	0.054	0.036	9.6	1500
500	L-34	2.2	12.7	4.50	2.60	15.18	17.60	8.80	1.64	0.056	0.037	9.6	1500
600		1.0	14.8	5.26	1.27	13.97	16.82	8.41	1.59	0.053	0.036	11.5	1800
600	S-65	1.4	14.8	5.26	1.78	15.22	18.06	9.03	1.64	0.055	0.038	11.5	1800
600		1.8	14.8	5.26	2.29	16.27	19.10	9.55	1.71	0.057	0.040	11.5	1800
600		2.0	14.8	5.26	2.54	16.77	19.60	9.80	1.75	0.058	0.041	11.5	1800
600	L-41	2.2	14.8	5.26	2.79	17.24	20.06	10.03	1.79	0.060	0.042	11.5	1800
700		1.0	17.0	6.02	1.38	15.86	19.14	9.57	1.76	0.056	0.040	13.5	2100
700	S-75	1.4	17.0	6.02	1.93	17.13	20.40	10.20	1.82	0.057	0.042	13.5	2100
700		1.8	17.0	6.02	2.48	18.37	21.62	10.81	1.87	0.059	0.043	13.5	2100
700		2.0	17.0	6.02	2.76	18.91	22.16	11.08	1.91	0.060	0.044	13.5	2100
700	S-47	2.2	17.0	6.02	3.04	19.48	22.72	11.36	1.94	0.061	0.045	13.5	2100
800		1.0	18.7	6.78	1.48	17.42	21.02	10.51	1.90	0.058	0.043	15.4	2400
800	S-85	1.4	18.7	6.78	2.07	18.89	22.48	11.24	1.93	0.058	0.044	15.4	2400
800		1.8	18.7	6.78	2.66	20.24	23.82	11.91	1.98	0.060	0.045	15.4	2400
800		2.0	18.7	6.78	2.96	20.85	24.42	12.21	2.01	0.061	0.045	15.4	2400
800	L-54	2.2	18.7	6.78	3.26	21.41	24.98	12.49	2.04	0.062	0.046	15.4	2400
900		1.0	20.0	7.55	1.62	19.15	23.00	11.50	1.96	0.060	0.045	17.3	2700
900	S-95	1.4	20.0	7.55	2.27	20.68	24.52	12.26	1.99	0.061	0.047	17.3	2700
900		1.8	20.0	7.55	2.92	22.18	26.00	13.00	2.02	0.062	0.049	17.3	2700
900		2.0	20.0	7.55	3.24	22.99	26.80	13.40	2.04	0.063	0.050	17.3	2700
900	L-60	2.2	20.0	7.55	3.56	23.39	27.20	13.60	2.08	0.064	0.050	17.3	2700
1000		1.0	21.0	8.33	1.73	20.62	24.66	12.33	2.00	0.061	0.046	19.2	3000
1000	S-106	1.2	21.0	8.33	2.08	21.42	25.45	12.73	2.01	0.062	0.047	19.2	3000
1000		1.6	21.0	8.33	2.77	23.02	27.04	13.52	2.04	0.063	0.048	19.2	3000
1000	L-67	2.0	21.0	8.33	3.46	24.44	28.44	14.22	2.08	0.064	0.050	19.2	3000
1000		2.2	21.0	8.33	3.81	25.10	29.10	14.55	2.10	0.065	0.050	19.2	3000
1100		0.8	22.0	8.94	1.45	20.93	25.17	12.58	2.06	0.062	0.049	21.2	3300
1100	S-118	1.2	22.0	8.94	2.17	22.70	26.92	13.46	2.07	0.062	0.049	21.2	3300
1100		1.6	22.0	8.94	2.90	24.40	28.60	14.30	2.09	0.063	0.050	21.2	3300
1100	L-74	1.8	22.0	8.94	3.26	25.17	29.40	14.70	2.10	0.064	0.050	21.2	3300
1100		2.0	22.0	8.94	3.62	25.87	30.06	15.03	2.12	0.064	0.051	21.2	3300
1200	S-129	0.6	22.6	9.55	1.13	20.96	25.32	12.66	2.08	0.063	0.049	23.1	3600
1200		1.0	23.0	9.55	1.88	22.95	27.37	13.69	2.13	0.064	0.050	23.1	3600
1200	L-82	1.4	23.0	9.55	2.63	24.81	29.22	14.61	2.13	0.064	0.050	23.1	3600
1200		1.8	23.0	9.55	3.38	26.43	30.82	15.41	2.16	0.065	0.051	23.1	3600
1300		0.6	23.7	10.14	1.16	21.97	26.54	13.27	2.16	0.064	0.049	25.0	3900
1300		1.0	23.7	10.14	1.94	24.03	28.58	14.29	2.16	0.064	0.050	25.0	3900
1300	L-92	1.4	23.7	10.14	2.72	25.99	30.52	15.26	2.16	0.065	0.050	25.0	3900
1300		1.8	23.7	10.14	3.49	27.72	32.24	16.12	2.17	0.066	0.051	25.0	3900
1400		0.2	21.5	10.71	0.40	19.94	24.08	12.04	1.89	0.064	0.049	26.9	4200
1400		0.6	24.3	10.71	1.19	22.88	27.60	13.80	2.19	0.065	0.050	26.9	4200
1400	L-102	1.0	24.3	10.71	1.99	25.08	29.74	14.87	2.18	0.065	0.050	26.9	4200
1400		1.4	24.3	10.71	2.79	26.96	31.60	15.80	2.18	0.065	0.051	26.9	4200
1500		0.2	22.5	11.28	0.41	20.86	25.20	12.60	1.97	0.064	0.050	28.8	4500

TABLE 1A Daily Nutrient Requirements of Dairy Cattle—Continued

				Feed Energy					Total	Minerals		Vitamins	
Body Weight (lb)	Breed Size, Age (wk)	Daily Gain (lb)	Feed DM (lb)	NE_m (Mcal)	NE_g (Mcal)	ME (Mcal)	DE (Mcal)	TDN (lb)	Crude Protein (lb)	Ca (lb)	P (lb)	A (1,000 IU)	D (IU)
1500	L-116	0.6	24.9	11.28	1.22	23.95	28.74	14.37	2.21	0.065	0.050	28.8	4500
1500		1.0	24.9	11.28	2.03	26.01	30.78	15.39	2.20	0.066	0.051	28.8	4500
1500		1.4	24.9	11.28	2.84	27.86	32.62	16.31	2.20	0.066	0.051	28.8	4500
1600		0.2	23.6	11.84	0.41	21.89	26.44	13.22	2.05	0.064	0.050	30.8	4800
1600	L-140	0.6	25.5	11.84	1.22	24.83	29.74	14.87	2.23	0.066	0.051	30.8	4800
1600		1.0	25.5	11.84	2.04	26.99	31.88	15.94	2.22	0.066	0.051	30.8	4800
1700	L-163	0.2	24.6	12.40	0.41	22.82	27.56	13.78	2.14	0.064	0.051	32.7	5100
1700		0.6	26.1	12.40	1.23	25.62	30.64	15.32	2.27	0.066	0.051	32.7	5100
1700		1.0	26.1	12.40	2.05	27.78	32.78	16.39	2.26	0.066	0.051	32.7	5100
Growing Veal Calves Fed Only Milk													
75	—	1.10	1.5	0.97	0.90	3.16	3.51	1.8	0.38	0.015	0.011	1.4	225
100	L-1.0	1.75	2.3	1.37	1.51	5.03	5.59	2.8	0.57	0.018	0.013	1.9	300
125	L-3.0	2.00	2.7	1.59	1.75	5.83	6.48	3.2	0.65	0.024	0.015	2.4	375
150	L-4.8	2.20	3.0	1.82	1.96	6.57	7.30	3.7	0.72	0.029	0.018	2.9	450
175	L-6.4	2.30	3.3	2.05	2.09	7.12	7.91	4.0	0.74	0.033	0.020	3.4	525
200	L-8.0	2.40	3.6	2.26	2.23	7.68	8.53	4.3	0.77	0.035	0.021	3.8	600
225	L-9.5	2.50	3.8	2.47	2.38	8.25	9.17	4.6	0.81	0.037	0.022	4.3	675
250	L-10.9	2.65	4.1	2.67	2.58	8.94	9.93	5.0	0.86	0.039	0.023	4.8	750
275	L-12.3	2.75	4.4	2.87	2.74	9.53	10.59	5.3	0.89	0.040	0.024	5.3	825
300	L-13.6	2.80	4.6	3.07	2.86	10.02	11.14	5.6	0.92	0.041	0.025	5.8	900
325	L-14.9	2.85	4.9	3.26	2.97	10.48	11.65	5.8	0.94	0.042	0.026	6.3	975
Maintenance of Mature Breeding Bulls													
1200	—	—	18.3	9.98	—	17.01	20.54	10.3	1.58	0.042	0.036	23.1	—
1400	—	—	20.6	11.20	—	19.07	23.04	11.5	1.76	0.049	0.040	26.9	—
1600	—	—	22.7	12.38	—	21.08	25.46	12.7	1.93	0.057	0.045	30.8	—
1800	—	—	24.9	13.53	—	23.05	27.84	13.9	2.09	0.064	0.049	34.6	—
2000	—	—	26.9	14.64	—	24.94	30.12	15.1	2.25	0.071	0.053	38.5	—
2200	—	—	28.9	15.72	—	26.77	32.34	16.2	2.41	0.079	0.057	42.3	—
2400	—	—	30.8	16.78	—	28.58	34.52	17.3	2.56	0.086	0.061	46.2	—
2600	—	—	32.7	17.82	—	30.35	36.66	18.3	2.71	0.093	0.064	50.0	—
2800	—	—	34.6	18.84	—	32.09	38.76	19.4	2.85	0.099	0.068	53.9	—
3000	—	—	36.5	19.84	—	33.79	40.82	20.4	3.00	0.107	0.072	57.7	—

[a] Breed size: S for small breeds (e.g., Jersey); L is for large breeds (e.g., Holstein).

[b] Age in weeks indicates probable age of S or L animals when they reach the weight indicated.

TABLE 2A Daily Nutrient Requirements of Lactating and Pregnant Cows

Body Weight (lb)	Feed Energy NE$_l$ (Mcal)	ME (Mcal)	DE (Mcal)	TDN (lb)	Total Crude Protein (lb)	Calcium (lb)	Phosphorus (lb)	Vitamin A (1,000 IU)
Maintenance of Mature Lactating Cows[a]								
700	6.02	10.00	11.66	5.84	0.71	0.028	0.023	24
800	6.65	11.06	12.89	6.45	0.77	0.032	0.026	28
900	7.27	12.08	14.08	7.05	0.83	0.035	0.028	31
1,000	7.86	13.07	15.23	7.63	0.89	0.038	0.030	35
1,100	8.45	14.04	16.36	8.19	0.95	0.040	0.032	38
1,200	9.02	14.99	17.47	8.75	1.01	0.043	0.034	41
1,300	9.57	15.91	18.55	9.29	1.06	0.046	0.037	45
1,400	10.12	16.82	19.61	9.82	1.12	0.048	0.039	48
1,500	10.66	17.72	20.65	10.34	1.17	0.051	0.041	52
1,600	11.19	18.60	21.67	10.85	1.22	0.053	0.043	55
1,700	11.71	19.46	22.68	11.36	1.27	0.056	0.045	59
1,800	12.22	20.31	23.67	11.86	1.32	0.059	0.047	62
Maintenance Plus Last 2 Months Gestation of Mature Dry Cows								
700	7.82	13.01	15.12	7.60	1.32	0.047	0.033	24
800	8.65	14.38	16.71	8.40	1.45	0.053	0.038	28
900	9.45	15.71	18.25	9.17	1.57	0.059	0.042	31
1,000	10.22	17.00	19.76	9.93	1.69	0.064	0.045	35
1,100	10.98	18.26	21.22	10.66	1.80	0.070	0.050	38
1,200	11.72	19.50	22.65	11.38	1.92	0.075	0.053	41
1,300	12.44	20.70	24.05	12.08	2.03	0.080	0.057	45
1,400	13.16	21.88	25.43	12.78	2.13	0.085	0.060	48
1,500	13.85	23.05	26.78	13.45	2.24	0.090	0.064	52
1,600	14.54	24.19	28.10	14.12	2.34	0.095	0.067	55
1,700	15.22	25.32	29.41	14.78	2.44	0.100	0.071	59
1,800	15.88	26.42	30.70	15.42	2.54	0.105	0.075	62
Milk Production—Nutrients Per Pound of Milk of Different Fat Percentages								
Fat (%)								
2.5	0.27	0.45	0.52	0.260	0.072	0.0024	0.0017	—
3.0	0.29	0.49	0.56	0.282	0.077	0.0025	0.0017	—
3.5	0.31	0.53	0.61	0.304	0.082	0.0026	0.0018	—
4.0	0.34	0.56	0.65	0.326	0.087	0.0027	0.0018	—
4.5	0.36	0.60	0.69	0.344	0.092	0.0028	0.0019	—
5.0	0.38	0.63	0.73	0.365	0.098	0.0029	0.0019	—
5.5	0.40	0.67	0.78	0.387	0.103	0.0030	0.0020	—
6.0	0.42	0.71	0.82	0.410	0.108	0.0031	0.0021	—
Body Weight Change During Lactation—Nutrients Per Pound Weight Change								
Weight loss	−2.23	−3.74	−4.33	−2.17	−0.32			
Weight gain	2.32	3.88	4.52	2.26	0.50			

[a] To allow for growth of young lactating cows, increase the maintenance allowances for all nutrients except vitamin A by 20 percent during the first lactation and 10 percent during the second lactation.

TABLE 3A Recommended Nutrient Content of Rations for Dairy Cattle

	Lactating Cow Rations					Nonlactating Cattle Rations					
	Cow Wt (lb)	Daily Milk Yields (lb)									
Nutrients (Concentration in the Feed Dry Matter)	≤ 900 1,100 1,300 ≥1,550	<18 <24 <31 <40	18–29 24–37 31–46 40–57	29–40 37–51 46–64 57–78	>40 >51 >64 >78	Dry Pregnant Cows	Mature Bulls	Growing Heifers and Bulls	Calf Starter Concentrate Mix	Calf Milk Replacer	Maximum Concentrations (All Classes)
Ration No.		I	II	III	IV	V	VI	VII	VIII	IX	Max.
Crude Protein, %		13	14	15	16	11	8.5	12.0	16.0	22.0	—
Energy											
NE_l, Mcal/lb		0.64	0.69	0.73	0.78	0.61	—	—	—	—	—
NE_m, Mcal/lb		—	—	—	—	—	0.54	0.57	0.86	1.09	—
NE_g, Mcal/lb		—	—	—	—	—	—	0.27	0.54	0.70	—
ME, Mcal/lb		1.07	1.15	1.23	1.31	1.01	0.93	1.01	1.42	1.71	—
DE, Mcal/lb		1.26	1.34	1.42	1.50	1.20	1.12	1.20	1.60	1.90	—
TDN, %		63	67	71	75	60	56	60	80	95	—
Crude Fiber, %		17	17	17	17[a]	17	15	15	—	—	—
Acid Detergent Fiber		21	21	21	21	21	19	19	—	—	—
Ether Extract, %		2	2	2	2	2	2	2	2	10	—
Minerals[b]											
Calcium, %		0.43	0.48	0.54	0.60	0.37	0.24	0.40	0.60	0.70	—
Phosphorus, %		0.31	0.34	0.38	0.40	0.26	0.18	0.26	0.42	0.50	—
Magnesium, %[c]		0.20	0.20	0.20	0.20	0.16	0.16	0.16	0.07	0.07	—
Potassium, %		0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	—
Sodium, %		0.18	0.18	0.18	0.18	0.10	0.10	0.10	0.10	0.10	—
Sodium chloride, %[d]		0.46	0.46	0.46	0.46	0.25	0.25	0.25	0.25	0.25	5
Sulfur, %[d]		0.20	0.20	0.20	0.20	0.17	0.11	0.16	0.21	0.29	0.35
Iron, ppm[d,e]		50	50	50	50	50	50	50	100	100	1,000
Cobalt, ppm		0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	10
Copper, ppm[d,f]		10	10	10	10	10	10	10	10	10	80
Manganese, ppm[d]		40	40	40	40	40	40	40	40	40	1,000
Zinc, ppm[d,g]		40	40	40	40	40	40	40	40	40	500
Iodine, ppm[h]		0.50	0.50	0.50	0.50	0.50	0.25	0.25	0.25	0.25	50
Molybdenum, ppm[i,j]		—	—	—	—	—	—	—	—	—	6
Selenium, ppm		0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	5
Fluorine, ppm[j]		—	—	—	—	—	—	—	—	—	30
Vitamins[k]											
Vit A, IU/lb		1,450	1,450	1,450	1,450	1,450	1,450	1,000	1,000	1,720	—
Vit D, IU/lb		140	140	140	140	140	140	140	140	270	—
Vit E, ppm		—	—	—	—	—	—	—	—	300	—

[a] It is difficult to formulate high-energy rations with a minimum of 17 percent crude fiber. However, fat percentage depression may occur when rations with less than 17 percent crude fiber or 21 percent ADF are fed to lactating cows.

[b] The mineral values presented in this table are intended as guidelines for use of professionals in ration formulation. Because of many factors affecting such values, they are not intended and should not be used as a legal or regulatory base.

[c] Under conditions conducive to grass tetany (see text), should be increased to 0.25 or higher.

[d] The maximum safe levels for many of the mineral elements are not well defined; estimates given here, especially for sulfur, sodium chloride, iron, copper, zinc, and manganese, are based on very limited data; safe levels may be substantially affected by specific feeding conditions.

[e] The maximum safe level of supplemental iron in some forms is materially lower than 1,000 ppm. As little as 400 ppm added iron as ferrous sulfate has reduced weight gains (Standish *et al.*, 1969).

[f] High copper may increase the susceptibility of milk to oxidized flavor (see text).

[g] Maximum safe level of zinc for mature dairy cattle is 1,000 ppm.

[h] If diet contains as much as 25 percent strongly goitrogenic feed on dry basis, iodine provided should be increased two times or more.

[i] If diet contains sufficient copper, dairy cattle tolerate substantially more than 6 ppm molybdenum (see text).

[j] Maximum safe level of fluorine for growing heifers and bulls is lower than for other dairy cattle. Somewhat higher levels are tolerated when the fluorine is from less-available sources, such as phosphates (see text). Minimum requirement for molybdenum and fluorine not yet established.

[k] The following minimum quantities of B-complex vitamins are suggested per unit of milk replacer: niacin, 2.6 ppm; pantothenic acid, 13 ppm; riboflavin, 6.5 ppm; pyridoxine, 6.5 ppm; thiamine, 6.5 ppm; folic acid, 0.5 ppm; biotin, 0.1 ppm; vitamin B_{12}, 0.07 ppm; choline, 0.26 percent. It appears that adequate amounts of these vitamins are furnished when calves have functional rumens (usually at 6 weeks of age) by a combination of rumen synthesis and natural feedstuffs.