# Nutrient Requirements of Beef Cattle (1984)

Pages
63

Size
8.5 x 10

ISBN
0309034477

Subcommittee on Beef Cattle Nutrition; Committee on Animal Nutrition; Board on Agriculture; National Research Council

# Nutrient Requirements of Beef Cattle

## Sixth Revised Edition, 1984

Subcommittee on Beef Cattle Nutrition
Committee on Animal Nutrition
Board on Agriculture
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1984

**National Academy Press, 2101 Constitution Avenue, NW, Washington, DC 20418**

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

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.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

This study was supported by the Bureau of Veterinary Medicine, Food and Drug Administration of the U.S. Department of Health and Human Services; the Agricultural Research Service of the U.S. Department of Agriculture; Agriculture Canada; and the American Feed Manufacturers Association.

**Library of Congress Cataloging in Publication Data**

Main entry under title:

Nutrient requirements of beef cattle.

(Nutrient requirements of domestic animals)
Bibliography: p.
Includes index.
1. Beef cattle—Feeding and feeds. I. National
Research Council (U.S.). Subcommittee on Beef Cattle
Nutrition. II. Series.
SF203.N88 1984 636.2′13 84-4804
ISBN 0-309-03447-7



Printed in the United States of America

# Preface

This report is one of a series issued under the direction of the Committee on Animal Nutrition, Board on Agriculture, of the National Research Council. It was prepared by the Subcommittee on Beef Cattle Nutrition and replaces the fifth revised edition of *Nutrient Requirements of Beef Cattle*, issued in 1976.

The report has been completely rewritten and updated. The main points of the revision are as follows:

1. Requirements for growing and finishing cattle are presented on the basis of medium- and large-frame animals.
2. Energy requirements and energy contents of feedstuffs for beef cattle have been recalculated from a larger data base.
3. Sections have been included on processing of feedstuffs and environmental influences on nutrient requirements of beef cattle.
4. The section on ration formulation has been deleted and is replaced by a section on prediction equations to permit estimates of feed intake, energy, protein, calcium and phosphorus requirements, and weight gain.
5. A table is presented on estimated water intake of cattle.
6. A separate table for composition of mineral supplements has been added. The text on minerals has been expanded.

To all individuals who contributed to this manuscript, the subcommittee expresses appreciation. In particular, the subcommittee expresses its thanks to Clarence B. Ammerman, Floyd M. Byers, Danny G. Fox, and Rodney L. Preston, who reviewed the report and provided insightful comments and suggestions for the subcommittee's consideration.

Review of this report was accomplished through the advice and guidance of the members of the Committee on Animal Nutrition. The subcommittee is indebted to Philip Ross, Deputy Executive Director, and Selma P. Baron, Staff Officer, of the Board on Agriculture, for their assistance in the preparation of this report. The subcommittee is especially grateful to Joseph P. Fontenot, who served as coordinator for the Board on Agriculture for the review of this report.

*CAN Subcommittee on Beef Cattle Nutrition*

WILLIAM H. HALE, *Chairman*
University of Arizona

JOCK G. BUCHANAN-SMITH
University of Guelph

WILLIAM N. GARRETT
University of California-Davis

GEORGE E. MITCHELL, JR.
University of Kentucky

DONALD C. CLANTON
University of Nebraska

RICHARD D. GOODRICH
University of Minnesota

FREDRIC N. OWENS
Oklahoma State University

# Contents

# 1 Introduction

With finite land resources and increasing world population, the use of animals is required to maximize food production and maintain the quality of life. Efficient animal production is not possible unless nutrient requirements are met. This edition of *Nutrient Requirements of Beef Cattle* is an extensive revision of the fifth edition, published in 1976.

Types of beef cattle have changed in response to economic pressures and consumer demand for leaner meats. The basic biology of all beef cattle is similar, but differences in mature size and rate of maturing have a marked influence on application of basic nutrition principles to the wide range of environmental and management conditions of practice. For this reason, the frame size of the animal has been considered in calculating nutrient requirements. The medium-frame steer was considered to have 450 to 520 kg live weight at usual market finish and the medium-frame heifer, 400 to 475 kg. The finished weight was considered to be over 520 and 475 kg for large-frame steers and heifers, respectively. Requirements are given for yearling steers and heifers showing compensatory growth (compensating yearling heifers and steers). Nutrient requirements have been determined for growing and finishing bulls, as bull feeding for carcass beef has become an important segment of the cattle feeding industry.

Growing and finishing cattle requirements for energy, protein, calcium, and phosphorus in amounts per day are presented in separate tables. Nutrient requirements expressed as nutrient concentrations in diet dry matter have been calculated from estimated feed intake and are presented in avoirdupois units. For the breeding herd, daily nutrient requirements and nutrient requirements expressed as nutrient concentrations in diet dry matter are presented in the same table. They are expressed in both metric and avoirdupois units in separate tables.

Net energy requirements and net energy contents of feeds have been recalculated from a larger data base. Requirements are listed on a live weight (shrunk) basis. Since animal requirements and feed values have been altered, it is inappropriate to use previous requirements or feed values in conjunction with information in this edition. The energy values given for the same International Feed Number (IFN) for a feed in the third revision of *United States-Canadian Tables of Feed Composition* (NRC, 1982) are not appropriate because equations for calculating ME, $NE_m$, and $NE_g$ are different. The equations used for calculating the energy values given in Table 8 are from equations given in the Energy section in Chapter 2 and on page 38.

An estimate of feed intake is necessary to calculate protein requirements and to list nutrient needs on a concentration basis. Feed intake equations have been developed for this purpose.

Digestible protein is no longer listed in tables, and crude protein requirements have been calculated factorially from equations that are presented in the Protein section. Protein requirements as given in this report do not consider safety margins, and the reader is referred to the discussion in the Protein section. Slight adjustments have been made in phosphorus requirements and major adjustments in calcium requirements, as true digestibility of calcium was considered to be 50 percent.

The feed composition table (Table 8) has been rearranged, and data on plant cell wall constituents have been added where they were available. Common mineral supplements used in cattle feeding appear in a separate table.

A list of formulas for calculating nutrient requirements for various classes of beef cattle has been added to simplify application of these requirements to computer use.

# 2 Nutrient Requirements: Excesses and Deficiencies

## ENERGY

Energy is an abstraction and can be measured only in reference to some defined standard conditions. Nutritionists now standardize their combustion (bomb) calorimeters using specifically purified benzoic acid, the caloric value of which has been determined in electrical units and computed in terms of joules/g mole. The calorie has, therefore, been standardized to equal 4.184 joules (Moore, 1977). This is approximately the amount of heat required to raise the temperature of 1 g of water from 16.5° to 17.5°C. The joule and the calorie are interchangeable, and each is a defined unit; neither is more absolute. The calorie represents a small amount of energy; thus, the kilogram calorie (1 kcal = 1000 calories) and the megacalorie (1 Mcal = 1,000,000 calories = 1000 kilocalories) are more convenient to use in conjunction with animal feeding standards.

Gross energy (E) is the heat released (heat of combustion) when an organic substance is completely oxidized to carbon dioxide and water. Gross energy is related to chemical composition. For example, Nehring and Haenlein (1973) relate gross energy of feedstuffs to their proximate constituents by the relationship:

E, kcal/100 g = 5.72 (crude protein, percent) + 9.5 (ether extract, percent) + 4.79 (crude fiber, percent) + 4.03 (nitrogen-free extract, percent).

Gross energy contained in a feedstuff is of limited use for assessing the value of a particular ingredient or diet as an energy source for animals. It does not provide information regarding the availability of the energy to the animal.

### *Expressing Energy Values of Feedstuffs*

The gross energy of a food minus the energy lost in the feces is termed digestible energy (DE). An approximately equivalent term, total digestible nutrients (TDN), attempts to measure digestible energy in weight units. TDN has no advantages over DE as the unit to describe feed values or to express animal requirements (Maynard, 1953). TDN can be converted to DE by the relationship 1 kg of TDN = 4.4 Mcal of DE (Schneider and Flatt, 1975). DE has the advantage of ease of measurement but fails to consider all losses of energy associated with the digestion and metabolism of food nutrients. The major weakness of DE as a basis for feeding systems is that it overestimates the available energy of high-fiber feedstuffs (hays, straws) relative to low-fiber, highly digestible products, such as grains.

Metabolizable energy (ME) is a measure of the dietary energy available for metabolism after energy losses that occur in the urine (UE), and the combustible gases (chiefly methane) are subtracted from digestible energy. ME has many of the same deficiencies as a basis for feeding systems as DE, because urinary energy losses and energy lost as methane are relatively predictable from DE; therefore, DE and ME are highly correlated. ME is most valuable as the starting point for nearly all systems of feed evaluation that are based on net energy concepts.

Classically, net energy is the net quantity of energy that is recovered (RE) in an animal product. RE can be a negative quantity for animals fed below their maintenance requirements. The use of net energy as the basis for a system of feed evaluation is complicated by the fact that the ME available from an animal's diet is used at different levels of efficiency depending on the physiological state of the animal (maintenance, growth, lactation, pregnancy) as well as the makeup of the diet. These complications have been partially accounted for in a net energy system for beef cattle by the convention that assigns two net energy values to each feedstuff. Animal requirements for energy are similarly subdivided. Net energy available or required for maintenance is termed $NE_m$, and net energy available or required for growth is termed $NE_g$ (Lofgreen and Garrett, 1968; NRC, 1981a). Two major advantages of the net energy system are: (a) animal requirements stated as net energy are independent of the diet, i.e., do not have to be adjusted for different roughage-concentrate ratios, and (b) feed requirements for maintenance are estimated separately from feed needed for the productive functions.

Interconversions between DE, ME, and NE values of feedstuff are possible. The following relationships have been estimated (all units are Mcal/kg DM):

$ME = 0.82\ DE$ (NRC, 1976; ARC, 1965).

$NE_m = 1.37\ ME - 0.138\ ME^2 + 0.0105\ ME^3 - 1.12$ (Garrett, 1980a).

$NE_g = 1.42\ ME - 0.174\ ME^2 + 0.0122\ ME^3 - 1.65$ (Garrett, 1980a).

*Animal Requirements for Energy*

The maintenance requirement for energy can be defined as that amount of feed energy that will result in no loss or gain in body energy. For some beef animals near their mature size (adult bulls, for example), maintenance may be the usual physiological state and the practical feeding goal. Maintenance in most other beef animals is more a theoretical condition that differs from the usual physiological or practical state. Nevertheless it is convenient and appropriate to consider maintenance energy requirements separately from any production requirement. Net energy required for maintenance is, by definition, the amount of energy equivalent to the fasting heat production. The $NE_m$ requirements for maintenance of beef cattle have been estimated as 77 kcal/$W^{0.75}$; W is body weight in kilograms (Lofgreen and Garrett, 1968; Garrett, 1980a). Maintenance requirements estimated by this expression are most applicable for penned animals in nonstressful environments with minimal activity. There are variations in maintenance requirements based on sex and breed (Garrett, 1971; Frisch and Vercoe, 1977; Webster, 1978). Physiological age also has an influence (Geay, 1982). The magnitude of these effects appears to be from 3 to 14 percent. In general, breeds and individuals maturing at heavier weights may require more, and *Bos indicus* breeds and crosses may require less energy for maintenance than would be estimated by the expression 77 $W^{0.75}$.

The efficiency of ME utilization must be considered in order to estimate the quantity of ME or DE (TDN) required for maintenance. The efficiency of ME use for maintenance or gain can be calculated for feedstuffs or mixed diets by using the relationship between $NE_m$ and ME or $NE_g$ and ME. Some values are given as examples in the table below. TDN and DE requirements were obtained by the conversion 1 kg TDN = 3.62 Mcal of ME and DE = ME/0.82 (NRC, 1976).

Efficiency of ME Use for Maintenance and Gain

| ME Concentration (Mcal/kg) | Approximate Roughage: Concentrate[a] | Efficiency of ME utilization | |
|---|---|---|---|
| | | Maintenance | Gain |
| 2.0 | 100:0 | 57.6 | 29.6 |
| 2.2 | 83:17 | 60.8 | 34.6 |
| 2.4 | 67:33 | 63.3 | 38.5 |
| 2.6 | 50:50 | 65.1 | 41.5 |
| 2.8 | 33:67 | 66.6 | 43.9 |
| 3.0 | 17:83 | 67.7 | 45.8 |
| 3.2 | 0:100 | 68.6 | 47.3 |

[a]Assuming average quality roughage contains 2.0 Mcal/kg and that the average concentrate contains 3.2 Mcal/kg.

The NE requirements for growth ($NE_g$) are estimated as the amount of energy deposited as nonfat organic matter (mostly protein) plus that deposited as fat. The caloric value of fat is 9.4 kcal/g, and for the nonfat organic matter an average value is 5.6 kcal/g. The quantities of protein and fat being deposited are related to two factors: (a) the intake of energy above the maintenance requirement (assuming all other nutrient requirements are also satisfied) and (b) the impetus to grow (i.e., the phase of growth or weight obtained relative to mature weight). For most conditions (continuously grown animals or mature animals without severely depleted energy stores), the energy content of a unit weight gain will be between 1.2 and 8.0 Mcal/kg. These figures are the energy content of the fat-free body (73 percent water, 22 percent protein, 5 percent minerals) (Reid et al., 1955; Garrett and Hinman, 1969) and an average energy content of adipose tissue. The composition of adipose tissue is variable between depots and with the total fatness of the animal, but it is unlikely to contain more than 85 percent fat as an average of all depots (Berg and Butterfield, 1976; Loveday and Dikeman, 1980). All relationships to estimate the caloric value of weight gain have been determined for some particular breeds and sex classes and therefore may have to be adjusted for most precise use for other breed types and conditions (see ARC, 1980, for a review). The relationship between retained energy (RE) and an observed weight gain is also influenced by the contents of the digestive tract, which can vary from less than 5 percent to 21 percent of the shrunk weight of cattle (Kay et al., 1970; Garrett, 1974a; Jesse et al., 1976; ARC, 1980) depending on the diet and the weighing conditions.

The primary relationships (data from Garrett, 1980a, and Garrett, unpublished) used to estimate the caloric value (RE is equivalent to the $NE_g$ requirement) of the daily empty body weight gain (EBG) of medium-frame British breed steers and heifers receiving hormonal adjuvants are:

$$\text{For steers: RE} = 0.0635\ W^{0.75}\ EBG^{1.097} \quad (1)$$

$$\text{For heifers: RE} = 0.0783\ W^{0.75}\ EBG^{1.119} \quad (2)$$

Equivalent relationships in logarithmic form are:

$$\text{For steers: Log}\ (RE/W^{0.75}) = 1.097 \log EBG - 1.197$$

$$\text{For heifers: Log}\ (RE/W^{0.75}) = 1.119 \log EBG - 1.106$$

In these equations, daily EBG and animal weight (W) are in kilograms on an empty body basis. The unit for RE is Mcal/day. The $NE_g$ is equivalent to the RE.

These basic relationships are easily modified for application to specific practical conditions. For example, information summarized by Garrett (1980a) indicates that cattle that have not received hormonal adjuvants contain about 5 percent more energy per unit gain. The steer equation modifed for application to nonimplanted animals would be:

$$\begin{aligned} RE &= 1.05\ (0.0635\ W^{0.75}\ EBG^{1.097}) \\ &= 0.0667\ W^{0.75}\ EBG^{1.097} \quad (3) \end{aligned}$$

Other modifications of the primary equations (1 and 2) can be made to estimate RE or $NE_g$ requirements of cattle with other frame sizes or sex classes. An example modification of equation 1 to make it more suitable for use with large-frame steer calves and medium-frame bulls follows.

The assumption is that energy retention of a large-frame calf or medium-frame bull is approximately equivalent to a medium-frame steer of a 15 percent lighter weight. Equation 1 becomes:

$$\begin{aligned} RE &= 0.0635\ (0.85\ W)^{0.75}\ EBG^{1.097} \\ &= 0.0562\ W^{0.75}\ EBG^{1.097} \quad (4) \end{aligned}$$

Other modifications of the primary equations (1 and 2) have been made to estimate the energy requirements of large-frame bulls and heifers (see Prediction Equations).

The examples given in the preceding paragraphs are meant to illustrate that general relationships between EBG and energy gain need adjustments for specific conditions in practice. The extent of the modification necessary is related to differences in body composition relative to weight and age and the influence of these variables on energy utilization (Garrett, 1971; Webster, 1978; Byers and Rompala, 1980; Garrett, 1980b).

The primary equations (1 and 2) and the modified versions discussed are on an empty body weight basis. Under practical conditions, empty body weights and EBGs are not known. The previous edition of this report (NRC, 1976) did not make a distinction between empty body weight and live weight (LW). The present subcommittee has decided to list the requirements in Tables 1 and 2 on an LW basis. LW is defined as weight after an overnight feed and water shrink (generally equivalent to about 96 percent of unshrunk weights taken in the early morning). The decision to list requirements on an LW basis makes it necessary to modify the primary energy requirement equations. Two adjustments are necessary: (1) EBG should be adjusted to a shrunk weight gain (LWG) basis. A multiple regression equation calculated from a data set with observations from 3500 cattle receiving various diets (Garrett, unpublished) is EBG = 0.93 LWG + 0.174 $NE_m$ − 0.28; r = 0.96; SE = 0.014; (2) The mean live weight (MLW) determined as [0.5 (initial weight + final weight)] should be adjusted to a mean empty body weight (MEBW) basis. The same data set (Garrett, unpublished) gives the following multiple regression:

$$MEBW = 0.88\ MLW + 14.6\ NE_m - 22.9;\ r = 0.98;\ SE = 1.5.$$

These equations could be substituted directly in the primary energy equations to estimate retained energy ($NE_g$ requirements for LWG). However, the relationships were established under specific experimental conditions, and it is not known how applicable they are to weights and weight gains observed under the widely varying conditions of cattle production. For this reason the subcommittee adopted the simple approach of using average ratios of EBG to LWG (0.956) and MEBW to MLW (0.891) to adjust the primary equations to an LW basis. The ratios are the coefficients calculated using a no-intercept regression of EBG versus LWG and EBW versus LW from the data set mentioned earlier. This simple approach might be expected to underestimate LW gains of cattle fed high-roughage diets and to overestimate the LW gains of those fed very high concentrate diets. For further information and another approach to the solution of the empty body weight to LW conversion problems, the reader is referred to ARC, 1980, p. 38.

The relationship used to estimate maintenance requirements (77 Kcal/$W^{0.75}$ as originally determined) also has weight on an empty body basis. The decision not to adjust this estimate is largely arbitrary. An adjustment related to conversion of LW to empty body weight would decrease the maintenance estimate. A decreased maintenance requirement under practical (as opposed to the experimental) environments does not (intuitively, at least) seem likely. Also, gut contents have to be carried and maintained at near-body temperatures. Therefore, a refinement of the maintenance estimate may not be appropriate at this time, particularly since any change contemplated would be within the error attached to the unadjusted estimate.

Current information is inadequate to modify the present general system describing the energy value of feeds and the energy requirements of cattle for all conditions encountered in production situations. Users are encouraged to adjust the primary equations to fit their specific practical conditions if continued use of the energy requirements given in the tables or by the equations indicates a consistent over- or underestimation of animal performance. Some other procedures for adjusting generally determined energy requirements to specific conditions have been suggested by Garrett (1976), Webster (1978), ARC (1980), and Fox and Black (1984).

The primary equations to predict energy requirements have been rearranged to estimate daily gain when animal weight and feed consumption are known:

$$\text{For steers: EBG} = 12.341\left(\frac{\text{RE}}{W^{0.75}}\right)^{0.9116}$$

$$= 12.341\ W^{-0.6837}\text{RE}^{0.9116}. \quad (5)$$

$$\text{For heifers: EBG} = 9.741\left(\frac{\text{RE}}{W^{0.75}}\right)^{0.8936}$$

$$= 9.741\ W^{-0.6702}\text{RE}^{0.8936}. \quad (6)$$

Equivalent relationships in logarithmic form are:

$$\text{For steers: Log EBG} = 0.9116 \log(\text{RE}/W^{0.75}) + 1.091.$$

$$\text{For heifers: Log EBG} = 0.8936 \log(\text{RE}/W^{0.75}) + 0.9884.$$

In these equations, RE is the net energy available for gain. Similar equations for bulls, cattle of other frame sizes, and all relationships modified to an LW basis are given in Appendix Table 10.

Energy deposition in the conceptus of beef females has been determined by Ferrell et al. (1976a) and can be calculated from the data of Prior and Laster (1979). Other information related to bovine fetal growth and weight change of the pregnant cow is available (Eley et al., 1978; Silvey and Haydock, 1978). The gross efficiency of ME use for conceptus development has been estimated as 11 to 15 percent for cattle (Ferrell et al., 1976b) and 12 to 13 percent for sheep (Rattray et al., 1974). The average figure of 13 percent was used to estimate the ME requirement for pregnancy and converted to equivalent $NE_m$ units to express requirements in net energy terms. The relationship used to estimate the pregnancy requirement [kcal/day of $NE_m$ equivalent based on expected calf birth weight and day of gestation (t)] assuming a diet of average quality forage (ME of 2.00 Mcal/kg) is:

$$NE_m = \text{calf birth weight}\ (0.0149 - 0.0000407t)e^{0.05883t - 0.0000804t^2}$$

The energy requirements for milk production have been estimated from the information available for the dairy cow (NRC, 1978). The requirement can be calculated and expressed in $NE_m$ units since ME is utilized for lactation and maintenance at similar levels of efficiency.

$$NE_m\ (\text{Mcal/kg of milk}) = 0.1\ (\text{percent fat}) + 0.35.$$

The total energy requirement determined by adding the maintenance and lactation requirements should be adequate to prevent weight loss in most lactating cattle not under environmental stress. Under many practical conditions the beef cow may seasonally lose weight (at calving and during early lactation) and gain weight (late lactation and during the nonlactation period). The possibility for increased calving percentages and maintenance of a once-a-year calving interval may be improved if the cow does not lose weight during late gestation and the breeding season.

The weight increase of thin nonlactating adult beef cows (exclusive of products of conception) probably contains between 5 and 12 percent protein and 50 and 75 percent fat. This is equivalent to 5.5 to 7.5 kcal/g (Garrett, 1974b; Swingle et al., 1979; ARC, 1980). The average value of 6.5 kcal/g can be used to approximate the empty body weight gain of thin beef cows.

Very little extra energy is required above maintenance for semen production and replenishment in mature bulls (Flipse and Almquist, 1961; Van Demark and Manger, 1964).

Energy requirements listed in all tables in this report assume the animals are not stressed by environmental conditions. Persistent cold or hot weather may result in cattle being outside the thermal neutral zone appropriate for a given feeding level (NRC, 1981b). In cold stress, additional energy will be required to maintain the animal. During heat stress, appetite will decrease, resulting in lower production by animals fed ad libitum. Since many weather factors (air temperature, wind velocity, precipitation, solar exposure) and many animal factors (age, breed, hair coat, fleshing, period of adaptation, and diet) influence an animal's response to the environment, adjustments in generally stated requirements must be on an empirical basis. Information regarding the effect of environment on energy requirements is summarized in Chapter 5 of this publication.

## PROTEIN

The preruminant calf has little rumen function, so protein nutrition parallels that for the nonruminant. Amino acid requirements can be met through milk or milk replacers (Roy and Stobo, 1975). Supplementing with certain amino acids may prove beneficial (Foldager et al., 1977), but urea usefulness is limited (Morrill and Dayton, 1978). Milk substitutes should meet protein requirements specified in the tables in this report, while creep supplements should be formulated to complement the protein and energy supplied by milk and grazed forage. After the rumen becomes functional, 6 to 8 weeks of age depending on diet, the crude protein needs for two systems must be met—the need for nitrogen for microbial fermentation in the reticulo-rumen and the need for postruminal amino acids for tissues of the host ruminant.

### *Microbial Requirements*

About 75 percent of the carbohydrate digested by ruminants is fermented by microbes in the rumen. During fermentation, volatile fatty acids, ammonia, methane, and $CO_2$ are released, and energy is liberated for microbial growth and multiplication. A wide variety of microbial types, including many species of anaerobic bacteria, protozoa, and even fungi, thrive in the rumen. Swept out of the rumen to the abomasum and small intestine with fluid and particles, these microbes typically furnish about half of the protein (amino acids) needed by the ruminant animal. Extensive reviews concerning types, metabolism, and importance of the microbial population of the rumen are available (Bryant, 1973; Smith, 1975; Hespell, 1979).

Ruminal bacteria can use various sources of nitrogen (primarily ammonia and some amino acids and peptides), energy (derived from fermentation), and minerals for growth. Any of these factors can limit bacterial growth since requirements are interrelated. The supply of ammonia can be inadequate when either the intake of protein or the ruminal degradation of protein is low. Ammonia deficiency in the rumen reduces the efficiency of bacterial growth and may reduce the rate and extent of digestion of organic matter in the rumen, which may reduce feed intake. The minimum concentration of ammonia-nitrogen in ruminal fluid needed for bacterial growth and digestion has been estimated by various procedures (Satter and Slyter, 1974; Mehrez et al., 1977; Edwards and Bartley, 1979; Hespell, 1979; Slyter et al., 1979) with little consensus. Concentrations above 5 mg ammonia-nitrogen per 100 ml generally have not increased bacterial protein production, although higher concentrations may increase both ruminal pH and organic matter digestion.

Ammonia is derived from degradation of protein or nonprotein nitrogen (NPN) in the rumen. Although most bacterial species in the rumen can survive using ammonia as their sole source of nitrogen (Bryant and Robinson, 1963), added protein may stimulate bacterial growth by providing amino acids (Maeng and Baldwin, 1976), essential branch-chained fatty acids (Bryant, 1973), or unidentified factors for ruminal bacteria to incorporate or use. Typically the least costly dietary source of ruminal ammonia is some form of NPN.

### *Nonprotein Nitrogen*

The NPN source most commonly fed to ruminant animals is urea. Urea is rapidly hydrolyzed to ammonia in the rumen, and excessive amounts of absorbed ammonia can prove toxic to the ruminant animal. Proper management procedures are necessary when NPN is fed both to prevent ammonia toxicity and to avoid reduction in feed intake. Single doses of urea at 0.3 to 0.8 g of urea per kilogram of body weight have toxic effects. Toxicity can be avoided by thoroughly mixing urea with the diet and setting the maximum concentration at 1 percent of the diet dry matter or one-third of the total protein in the diet. In typical diets for beef cattle, this concentration usually exceeds the amount that is needed. Slowly degraded sources of NPN help avoid ammonia intoxication. Urea is used more completely when high-energy, low-protein diets are fed. High-concentrate diets will provide more energy for synthesis of bacterial protein from ammonia and will increase the amount of ammonia retained in ruminal fluid due to a lower ruminal pH. Ammonia absorption from the rumen and the likelihood of toxicity decrease as ruminal pH declines (Bartley et al., 1976). When NPN is substituted for protein in a diet, special care in mineral supplementation must be exercised, since most sources of protein provide substantial amounts of sulfur, potassium, and phosphorus, which are absent in NPN sources.

NPN addition to a diet is useful only when the ruminal concentration of ammonia is inadequate for optimal bacterial action to (1) digest organic matter or (2) supply ammonia for microbial synthesis of protein. The amount of urea that can be used in the rumen for synthesis of microbial protein with a specific diet theoretically can be calculated based on the amounts of (1) protein degraded to ammonia in the rumen and (2) bacterial protein synthesis. Bacterial protein synthesis usually is proportional to the amount of energy available in the rumen. Relationships that have been derived are as follows:

Urea potential (g/kg dry feed) = $11.78\ NE_m + 6.85 - 0.0357\ CP \times DEG$ (Burroughs et al., 1975), and

Urea potential (g/kg dry feed) = $31.64 - 3.558\ CP + ([945\ NE_m - 887 - 179\ NE_m^2])^{0.5}$ (derived from Satter and Roffler, 1975),

where CP, $NE_m$, and DEG are dietary protein (percent), net energy for maintenance (Mcal/kg), and ruminal degradation of protein, respectively. These equations provide similar estimates of the amount of urea that can be supplemented to a diet based on its protein and energy content. Unfortunately, ruminal degradation of dietary protein is difficult to predict. Roughage level, feed intake level, and feed processing influence both degradation of protein in the rumen and energy supply for and efficiency of bacterial growth. Consequently, these equations must be modified for specific feeding and management conditions. Additional research is needed to refine the factors that fit into these equations before the equations can be applied successfully. Several systems have evolved in the past decade that can be used to estimate urea usefulness, protein bypass, and postruminal requirements for ruminant animals. The reader is referred to reviews and symposia for information on and comparison of these systems (Owens, 1982; Owens and Bergen, 1983).

### *Ruminal Protein Degradation and Bypass*

Dietary protein is digested in the rumen to a variable degree depending on feed, bacterial, animal, and time conditions. The balance of the dietary protein that escapes destruction in the rumen and passes to the omasum and abomasum is commonly called *bypass* or *escape* protein. (These terms will be used interchangeably here.) In addition, a small portion of the dietary protein passes directly to the omasum without mixing with ruminal contents. Protein escaping or bypassing ruminal destruction is either digested postruminally or is excreted in feces. Since the extent of ruminal degradation of dietary protein depends on bacterial, animal, and time conditions, in addition to chemical and physical properties characteristic of the protein, degradability is a variable not a constant. Hence, rate and extent of degradation rather than degradability will be discussed here.

In the rumen, most protein that is soluble in ruminal fluid, plus a variable proportion of the insoluble protein, is degraded to ammonia (Henderickx and Martin, 1963; Chalupa, 1975). Solubility alone is a poor index of the extent of degradation of protein in the rumen (Satter et al., 1977), except possibly with high intakes of a high-concentrate diet. Current information (Chalupa, 1975; Satter et al., 1977; ARC, 1980) suggests that protein from various feedstuffs may be classified into three relative ruminal bypass or escape categories as follows: (1) low bypass (under 40 percent)—soybean meal, peanut meal; (2) medium bypass (40 to 60 percent)—cottonseed meal, dehydrated alfalfa meal, corn grain, brewers dried grains; and (3) high bypass (over 60 percent)—meat meal, corn gluten meal, blood meal, feather meal, fish meal. These estimates do not consider feed processing conditions or animal, dietary, and microbial variables, which can markedly alter bypass, especially for the more rapidly degraded protein sources. These factors act through modifying (1) ruminal retention time for digestion and (2) microbial activity within the rumen. Until these factors are more fully quantitated and the postruminal need for protein is more precisely described, the applicability of specific bypass estimates for various feedstuffs is limited. Amino acid composition of bypassed protein from a feedstuff may not parallel that of the total protein in the feedstuff (Macgregor et al., 1978). When high bypass protein is fed, the amount of NPN needed will increase since less dietary protein is degraded to ammonia in the rumen. Increased bypass or escape does not ensure increased animal production, however, since (1) bypassed protein may be poorly digested in the small intestine, (2) the balance of amino acids in postruminal protein may be poor, or (3) energy supply or nutrients other than amino acids may be limiting animal production.

### *Postruminal Supply and Requirements*

The supply of protein to the small intestine is the sum of the fed protein that escapes or bypasses ruminal destruction and the microbial protein synthesized within the rumen. Efficiency of microbial growth varies with specific culture conditions, such as pH, dilution rate, and limiting nutrients. Microbial protein synthesis is usually correlated with the amount of organic matter digested in the reticulo-rumen. Microbial crude protein synthesized in the rumen ranges from 77 to 270 g/kg of organic matter fermented (mean of 151; Thomas, 1973). Higher values are characteristic of roughage diets and faster bacterial growth rates.

Efficiency of converting feed protein or nitrogen to nonammonia nitrogen leaving the rumen is variable. Ruminal output as a percentage of protein intake may exceed 100 percent. Nitrogen recycled to the rumen can be used for protein synthesis by ruminal microbes, resulting in ruminal output of protein being greater than protein intake, especially when feeding low-protein diets or diets containing large amounts of protein, which is not degraded in the rumen. In contrast, when ruminal degradation of protein is high, or the amount of ammonia available exceeds the bacterial need, ruminal protein output will be less than the amount of protein consumed. In most experiments, protein flow out of the rumen has been between 75 and 120 percent of protein fed and generally is near 100 percent with typical diets containing 11 to 12 percent crude protein. In this publication an efficiency of converting (CE) dietary protein to ruminal protein output of 100 percent was assumed to calculate dietary protein needs from postruminal protein requirements. This value should be modified when information on ruminal bypass and microbial protein synthesis permits.

The crude protein (CP) requirement of cattle can be subdivided into specific metabolic costs or factors. These include metabolic fecal loss (F), endogenous urinary loss (U), scurf loss (S), and synthesized products containing protein, including tissue growth (G), fetal growth (C), and milk produced (M). The factorial equation used in this publication is: $CP = (F + U + S + G + C + M)/(D \times BV \times CE)$. This is derived from the classical equation in which biological value (BV) equals retained plus metabolic and endogenous losses divided by true digestibility (D). Components of this equation can be estimated from animal experiments.

Metabolic fecal protein loss (F) in grams of protein per day appears to be a function of dry matter intake or fecal dry matter excretion. This is the major protein cost for mature ruminants. Further information about the influence of fiber intake on F is needed. The current estimates of metabolic fecal protein (6.25N) loss are 30 g of protein per kilogram of dry matter intake or 68 g of protein per kilogram of dry matter output in feces (NRC, 1978). Metabolic fecal protein estimated from feed intake (30 × dry matter intake) is greater than that estimated from fecal dry matter output (68 × fecal output) for all diets with digestibilities over 55 percent. Which equation is more appropriate is uncertain.

Classically, F has been considered to represent tissue protein eroded from the intestinal tract as fibrous matter is pushed through. But since much of the fecal nitrogen is microbial debris, F may originate partially from NPN and not be derived completely from tissue amino acids. If a large proportion of the metabolic fecal protein originates from nonspecific sources of nitrogen rather than completely from nitrogen eroded from the intestinal tract, the dietary protein needed to replace F can be reduced, since the inefficiencies of metabolism need not be deducted. To calculate F for beef cattle, 99 protein level comparisons in 34 publications over the past 15 years in the *Journal of Animal Science*, *Journal of Dairy Science*, and *Canadian Journal of Animal Science* were reviewed. F was estimated using data from deficient cattle only. Two factors, feed intake and the total of other uses of protein (tissue, urinary loss, scurf loss), were regressed against dietary protein intake. The slopes were interpreted to represent $F/(BV \times D)$ and $1/(BV \times D)$. This permitted F to be calculated. F was estimated to be 33.44 g of protein per kilogram of dry matter intake.

To estimate F, knowledge of feed intakes of various types of cattle at various rates of gain is required. Two equations were derived to estimate feed intake. These equations were: for medium-frame steer calves, large-frame heifers, and medium-frame bulls, daily dry matter intake (kg) = $W^{0.75}(0.1493\,NE_m - 0.046\,NE_m^2 - 0.0196)$; for breeding females, daily dry matter intake (kg) = $W^{0.75}(0.1462\,NE_m^2 - 0.0517\,NE_m^2 - 0.0074)$ with $NE_m$ being net energy for maintenance in Mcal/kg and W being the shrunk weight in kilograms. For a smaller- or larger-frame size, shrunk weight in the equation was decreased or increased by 10 percent for steers and heifers and by 5 percent for bulls.

To derive the energy density of the diet needed for cattle gaining at different rates, an iterative equation was used to calculate the energy content of the feed consumed to provide enough energy to support a specified rate of gain *and* to meet the constraints imposed for intake. $NE_m$ values are minimums for the levels of performance listed, except where feasible $NE_m$ solutions fell below 1.07 Mcal/kg. Since few diets containing less than 1.07 Mcal/kg would be fed, this minimum energy density was used in calculations, and feed supply was considered to be limited for cattle in this category. If feed intake is greater than specified for a class of cattle but the rate of gain and the protein deposition remain as specified, then protein requirements expressed on a grams per day basis will be greater than those listed in the tables in this publication. This increase will equal 62 g more protein daily for every kilogram increase in feed intake because of the increase in metabolic fecal loss. But protein requirement, when expressed as a percentage of the diet dry matter, will be lower than listed in the tables here by 2 to 6 percent for each 10 percent increase in feed intake since required diets always contain more than 62 g of protein in a kilogram of dry matter.

Endogenous urinary loss (U), in grams of protein (6.25N) per day, estimated from protein-free diets, can be calculated from body weight in kilograms (W) as: $U = 2.75\,W^{0.5}$. This loss includes a portion of the nucleic acids synthesized by ruminal microorganisms. Additional nitrogen is lost in urine as a result of improper ratios of absorbed amino acids and the presence of nucleic acids in nonammonia nitrogen reaching the small intestine. This is accounted for by the biological value adjustment. Skin, hair, and scurf loss (S) in grams per day is estimated from surface area as $S = 0.2\ W^{0.6}$ (NRC, 1978).

Tissue protein deposition in the empty body (G) in grams of protein per day has been estimated by comparative slaughter techniques and deuterium dilution procedures. Protein deposition is the multiple of the rate of liveweight gain and the chemical composition of the gain. Composition of tissue gained depends on physiological maturity of the animal and the rate of liveweight gain. Protein deposition rates have been estimated using several equations. Byers and Rompala (1979) suggested that: $G = 0.7108 - 0.1038 \log_e EBW + 0.03906 \log_e (EBG \times (\text{mature } EBW/EBW))$; where EBW is empty body weight (kg), and EBG is empty body weight gain, as discussed in Chapter 2 of this publication. W. N. Garrett (1980, personal communication) suggested that: G (g) = ADG × (0.2422 − 0.0236 × retained energy/kg gain), where ADG is the average daily gain in kilograms. Fox et al. (1982), using data from Simpfendorfer, proposed that for cattle over 250 kg, G (g) = ADG in kg × (0.235 − 0.00026 × shrunk weight in kilograms). R. D. Goodrich (1968, personal communication) proposed that protein content (percent) of gain was 20.25 − 0.0225 × shrunk weight in kilograms. For growing-finishing cattle, the mean protein deposition for the above equations was calculated over the weight range of 250 to 500 kg and rates of live weight gain from 0.5 to 1.5 kg daily, assuming that a mature weight would be 750 kg. For 350- to 400-kg cattle gaining 1 kg daily, values for these equations are similar. The mean values for protein deposition from these equations were regressed against energy content of weight gained calculated from the net energy equations. The generated equation was: protein deposition (g) = daily gain in kg × (268 − 29.4 × energy content of gain in Mcal/kg); $r^2 = 0.964$. As in the net energy equations, protein composition of gain of bulls and large-frame steers was assumed to be equal to that of medium-frame steers of 15 percent lower weight. For medium-framed heifers, the composition of gain was considered to be equal to that of medium-frame steers weighing 15 percent more than the shrunk weight of heifers. These factors are based partly on suggestions of Minish and Fox (1982).

Protein deposition in the products of conception (C) accelerates as pregnancy progresses, but over the last third of pregnancy C averages 55 g per day according to the equation of Prior and Laster (1979). Protein output in milk (M) in grams per day is the multiple of milk production and milk protein percentage. Milk production varies with breed but generally ranges from 3 to 10 kg daily (Lamond et al., 1969; Williams et al., 1979), and protein content averages 3.35 percent.

True protein digestibility (D), which is protein digestibility corrected for metabolic fecal loss, and biological value (BV) vary among feedstuffs and dietary conditions. Small-intestinal apparent digestibility of amino acid nitrogen from feed plus microbial protein has averaged 66 percent (Armstrong and Hutton, 1975; Zinn and Owens, 1983), but true digestibility in the total tract is near 90 percent. When estimating nitrogen needs to replace factored use of nitrogen, the higher figure must be used. Digestibility of bypassed protein can vary with feedstuffs and processing methods such as heat treatment. Heating of forage can reduce protein digestibility drastically. True digestibility of feed protein can be estimated through pepsin or acid detergent fiber digestion techniques. Because of heat damage, the true digestibility estimate of feeds may need to be reduced from the 90 percent estimate used in the calculations here.

The BV of microbial crude protein, estimated from studies with nonruminants, has ranged from 66 to 81 percent. The high nucleic acid content of microbial cells is partially responsible for this low biological value. Nitrogen recycling by ruminants will increase apparent BV. For calculating requirements, protein intake of deficient cattle was regressed against total protein use (gain, urinary loss, scurf loss, metabolic fecal protein). This regression revealed an efficiency of use of 60 percent. This factor would be the multiple of BV and digestibility. If true digestibility of protein is 90 percent, BV would be 66 percent. Postruminal infusion of certain amino acids (lysine, threonine, and amino acids containing sulfur) can increase the apparent biological value of microbial protein for steers (Chalupa, 1975). However, supplementation of these amino acids beyond the rumen in growing cattle fed high amounts of higher-energy, urea-supplemented diets has not consistently improved apparent biological value.

Protein requirements estimated by this factorial method were compared with results from the 99 comparisons mentioned previously. Unfortunately, frame size, body condition, previous dietary history, stage of growth, and diet composition were not well specified; thus, the usefulness of this data base is limited. If the rate of gain increased when a higher level of protein was fed (52 cases), dietary protein was deficient. When added protein did not increase rate of gain, protein was adequate. When added protein increased gain, feed intake was increased 75 percent of the time and energetic efficiency was increased 95 percent of the time, indicating that protein status can influence performance indirectly through feed intake. Compared with this data base, protein requirements estimated by the factorial method underestimated the true requirement in 39 percent of the cases where gain responses were seen to added protein, overestimated the true requirement in 21 percent of the cases where no response was observed to added protein, but correctly predicted response to added protein in 68 percent of the cases, including both deficient and adequately supplemented cattle. The listed requirements should be sufficient for a given class of cattle in 50 percent of the cases. The standard deviation in the protein requirement was 14 percent of the estimated requirement. To calculate adequate requirements for cattle in 84 percent of the trials, an additional 14 percent must be added to minimum protein requirements presented in Tables 2 and 10. Additional protein may be economically justified under certain feeding conditions, but adding an additional 28 percent to the listed values to meet estimated needs in 95 percent of the trials reported in the literature may not be economically feasible.

Because of efficiency of protein use, each gram of dietary protein deficiency should decrease protein deposition by 1.7 g and rate of gain by about 10 g per day. A higher protein level, with a safety margin, may prove advantageous when the cost of protein is low relative to energy. Furthermore, providing protein in amounts higher than specified in the tables in this publication may increase animal performance early in a feeding period, although cattle fed a lower-protein diet will make compensatory gains later. Requirements to maximize gain when starting cattle on feed may be higher than the average requirement for cattle during an entire finishing period. With certain diets, supplemental protein may be withdrawn for heavier cattle when other nutrients are provided in adequate amounts. Compared with previously estimated protein requirements, those listed in this publication recommend higher amounts early in the finishing period and lower amounts late in the finishing period.

Protein is often fed at levels in excess of the absolute requirements of growing cattle because of the low marginal cost of protein. In contrast, feeding protein in excess of requirements is infrequent with lactating beef cows that obtain their other nutrients from grazed forage. The economic sacrifices in performance and reproduction and the potential for use and replenishment of protein reserves must be balanced against the cost of feeding protein to cattle to determine the most economical level of supplementation.

Requirements are no longer presented on a digestible protein basis because metabolic fecal protein makes up a large proportion of the apparently indigestible protein. Previously, most of the digestible protein requirements and feed protein digestibilities were calculated from crude protein figures.

Requirements on the basis of percentage in the diet have been calculated from feed intake. Amounts per day rather than percentage requirements should be used when feed intakes deviate from listed values. Certain additional factors, such as heat, cold or shipment stress, diet processing, feed additives, estrogenic implants, and previous protein and energy intakes, may alter feed intake, rate of weight gain, and composition of tissue gain. Adjustments for the effects of these factors on feed intake and the rate of protein deposition are discussed in another publication (NRC, 1981) and are not well quantitated.

### *Protein Deficiencies and Toxicities*

Ammonia deficiency in the rumen reduces the rate and extent of digestion and may reduce feed intake. Postruminal amino acid deficiencies also may reduce energy intake and efficiency of feed and protein use. Through recycling nitrogen to the rumen, efficiency of protein use is greatest with a marginal protein deficiency. Requirements for protein listed in Tables 2, 6, 10, and 11 may be inadequate for certain diets and feeding conditions. When protein constitutes less than 10 percent of the dietary dry matter, ammonia may be insufficient for ruminal microbes. The amount of ammonia needed for ruminal microbes can be calculated from the urea potential equations given earlier.

Based on results of the literature survey mentioned earlier, a change in feed intake may be useful as an indicator of protein deficiency. If the intake of feed increases when protein is added to the diet, protein was probably deficient, while if intake does not increase, protein probably was not a limiting factor. Protein concentrations above the table values may increase efficiency of feed use slightly, but the economics of feeding excessive amounts of protein must be carefully considered.

Diets containing up to 40 percent protein have been fed to steers. Feed intake was reduced for several days when protein was added, but no signs of ammonia toxicity were evident (Fenderson and Bergen, 1976). Excesses of NPN or soluble protein may precipitate ammonia toxicity, as discussed earlier.

### *How Protein Requirements Were Calculated*

The method used to estimate protein requirements will be illustrated for a 250-kg medium-frame steer calf gaining 1.2 kg daily. All weights are shrunk weights. First, daily energy needs for maintenance (4.84 Mcal) and gain (4.28 Mcal) were calculated from net energy equations. To calculate the protein requirements for pregnant and lactating cattle, the need for added energy for the developing fetus or for milk production would be added. An $NE_m$ for the diet to be used was estimated and feed intake calculated (kg = $[0.1493\, NE_m - 0.046\, NE_m^2 - 0.0196]\, W^{0.75}$). Daily $NE_m$ and $NE_g$ supplies were then computed and compared with the energy needed for maintenance and gain. The level of $NE_m$ in the planned diet was then decreased or increased until the feed intake predicted by the intake equation matched the need for energy calculated from the net energy equation. For this steer a dietary $NE_m$ of 1.81 Mcal/kg should be consumed in adequate quantities (6.28 kg) to produce a 1.2-kg daily gain. The 6.28-kg intake was used to calculate metabolic fecal protein loss (33.44 g protein per kg of dry matter intake = 210 g). Endogenous urinary protein loss ($2.75\, W^{0.5}$) and scurf loss ($0.2\, W^{0.6}$) equal 43.5 and 5.5 g daily. Based on energy content of gain (4.28 Mcal $NE_g$ deposited per 1.2 kg weight = 3.56 Mcal/kg gain), the protein deposited is calculated (gain in kg × [268 − 29.4 × energy content of gain in Mcal/kg]) = 196 g. Protein deposition plus fecal, urinary, and scurf loss totals 455 g per day. (Protein deposition in milk or in the developing fetus if appropriate would be added here.) At a true digestibility of 90 percent, a biological value of absorbed amino acids of 66 percent, and an assumed efficiency of 100 percent for converting dietary protein to protein leaving the rumen, the daily dietary protein need is 455/(0.90 × 0.66 × 1.00) = 766 g. As a proportion of the dry matter in the diet (6.28 kg), the protein requirement equals 12.2 percent.

An alternative approach is to project intake, performance, and protein requirements for cattle fed a diet containing a specified level of energy. For example, with a diet having an $NE_m$ of 1.6 Mcal/kg fed to a 350-kg large-frame bull, dry matter intake ($0.1493\, NE_m - 0.046\, NE_m^2 - .0196) \times (1.05 \times W)^{.75}$ should be 8.52 kg per day. Fecal protein loss would be 285 g daily (33.44 × 8.52). This amount of feed provides energy for maintenance (6.23 Mcal/1.6 Mcal per kg = 3.89 kg feed), leaving 4.63 Mcal $NE_g$ ([8.52 − 3.89 kg] × 1.0 Mcal $NE_g$), which will support a daily gain of 1.28 kg ($17.35\, NE_g^{.9116}\, W^{-.6837}$) as calculated from the net energy equations. The energy content of gain is 3.62 Mcal/kg (4.63 Mcal $NE_g$/1.28 kg) for a daily protein gain of 207 g (1.28 × [268 − 29.4 × 3.62]). Urinary loss and scurf loss would total 51.4 and 6.7 g protein per day for a total daily protein use of 550 g. With a 90 percent digestibility, a biological value of 66 percent, and a ruminal efficiency of protein output at 100 percent of intake, the crude protein requirement is 926 g per day. As a portion of the predicted dry matter intake (8.52 kg), this equals 10.9 percent crude protein.

The amount of the dietary protein that can be provided as NPN can be solved from the urea utilization equations outlined earlier providing the extent of ruminal degradation of dietary protein can be predicted. Proper management must be exercised to avoid NPN toxicity, as discussed earlier. These equations were derived from the relationships mentioned earlier assuming that all nonprotein nitrogen is degraded to ammonia within the rumen and is used with an efficiency equal to ammonia released from dietary protein. The prediction equations are:

$$IP = (7.128\, CP - 11.78\, NE_m - 6.85)/(7.128 - 0.0357\, DEG)$$ (calculated from Burroughs et al., 1975), and

$$IP = 2CP - 8.89 - (74.62\, NE_m - 70.04 - 14.13\, NE_m^2)^{0.5}$$ (calculated from Satter and Roffler, 1975),

where IP is the percentage of intact dietary protein out of which the DEG percentage of the protein is degraded in the rumen. CP is the percentage protein required, and $NE_m$ is in Mcal per kilogram of dry diet. These relationships can be used to determine the minimum amount of intact protein that can be fed when supplemented with NPN. The difference between IP and CP is the amount of dietary protein that can be provided as NPN.

The amount of urea that can be included in the diet for the medium-frame beef steers of the example used previously was calculated assuming that 40 percent of the dietary protein was degraded in the rumen. If the requirement is 12.2 percent crude protein, and 40 percent of the intact protein fed is degraded in the rumen, the amount of intact protein needed is 10.3 and 11.8 percent according to the two equations, respectively. NPN could provide the difference (1.9 or 1.0 percentage equivalents of protein), which is 0.68 or 0.37 percent urea in the diet for this example. When a more extensively degraded intact protein is fed, the amount of NPN that can be used is reduced; with a higher bypass protein, more NPN can be used. These calculations have all the limitations of the urea potential estimates as discussed in the Nonprotein Nitrogen section in Chapter 2.

## MINERALS

Discussions concerning calcium, cobalt, copper, iodine, iron, magnesium, manganese, molybdenum, phosphorus, potassium, selenium, sodium and chlorine, sulfur, and zinc are included herein. For each of these minerals, information is presented concerning justification for inclusion as a required nutrient, absorption and excretion, requirements, factors affecting requirements, interrelationships with other minerals and vitamins, deficiency signs, toxicity signs, and common sources. For many of the minerals, information on requirements and quantitation of factors that affect requirements is lacking. Users of the information presented here on mineral requirements must recognize that these are influenced by many factors and that single value requirements may be misleading. Though requirements herein are expressed as a percentage of the diet, animal needs are for specific quantities per day. If feed intake differs markedly from that listed in the tables, percentages in the diet may need to be adjusted to maintain adequate intakes of specific minerals. Calcium and phosphorus requirements are presented in detail in Table 3. Requirements and maximum tolerable levels for other minerals are presented in Table 4.

Other elements (aluminum, arsenic, barium, bromine, chromium, fluorine, nickel, rubidium, silicon, strontium, vanadium) have been suggested to be required by a variety of animals. However, little information is available for cattle concerning requirements or deficiency signs for these elements.

Minerals that are lacking in the diet may be force fed in complete nitrogen-vitamin-mineral supplements or by self-feeding common salt-mineral mixtures formulated to provide needed minerals when the mixture is consumed in amounts to satisfy the animals' appetite for common salt. Other than for common salt, animals apparently do not have the ability to select needed minerals.

Presented in Table 5 are maximum tolerable levels (NRC, 1980) of several elements that are known to be toxic to cattle. Maximum tolerable levels of these elements are influenced by a variety of dietary and animal factors. However, amounts of these elements in excess of the levels given are likely to result in adverse effects in cattle.

### *Calcium*

Calcium (Ca) is the most abundant mineral in the body. It is needed for bone formation, development of teeth, production of milk, transmission of nerve impulses, maintenance of normal muscle excitability (along with sodium and potassium), regulation of heartbeat, movement of muscles, blood clotting (conversion of prothrombin to thrombin), and activation and stabilization of enzymes (i.e., pancreatic amylase). Most of the calcium in the body is found in the skeleton and teeth, and these pools constitute approximately 2 percent of body weight. In blood, calcium is found mostly in plasma, with a homeostatically controlled concentration of about 10 mg/100 ml.

Calcium is absorbed actively from the duodenum and jejunum. The solubility of calcium compounds, and hence the absorption of calcium, is favored by acid conditions and hindered by alkaline conditions in the small intestine. Thus, most calcium is absorbed in the proximal portion of the duodenum. Calcium absorption is depressed by fluorine (Ramberg and Olson, 1970), is greater in young than old animals (Hansard et al., 1954), is greater during periods of low calcium intake than when calcium intake is high, and is depressed during a lack of vitamin D (DeLuca, 1974). Strontium absorption and metabolism parallel those of calcium (Comar et al., 1961).

Several changes occur in response to a lowering of plasma calcium. First, parathyroid hormone is released. It stimulates the production of 1,25-dihydroxy cholecalciferol, a metabolically active form of vitamin D. The 1,25-dihydroxy cholecalciferol increases production of calcium-binding protein in the intestines, and in conjunction with the parathyroid hormone it increases calcium resorption from bone and increases phosphorus loss in urine.

If plasma calcium levels become elevated, calcitonin is produced and parathyroid hormone production is inhibited. Thus, calcium absorption and bone resorption are slowed. The interplay of parathyroid hormone, thyrocalcitonin, and 1,25-dihydroxy cholecalciferol maintains plasma calcium within narrow limits. Therefore, plasma calcium is usually inadequate as a measure of calcium status.

At parturition, dairy cows exhibit a drop of 1 to 2 mg calcium/100 ml plasma calcium. Milk fever may develop if plasma calcium drops below 5 mg/100 ml (Jacobson et al., 1975).

Calcium is excreted mainly in feces with only small quantities appearing in urine. The low urinary loss is due to an effective reabsorption of calcium by the kidney.

Calcium and phosphorus requirements for growing and finishing cattle (Table 3) were calculated on the basis of needs for maintenance plus those for production. Maintenance requirements were calculated as 1.54 g of retained calcium (Hansard et al., 1954, 1957) and 2.80 g of retained phosphorus (Kleiber et al., 1951; Lofgreen and Kleiber, 1953, 1954; Tillman and Brethour, 1958; Lofgreen et al., 1952) for each 100 kg of body weight. Retained calcium and phosphorus needs above maintenance were calculated as 7.1 and 3.9 g, respectively, per 100 g of protein gain. The calcium and phosphorus contents of gains were calculated from data presented by Ellenberger et al. (1950). Calcium and phosphorus needs, above maintenance, during the first 3 to 4 months of lactation were calculated as 1.23 g of calcium and 0.95 g of phosphorus per kilogram of milk produced (NRC, 1978). Milk productions were assumed to be 5 or

10 kg per cow daily. Fetal calcium and phosphorus contents were assumed to be 13.7 and 7.6 g/kg fetal weight. This requirement was distributed over the last 3 months of pregnancy. Average birth weight was assumed to be 30 kg. Total amounts of available calcium and phosphorus for the various classes of cattle were calculated by adding maintenance and production requirements.

These values were converted to dietary calcium and phosphorus requirements assuming a true digestibility for dietary calcium of 50 percent (Hansard et al., 1954, 1957) and a true digestibility for dietary phosphorus of 85 percent (Kleiber et al., 1951; Lofgreen and Kleiber, 1953, 1954). The calcium and phosphorus requirements determined in this manner are in general agreement with those reported by Beeson et al. (1941), Mitchell (1947), Wise et al. (1958), Wentworth and Smith (1961), Baker (1964), Varner and Woods (1968, 1972), and Ricketts et al. (1970). Reports by Call et al. (1978) and Butcher et al. (1979) showed that diets that contained 0.14 percent phosphorus on an as-fed basis met requirements of beef cows. A diet that contained 0.09 percent phosphorus resulted in reduced appetites after 8 to 14 months. The 0.14 percent phosphorus diet would provide only slightly less phosphorus than determined herein, since cattle in the report by Call et al. (1978) weighed only 163 to 377 kg.

Since true digestibilities of calcium and phosphorus in feedstuffs vary, dietary calcium and phosphorus requirements shown in Tables 3 and 7 may in some instances need to be adjusted. Calcium requirements are influenced by such animal factors as age, weight, and type and level of production. Young animals absorb calcium more efficiently than older animals (Hansard et al., 1957), but they have higher requirements because of a higher rate of bone growth. Also, high rates of gain or milk production, high-fat diets, and pregnancy increase calcium requirements. The effect of calcium-phosphorus ratio on the performance of ruminants appears to have been overemphasized in the past. Several studies have shown that dietary calcium-phosphorus ratios between 1:1 and 7:1 result in near normal performance (Dowe et al., 1957; Wise et al., 1963; Smith et al., 1966; Ricketts et al., 1970), providing that phosphorus consumption meets requirements.

A deficiency of calcium results in rickets in young animals and osteomalacia in older animals. Rickets may be caused by a deficiency of calcium, phosphorus, or vitamin D. It is characterized by improper calcification of the organic matrix of bones of young, growing animals. Thus, the bones are weak, soft, and lack density. Signs include swollen, tender joints; enlargement of the ends of bones; an arched back; stiffness of the legs; and development of beads on the ribs. If the condition causing rickets is not corrected, calves will develop bowed and deformed legs, because of the effects of muscle tension and weight on the weak, soft leg bones. Also, rachitic bones are highly susceptible to fracture.

Osteomalacia is the result of demineralization of the bones of adult animals. Since calcium and phosphorus in bone are in a dynamic state, high metabolic demands on calcium and phosphorus stores, such as occur during pregnancy and lactation, may result in osteomalacia. This condition is characterized by weak, brittle bones that may break when stressed. Dairy cows that have lactated heavily and that have been fed insufficient calcium are prone to develop osteomalacia.

Ruminants tolerate high levels of dietary calcium. Colovos et al. (1957) noted reduced protein and energy digestibilities in dairy heifers fed high levels of ground limestone. Calcium reduces the absorption of tetracyclines, manganese, and zinc (Suttle and Field, 1970). Reduced feed consumption and daily gains may occur when high-calcium diets are fed. A hypercalcemia as the result of excess calcium absorption stimulates the production of calcitonin by the thyroid. Calcitonin inhibits bone resorption. If high dietary levels of calcium are maintained and the body remains under the influence of calcitonin, the cortex of bones may thicken (osteopetrosis) because of continued deposition but limited resorption.

The calcium content of feedstuffs varies greatly. Sources of variation in calcium content include types of plant, portion of plant fed, and stage of maturity. Calcium concentrations in forages generally decline with maturity. Legumes are high in calcium, and the cereal grains are low in calcium. Several of the oilseed meals are good sources of calcium. Sources of supplemental calcium include calcium carbonate, ground limestone, bone meal, dicalcium phosphate, defluorinated phosphate, monocalcium phosphate, and calcium sulfate.

### *Cobalt*

The cobalt (Co) requirement of cattle is actually a cobalt requirement of rumen microorganisms. The microbes incorporate cobalt into vitamin $B_{12}$, which is utilized by both microorganisms and animal tissues. Vitamin $B_{12}$ (cobalamin) is of key importance in the utilization of propionic acid. The main physiological manifestation of cobalt or $B_{12}$ deficiency is impaired propionate metabolism, since it is needed for activity of methylmalonyl-CoA isomerase, an enzyme that catalyzes the converson of methylmalonyl-CoA to succinyl-CoA (Marston et al., 1961). Vitamin $B_{12}$ is also a part of the enzyme 5-methyltetrahydrofolate:homocysteine methyltransferase (Gawthorne and Smith, 1974). This enzyme catalyzes the recycling of methionine from homocysteine after the loss of its labile methyl group.

Vitamin $B_{12}$ is also needed for normal liver folate metabolism.

About 43 percent of the body cobalt is stored in muscles and approximately 14 percent is in bone (Underwood, 1977). However, cobalt stored in tissues does not readily pass to the rumen for synthesis of $B_{12}$. The remainder of the body cobalt is distributed among other tissues, with the kidney and liver containing the most cobalt. Cobalt levels (dry basis) in kidney, liver, pancreas, spleen, and heart average 0.25, 0.15, 0.11, 0.09, and 0.06 ppm, respectively. Whole blood contains about 0.9 ng of vitamin $B_{12}$/ml in calves and 0.5 ng/ml in mature cows (Smith and Loosli, 1957).

About 3 percent of ingested cobalt is converted to vitamin $B_{12}$ in the rumen (Smith and Marston, 1970). Of the total vitamin $B_{12}$ produced, only 1 to 3 percent is absorbed. The absorptive site is the lower portion of the small intestine. Substantial amounts of $B_{12}$ are secreted into the duodenum and then resorbed in the ileum. Cobalt and vitamin $B_{12}$ are mainly excreted in the feces, although variable amounts are excreted in urine (Smith, 1965; Smith and Marston, 1970).

A cobalt concentration of 0.10 ppm in diet dry matter is considered adequate for all cattle (Smith and Loosli, 1957). Other estimates range from 0.07 to 0.11 ppm in the dry matter (Underwood, 1977). Calves may be slightly more sensitive to cobalt deficiency than mature cattle. Cobalt-deficient soils occur in many parts of the world with large deficient areas in Australia, New Zealand, and along the southeast Atlantic coast of the United States (Ammerman, 1970). Cattle grazing in these areas develop deficiency signs ranging from subclinical to acute. If cattle are confined to cobalt-deficient pastures or diets, they appear normal for several weeks or months, depending on age and degree of deficiency (Underwood, 1966). As body stores of vitamin $B_{12}$ are depleted, a gradual loss of appetite and body weight occurs, followed by extreme anorexia, muscular wasting, and severe anemia, culminating in death. In severe deficiency the mucous membranes become blanched, the skin turns pale, a fatty liver develops, and the body becomes almost totally devoid of fat. Anemia develops after anorexia occurs, which may be a result of propionate accumulation. In extreme cobalt deficiency, plasma glucose levels fall as a result of impaired propionate metabolism. Elevated plasma glutamic-oxaloacetic transaminase and low ascorbic acid levels reflect the severe liver damage. Plasma pyruvate levels are high because of an induced thiamine deficiency. A vitamin $B_{12}$ level of less than 0.1 $\mu$g/g of fresh liver is indicative of a moderate cobalt deficiency, with levels below 0.07 $\mu$g/g indicative of severe deficiency (Andrews et al., 1959). Plasma levels of about 0.2 ng/ml are indicative of a cobalt deficiency, although there is considerable individual variability. The best indicators of a cobalt deficiency are low plasma $B_{12}$ levels, loss of appetite, and elevated blood pyruvate.

Cobalt toxicity in ruminants is rare because toxic levels are about 300 times requirement levels. Keener et al. (1949) fed up to 110 mg/kg of body weight of cobalt daily to young dairy calves without harmful effects. When calves were fed greater amounts, a mild polycythemia occurred. Other signs of excessive cobalt intake are excessive urination, defecation, and salivation; shortness of breath; and increased hemoglobin, red cell count, and packed cell volume. Cobalt fed as sulfate, chloride, or carbonate was shown to be equally toxic when fed in excess (Keener et al., 1949). Methionine may aid in protecting against cobalt toxicity (Dunn et al., 1952).

Legumes are generally higher in cobalt than grasses, although availability of cobalt in soil causes much variability. Alfalfa may vary from 0.09 to 0.56 ppm cobalt in dry matter (NRC, 1978). Oilseed meals are generally good sources. Cereal grains, particularly corn, are poor, with concentrations of 0.01 to 0.06 ppm. Cobalt can be added to diets or mineral mixes as cobalt oxide or salts such as cobalt sulfate and cobalt chloride. Cobalt sulfate and cobalt oxide administered by drenching were equally effective for lambs grazing cobalt-deficient pastures (Underwood, 1977). A cobalt pellet (composed of cobalt oxide and finely divided iron) that lodges in the reticulum has been successful in preventing deficiency for extended periods in cattle grazing deficient pastures.

### *Copper*

Copper (Cu) is necessary for hemoglobin formation, iron absorption from the small intestine, and iron mobilization from tissue stores. Ceruloplasmin, which is synthesized in the liver and contains copper, is necessary for the oxidation of iron, permitting it to bind with the iron transport protein, transferrin. Copper is also essential in connective tissue metabolism. Lysyl oxidase, a copper-containing amine oxidase, is involved in the crosslinking of polypeptide chains in elastin and collagen (Kim and Hill, 1966; Carnes, 1971). Other enzymes that contain or require copper for biological activity include cytochrome oxidase, uricase, tyrosinase, glutathione oxidase, butyryl coenzyme A dehydrogenase, catylase, aminolevulinic acid hydrase, ascorbic acid oxidase, laccase, $\beta$-mercaptopyruvate transulfurase, lecithinase, and oxaloacetate decarboxylase.

Normal blood copper levels range from 70 to 170 $\mu$g/100 ml in most ruminants (Beck, 1956). Cunningham (1931) reported copper levels in liver, heart, lung, spleen, and kidney from newborn calves of 470.0, 14.8, 4.9, 4.8, and 15.7 ppm in the dry matter of respective tissues. Normal tissue copper levels vary with dietary intake, species, age, and nutritional status. Hepatic copper concentrations in hypercupremic sheep and cattle may increase 10-fold over normal animals. These high levels of hepatic copper may cause the hemolytic crises that result in death of animals fed high levels of copper (NRC, 1980).

Copper is absorbed from the upper portion of the duodenum. In sheep, considerable absorption takes place from the large intestine (Underwood, 1977). The extent of absorption may be influenced by age, some hormones, pregnancy, and some diseases (Goodrich et al., 1972). Mills (1956, 1958) reported that the chemical form of copper may influence its availability to animals and that neutral or anionic organic copper complexes appear to be more readily absorbed than copper sulfate. Also, several nutrient interrelationships have a profound effect on the absorption of this element.

Hill and Matrone (1970) noted that zinc and silver are antagonistic to copper absorption. Histidine and other amino acids favor the absorption of several metals (copper, iron, zinc) because they prevent the formation of metal hydroxides and metal-phosphates that are poorly absorbed (Forth et al., 1973).

Copper excretion is an active process in which copper is released into bile and ultimately into feces (Underwood, 1977). Trace amounts of copper are excreted in urine, perspiration, and milk. In cases of bile duct obstruction or Wilson's disease (NRC, 1980), copper may be excreted in urine.

Diet concentrations of 4 to 10 ppm copper have generally been considered to meet requirements of beef cattle (Goodrich et al., 1972). Diets with less than 3 to 5 ppm copper may result in subnormal plasma and liver copper levels in cattle. However, dietary levels of molybdenum and inorganic sulfur may influence the amounts of copper required by ruminants. Goodrich and Tillman (1966) determined that supplemental molybdenum or sulfur as sulfate decreased copper retention and storage in livers of sheep. Calves fed milk diets for long periods, older cattle fed forages grown on copper-deficient soils, and animals fed diets high in molybdenum and sulfate may develop copper deficiency signs (NRC, 1980).

Generally, plasma copper levels below 60 $\mu g/100$ ml are indicative of copper deficiency in cattle. However, the first clinical sign of a hypocupremic condition is usually achromatrichia (lack of pigmentation). Low copper intakes reduce the synthesis and activity of the copper-containing enzyme, tyrosinase, which is required for the conversion of tyrosine to melanin. Tyrosinase is required for pigmentation of hair, wool, and feathers (Underwood, 1977).

Amine oxidase is responsible for the oxidation of the epsilon-amino group of lysine, which is necessary for the crosslinking of polypeptide chains of elastin and collagen. Underwood (1977) noted that hypocupremic animals have decreased levels of amine oxidase and that this factor may predispose fibrosis of the myocardium, thin bones with broadened epiphyseal cartilage, and low osteoblastic activity in bones. Hypocupremic cattle and sheep may develop spontaneous fractures or osteoporosis due to decreased crosslinking in collagen. Starcher et al. (1964) reported that hypocupremic chicks had decreased aortic elastin contents. Sheep that graze on copper-deficient soils may give birth to lambs having "swayback," which appears to be caused by cerebral demyelinization (Marston et al., 1948).

Soil concentrations of copper may vary considerably by geographical location. In the United States, some soils have been found to contain more than 37 ppm of copper (Shacklette, 1970). Thus, plants grown in these regions may have high copper contents (NRC, 1980). Also, curing or drying of forages may alter the chemical form of copper, making it more available than copper in fresh green plants (Underwood, 1977) and predisposing animals to copper poisoning.

Copper toxicity is initially characterized by increased serum transaminase and lactic dehydrogenase activities. During the hemolytic crises, blood copper, methemoglobin, and creatine phosphokinase increase, while levels of hemoglobin and glutathione are depressed (NRC, 1980). Hypercupremia in sheep promotes renal tubular necrosis; spongy lesions in the white matter of the brain; dark, stained kidneys; and swollen livers (NRC, 1980). In acute oral toxicity, animals may experience nausea, vomiting, salivation, abdominal pain, convulsions, paralysis, collapse, and death. Hypercupremic conditions may also predispose the animal to anemia, muscular dystrophy, decreased growth, and impaired reproduction (NRC, 1980).

Maximum tolerable dietary levels of copper during growth, as recommended by the National Research Council (1980), are 115 ppm for cattle. Maximum tolerable levels are greater for adults than for young, growing animals.

Grains are generally lower in copper than forages. Most forages provide 3 or 4 times the copper requirement of beef cattle. Plants that contain high levels of molybdenum, sulfur, phytate, or lignin may reduce copper absorption (Underwood, 1977). In regions where copper-deficient soils exist, if soil molybdenum levels are high or if plant sources of copper are in chemical forms that are unavailable to the animal, copper supplementation may be necessary. Chapman and Bell (1963) ranked inorganic forms of copper in decreasing order of availability as $CuCO_3$, $Cu(NO_3)_2$, $CuSO_4$, $CuCl_2$, $Cu_2O$, CuO (powder), CuO (needles), and Cu (wire).

### *Iodine*

Iodine (I) is present in most cells of the body. Inorganic iodine is taken up by the thyroid gland for the synthesis of thyroid hormones. Thyroid hormones have an active role in thermoregulation, intermediary metabolism, reproduction, growth and development, circulation, and muscle function. Dietary organic iodine is degraded to more usable inorganic forms before being absorbed. In nonruminants, dietary inorganic iodine is absorbed along the gastrointestinal tract and transported by loose attachment to plasma proteins (Underwood, 1977). In ruminants the rumen is the primary absorption site, while the abomasum aids in excretion of iodine (Barua et al., 1964). After absorption, iodine is distributed throughout the body. Of a total of 50 mg of iodine in the human body, 10 to 15 mg are located in the thyroid gland (Harper et al., 1979).

Concentrations of iodine in the thyroid vary with the amount of iodine intake, age, and gland activity. Iodine stored in the thyroid exists in several forms: inorganic iodide, mono and diiodotyrosine, thyroxine, triiodothyronine, and thyroglobulin. Eighty percent of hormonal iodine stored by the thyroid is thyroxine ($T_4$); the balance is in the form of transition products. Accumulation of inorganic iodine and conversion of transition products to thyroxine is completed over a 48-hour period. Kidney and skeletal muscle also contain large proportions of total body iodine. In the female, iodine concentrations in ovaries are 3 to 4 times that of muscle (Gross, 1962). Small amounts of iodine found in bile, hair and skin, stomach, and mammary glands act as storage sites that may endogenously supply the body with iodine when the need exists. Two-thirds of ingested inorganic iodine is excreted by the kidney. The level of urinary iodine is positively correlated with plasma iodine concentration and dietary uptake.

Milk may also be considered a form of iodine secretion. The amount of iodine in milk is influenced by iodine intake, season, level of milk production, and use of iodine disinfectants. Hemken et al. (1972) fed 0, 6.8, or 68 mg of potassium iodide daily to lactating dairy cows; the resulting milk contained 0.008, 0.081, and 0.694 ppm of iodine. Average iodine content of milk from 111 herds was 0.646 ppm with a range of 0.04 to 4.84 ppm (Hemken, 1978). High levels of iodine in milk are the result of either feeding high levels of dietary iodine or use of iodine as a sanitizing agent. Udder washes caused the iodine content of milk to increase by an average of 0.035 ppm (Conrad and Hemken, 1975). Colostrum contains twice as much iodine as milk during midlactation.

Deficiencies of iodine may occur when animals consume feeds grown on iodine-deficient soils. In the United States the Northwest and Great Lakes regions are recognized as iodine-deficient areas. Samples of hay from Maryland farms contained 1.31 to 2.54 ppm iodine, while those from Illinois contained 0.62 to 1.02 ppm iodine (Hemken et al., 1972). Signs of an iodine deficiency include goiter, hairlessness in the young, retarded growth and maturity, lowered metabolic rate, and increased water retention. In some cases the deficient condition does not originate from a deficient diet but is caused by the presence of dietary substances that affect thyroid function and/or iodine uptake. Underwood (1977) reported interrelationships that interfere with iodine metabolism as (1) thiocyanates, perchlorate, and rubidium salts; (2) high dietary arsenic, fluorine, or calcium levels; (3) deficient or high cobalt levels; and (4) low manganese intakes. Soybean meal and cottonseed meal have both been shown to have goitrogenic effects by increasing serum thyroxine losses to the intestinal tract (Miller et al., 1972).

Cattle requirements for iodine have not been extensively studied. The estimated iodine requirement for a 500-kg cow is about 1 mg per day. A normal diet for a lactating cow provides 3.5 to 5 times this amount.

Iodine toxicity has been studied in many animals. Symptoms of iodine toxicity include anorexia, coma, death, and necrosis of kidney, liver, and mucosal linings of the gastrointestinal tract.

Calves with an initial weight of 100 kg were fed calcium iodate to provide dietary levels of 10 to 200 ppm iodine (Newton et al., 1974). Diets containing iodine in excess of 50 ppm depressed growth rate and feed intake. Calves fed diets with added iodine had increased adrenal weights, but no consistent iodine effect on the weight of thyroid glands was observed. It was concluded that 50 ppm iodine was the minimum toxic level for calves. Yearling heifers suffered depressed daily gains when fed a level of 435 ppm iodine, but additions of 71, 140, or 283 ppm iodine to their diets had no effect on daily gains (Fish and Swanson, 1977). Lactating cows fed diets with 200 ppm iodine [from ethylenediamine dihydroiodide (EDDI)] for 49 weeks exhibited no changes in thyroid or pituitary function (Convey et al., 1977). Providing iodine, as EDDI, at levels of 2.5 mg/kg of body weight to pregnant cows had no effect on the cow or her unborn calf. Levels of 5 to 7.5 mg/kg of body weight increased the incidences of premature births and weak and abnormal calves at birth and the number of stillbirths.

Feed additives that supply iodine include calcium iodate, cuprous iodide, ethylenediamine dihydroiodide, potassium iodate, potassium iodide, sodium iodate, sodium iodide, and pentacalcium periodate.

The most convenient and widely used method of supplementing the diet with iodine is the use of iodized salt. Problems with iodine deficiency in cattle should not occur if iodized salt blocks are not weathered and iodine is administered at proper levels. Biological availability of iodine supplements was reviewed by Ammerman and Miller (1972) and Miller et al. (1975) studied metabolism of iodine from several sources.

### *Iron*

Iron (Fe) has important biochemical functions in animals since it is a component of hemoglobin, myoglobin, cytochrome, and the enzymes catylase and peroxidase. The iron in these materials exists in porphyrin rings. Because it is an integral part of these materials, iron is involved in the transport of oxygen to cells as well as cellular respiration. In cattle a majority of body iron is in the form of hemoglobin, with lesser amounts existing as protein-bound stored iron, myoglobin, and cytochrome. The spleen contains iron in high concentrations, with lower levels found in the liver, kidney, and heart (Standish et al., 1969).

Iron may be absorbed from all sections of the small intestine, but the principal site of absorption is the duodenum. The percentage of dietary iron that is absorbed is low in animals that have normal iron status but is increased in animals deficient in iron. Ferrous iron is absorbed to a much greater extent than ferric iron. Reduction of ferric to ferrous iron occurs in the small intestine.

Loss of iron from the body is low and occurs in urine, feces, sweat, dermis, and blood (Dubach et al., 1955). Hemorrhage may represent a severe loss of iron and greatly increases the requirement.

Iron requirements of ruminants are not well established. However, it is understood that young animals have higher iron requirements than adults. Based on research by Bremner and Dalgarno (1973) and Matrone et al. (1957) and the summary by the NRC (1978), the iron requirements of calves are thought to be about 100 ppm, while 50 ppm appears adequate for older cattle.

Iron deficiencies are most likely to occur in young animals (with high iron requirements) that are fed milk diets (milk contains less than 10 ppm iron) and in animals with excessive blood loss. Signs of a lack of iron include hypochromic microcytic anemia (reduced hemoglobin, reduced packed cell volume), reduced saturation of transferrin, listlessness, pale mucus membranes, reduced appetite and weight gain, and atrophy of the papillae of the tongue (Blaxter et al., 1957; Thomas, 1970; Bremner and Dalgarno, 1973).

Iron toxicity is characterized by reduced feed intake and reduced daily gain and by increased hemosiderin contents of reticulo-endothelial cells and of parenchymal cells of liver, kidney, and spleen (siderosis). Diarrhea, hypothermia, and metabolic acidosis are also observed. Physiological lesions include vascular congestion of liver, kidney, heart, lungs, brain, spleen, and gastrointestinal tract (NRC, 1980). Minimum toxic levels of iron have been reported to be as low as 1000 ppm and as high as 2500 ppm (Hartley et al., 1959; Standish et al., 1969, 1971; Koong et al., 1970; Standish and Ammerman, 1971). An iron level of 1000 ppm is given by the NRC (1980) as the maximum tolerable level for cattle. This is higher than the iron contents of most feedstuffs.

Iron contents of common feeds are: forages, 100 to 500 ppm; cereal grains, 30 to 80 ppm; oilseed meals, 100 to 400 ppm; meat and fish meals, 400 to 600 ppm; and calcium and phosphorus mineral supplements, 40 to 7000 ppm. Much of the variation in iron contents of feeds is likely due to contamination during manufacture or sample preparation. Ammerman et al. (1967) ranked iron sources in decreasing order of availability, as ferrous sulfate, ferrous carbonate, ferric chloride, and ferric oxide. Thompson and Raven (1959) and Raven and Thompson (1959) reported that iron in grasses and legumes was less available than in ferric chloride.

### *Magnesium*

Magnesium (Mg) is the fourth most abundant cation in the body. It is required for skeletal development as a constituent of bone; it plays an important role in neuromuscular transmission and activity; and it is required to activate many enzyme systems by forming a metal-enzyme complex. Enzymes requiring magnesium include those that split and transfer phosphate groups; this includes both phosphates and enzymes concerned in reactions involving ATP. Since ATP is required in many metabolic reactions, it can be inferred that the action of magnesium also extends to these reactions. Magnesium is also required as a cofactor in decarboxylation and an activator of many peptidases (Wacker and Vallee, 1964).

Approximately 65 percent of total body magnesium is contained in bone. One-third of magnesium in bone is combined with phosphorus, and the remainder is adsorbed loosely on the surface of the mineral structure. The remaining 35 percent is distributed among various tissues and organs. Normal plasma magnesium levels range from 1.8 to 2.0 mg/100 ml (Underwood, 1966), with values below 1.0 to 1.2 mg/100 ml indicative of magnesium deficiency.

Absorption of magnesium occurs prior to the intestines (Grace et al., 1974; Greene et al., 1983), from the small intestine (Field, 1961) and some from the large intestine (Smith, 1962; Care and Van't Klooster, 1965). Excretion of endogenous magnesium is primarily via feces. However, urine is considered the major disposal route for magnesium absorbed in excess of requirements (Rook et al., 1958).

Magnesium requirements of young calves have been reported to range from 12 to 30 mg/kg body weight per day (Huffman et al., 1941; Blaxter et al., 1954; Blaxter and McGill, 1956). Data are limited regarding requirements for growing and finishing cattle; however, requirements are assumed to be similar to those for calves. Beef cow requirements are between 7 and 9 g/day during gestation and 21, 22, and 18 g/day during early, mid, and late lactation, respectively (O'Kelley and Fontenot, 1968, 1969).

Magnesium requirements may be increased by feeding high levels of aluminum, potassium, phosphorus, or calcium, as these minerals decrease the efficiency of magnesium absorption and/or utilization (Wise et al., 1963; Newton et al., 1972; Greene et al., 1983). Age and magnesium status of cattle may alter requirements, since younger cattle and magnesium-deficient cattle appear to have more efficient magnesium absorption mechanisms (Smith, 1962). Beef cows with high levels of milk production also have higher magnesium requirements (Blaxter and McGill, 1956).

Deficiences of magnesium may occur as a result of simple deficiencies, such as with young calves restricted to milk diets (Blaxter et al., 1954; Blaxter and Rook, 1954); however, deficiencies are more frequently associated with the acute metabolic disorder hypomagnesemic tetany, commonly referred to as grass tetany. Hypomagnesemic tetany is most likely to occur with beef cows during initial stages of lactation while grazing pastures containing less than 0.2 percent magnesium (Underwood, 1966). Older cattle are probably more susceptible than younger cattle because of lowered labile magnesium stores and decreased absorption efficiency (Smith, 1962; Thomas, 1965).

Magnesium-deficient cattle exhibit anorexia and reduced dry matter digestibilities (Martin et al., 1964). Deficiencies in young cattle may result in defective bones and teeth. Initial signs of magnesium deficiency include nervous apprehension, ears carried backwards, staring eyes, and an ataxic gait. As the deficiency becomes more severe, cattle become hypersensitive to tactile or sound stimuli, with muscle tremors occurring and finally giving way to convulsions. Death usually occurs during or after one of these convulsions.

Activities of many magnesium-dependent enzymes are depressed during magnesium deficiency (Moore et al., 1938; Tufts and Greenberg, 1938; Elin et al., 1971). Subnormal levels of blood magnesium are common, and clinical signs of tetany usually occur when blood levels drop to 1.0 and 1.2 mg/100 ml (Underwood, 1966). Tissue levels of potassium decline, and calcium and sodium may rise in magnesium-deficient animals.

Magnesium toxicity does not occur in cattle fed typical rations. Supplemental levels of magnesium up to 114 g/day have been fed without affecting cattle; however, levels of 170 to 350 g have resulted in deleterious effects (Care, 1960). Maximal tolerable levels have been established as 0.4 percent of the ration by the NRC (1980). Feeding toxic levels has resulted in anorexia, reduced performance, and occasional diarrhea (Pierce, 1959). Cattle experiencing toxicity may also exhibit lack of reflexes and respiration depression. Plasma and urinary magnesium levels are highly correlated with magnesium intake (above requirements) and are useful in detecting toxicity.

Commonly used feedstuffs vary widely in magnesium concentration and availability. Magnesium contents of most cereal grains are between 0.12 and 0.18 percent. Protein supplements of animal origin are low in magnesium, while those of plant origin usually contain 0.3 to 0.6 percent. Magnesium contents of herbage plants vary greatly and are normally higher in legumes than grasses. Magnesium fertilization usually increases plant magnesium content. Also, magnesium availability increases with increasing plant maturity (Underwood, 1966).

Several sources of inorganic magnesium may be used to supplement cattle. Magnesium carbonate, oxide, and sulfate are considered good sources of supplemental magnesium; however, magnesium from magnesite and dolomitic limestone is not readily available to cattle (Gerken and Fontenot, 1967; Ammerman and Chicco, 1968).

### *Manganese*

Manganese (Mn) is nutritionally essential for both plants and animals. Deficiencies of manganese lead to degenerative reproductive failure in both males and females, bone malformations and crippling, ataxia, depigmentation, and deterioration of the central nervous system. Manganese is a preferred metal cofactor for many enzymes involved in carbohydrate metabolism and in mucopolysaccharide synthesis. Manganese enzyme systems include glycosyltransferase, pyruvate carboxylase, GTP oxaloacetate carboxylase, isocitrate dehydrogenase, malic dehydrogenase, arginine synthetase, and glutamine synthetase. A large number of enzyme systems that require magnesium can utilize manganese. Manganese ( + 2) may also replace zinc ( + 2) in zinc-dependent enzymes, but this usually reduces the catalytic properties.

All ruminant tissues contain manganese in low concentrations. The glandular organs that are most sensitive to manganese status are liver, kidney, pancreas, and pituitary, and they exhibit the highest manganese content, with a measureable amount found in bone (Hidiroglou, 1979). The liver contains important mobilizable manganese stores. Bentley and Phillips (1951) measured liver stores of manganese at 12 ppm (DM basis) when cattle were fed dietary manganese at 30 ppm.

Ruminants regulate manganese levels in blood and tissues via homeostatic control of intestinal absorption. Manganese is excreted via feces, with little in urine. Bertinchamps et al. (1966) concluded that bile was the principal route of manganese excretion. Phosphorus, calcium, iron, zinc, copper, magnesium, and molybdenum have been implicated as interacting with manganese. Work by Hidiroglou et al. (1978) and Lassiter et al. (1972) suggests a calcium-phosphorus-manganese interaction.

Requirements for manganese are increased by elevated dietary levels of calcium and phosphorus (Hawkins et al., 1955; Lassiter et al., 1972); thus, establishment of a single requirement value is difficult and may be misleading. Also, only limited information is available concerning manganese requirements of ruminants. Mature females have higher requirements for manganese than feedlot cattle because of an increased need for reproduction and fetal development (Bentley and Phillips, 1951; Rojas et al., 1965). Dyer et al. (1964) noted that cows fed diets with 56 ppm of manganese had normal calves, but those fed diets with 47 ppm manganese and a high level of calcium gave birth to deformed calves. The manganese requirement of 40 ppm given by Hidiroglou (1979) and the NRC (1978) should be adequate for normal reproduction, but 20 ppm is likely to be adequate for growing-finishing cattle (Underwood, 1977).

Hidiroglou et al. (1978) listed the average plasma manganese value for cattle as 25 ng/ml. According to Leach (1971), there are at least two manganese-dependent enzyme systems that are severely affected by manganese deficiency, resulting in skeletal and postural defects. These are the polymerase system, which is responsible for chain elongation of polysaccharides, and the galatosyltransferase system, which links protein molecules with polysaccharides. Chondroitin sulfate is the mucopolysaccharide most severely affected by a lack of manganese, thus affecting synthesis of bone connective tissue.

Impairment of reproductive function in males and females occurs during manganese deficiency. Along with impaired spermatogenesis (Underwood, 1977), irregular or absent estrus, and delayed conception, Utter (1976) and Hidiroglou et al. (1978) noted that manganese is known to be an activator of numerous enzymes, including hydrolases, kinases, decarboxylases, and transferases. Inhibition of these enzyme systems could result in insufficient material for fetal growth and, therefore, may contribute to abortion and deformities. Hidiroglou and Shearer (1976) reported a high manganese content of corpora lutea, suggesting another possible role for manganese in normal reproduction. For males, manganese deficiency is demonstrated by impaired spermatogenesis; testicular and epididymal degeneration; sex hormone inadequacy; and, eventually, sterility.

For ruminants, manganese is among the least toxic of the required minerals. There are few documented toxicities. At 125 ppm manganese, hemoglobin levels are depressed, and anemia occurs in growing pigs. Supplementation with iron overcomes the hemoglobin depression at 125 ppm manganese. When 1250 ppm manganese was fed, growth of pigs was irreversibly depressed (Matrone et al., 1959). The manganese-iron antagonism also is suggested to occur in cattle.

Ruminants fed diets with 1000 ppm manganese have near normal growth rates and feed intakes and do not exhibit obvious indications of toxicity. Cunningham et al. (1966) noted a significant depression in blood hemoglobin as levels of a dietary manganese were elevated above 1000 ppm. The NRC (1980) states that with a balanced diet about 1000 ppm is the maximal tolerable level on a short-term basis for sheep and cattle, with about 2000 ppm the maximum level for poultry and only 400 ppm for swine.

Manganese levels in pastures, grains, and forages are variable because of variations in plant species, soil types, soil pH, and fertilization practices. Forages contain high levels of manganese, with a grass-legume forage approaching levels of 100 ppm (DM basis), while such grains as corn, barley, and oats contain from 15 to 40 ppm manganese (Redshaw et al., 1978; Hidiroglou, 1979).

### *Molybdenum*

Molybdenum (Mo) is found in nearly all body cells and fluids, but its essentiality is due to its biochemical role in the enzymes xanthine oxidase, aldehyde oxidase, and sulfide oxidase. These metallo-enzymes contain molybdenum, as well as FAD, and are involved in the oxidation of purines and reduction of cytochrome C. Xanthine oxidase, which contains both molybdenum and copper, is involved in the reduction of iron (3 + ferritin to 2 + ferritin) and iron metabolism (De Renzo et al., 1953; Mahler et al., 1954; Seelig, 1972).

Most of the molybdenum in the body is found in skeletal muscle, with lesser quantities found in liver, muscle, kidneys, skin, wool, and hair. Dick (1956) reported data that showed about 2 percent of body molybdenum is in liver. Molybdenum contents of soft tissue, blood, and milk are affected by molybdenum intake and are also greatly affected by copper and sulfur intakes.

Hexavalent molybdenum, such as that in sodium and ammonium molybdates, is well absorbed by cattle. Molybdenum in forages also is readily absorbed and may interfere with copper metabolism in cattle. The molybdenum from dried forage may not be as available as that from green forage, since forages that interfere with copper metabolism when grazed do not cause difficulties when fed as dry forage. Absorption of molybdenum is from the intestine, and excretion of molybdenum is primarily via urine, with small amounts excreted in bile and milk.

Requirements for molybdenum are not established. An exact estimate of the molybdenum requirement is impossible since copper and sulfate alter molybdenum metabolism. Furthermore, the majority of research on molybdenum has concentrated on the interrelationship with copper and sulfate, rather than on a specific requirement. Ward (1978) speculated that there is no safe dietary level of molybdenum because of such interactions. Work by Ellis et al. (1958) with growing lambs showed faster gains when dietary molybdenum was increased from 0.36 to 2.37 ppm.

Molybdenum and sulfur both interfere with copper metabolism, and several mechanisms have been proposed to explain these interrelationships. Dowdy and Matrone (1968a,b) used sheep, pigs, and chickens to substantiate the existence of a copper-molybdenum complex and to verify the antagonistic action of molybdenum on copper metabolism. These workers concluded that excess molybdenum may cause a copper deficiency as a result of the formation of absorbable, but metabolically unavailable, copper-molybdate complex. The molar ratio of copper to molybdenum in the complex was about 4:3. The complex formed optimally at a neutral pH and contained no sulfur. This complex may explain certain instances where plasma copper levels have been normal but where copper deficiency signs have been observed.

Sulfur, in the absence of molybdenum, also may cause a copper deficiency because of the formation of insoluble, unabsorbed copper sulfide in the gut. Rumen microorganisms rapidly convert sulfate and other sulfur-containing compounds to sulfide, providing conditions favorable for the formation of unavailable copper sulfide.

Sulfide also may be absorbed and form copper sulfide in the body. Sulfide oxidase, an enzyme that liberates copper from copper sulfide, is inhibited by molybdenum. Thus, molybdenum may contribute to a copper deficiency by preventing the liberation of copper from copper sulfide in the body. Plasma copper levels would remain normal, but the animal would be copper deficient.

The combined effects of dietary sulfur and molybdenum on copper status are synergistic. This may be due to the formation of unabsorbable copper thiomolybdate (Huisingh et al., 1973; Dick et al., 1975; Suttle, 1975). The formation of copper sulfide and copper thiomolybdate would greatly reduce copper absorption, since both render copper unavailable. Thus, plasma and liver copper levels are reduced and symptoms of copper deficiency develop. Likewise, blood levels of molybdenum decline and fecal excretion increases. The formation of copper sulfide, copper molybdate, and copper thiomolybdate (one or more of which may occur under specific conditions) can explain most observations of the copper-sulfur-molybdenum interrelationship. The formation of copper sulfide and copper thiomolybdate in the digestive tract explains those instances where molybdenum or molybdenum and sulfur caused decreased absorption of copper and decreased blood and liver copper. Formation of copper molybdate, which is absorbed but not utilized, explains those instances where blood copper levels are elevated and liver copper remains normal but the animal exhibits signs of copper deficiency.

Clinical signs of molybdenum toxicity in cattle are diarrhea, anorexia, anemia, ataxia, and bone malformation. Depigmentation of skin and hair, with a loss of crimp in wool, are the clinical signs exhibited by sheep. Signs of molybdenosis are similar to those of a copper deficiency.

Molybdenum levels of 5 to 6 ppm inhibit copper storage and produce signs of molybdenosis (NRC, 1980). Elevated dietary copper alleviates the toxic effects of molybdenum (Ferguson et al., 1943; Miller and Engel, 1960; Mills, 1960; Ward, 1978). When added to experimental diets, molybdenum has been supplied as sodium or ammonium molybdate.

### *Phosphorus*

Phosphorus (P) has varied, but extremely important, biochemical and physiological roles. It is deposited in bone as calcium hydroxy appetite $[Ca_{10}(PO_4)_6(OH)_2]$. Phosphorus is a component of phospholipids, which influence cell permeability and are components of myelin sheathing of nerves. Many energy transfers in cells involve the high-energy phosphate bonds in ATP. Phosphorus plays an important role in blood buffer systems. Activation of several B-vitamins (thiamin, niacin, pyridoxine, riboflavin, biotin, and pantothenic acid) to form coenzymes requires their initial phosphorylation. Phosphorus also is a part of the genetic materials DNA and RNA.

Normal blood plasma phosphorus levels vary from 4 to 8 mg/100 ml. Erythrocytes contain much more phosphorus than does plasma; thus, whole blood contains 6 to 8 times as much phosphorus as does plasma. A major fraction of total body phosphorus is found in bone. Phosphorus is also found in high concentrations in brain, muscle, liver, spleen, and kidneys.

Like calcium, phosphorus absorption is an active process. Sodium may be required for the absorption of phosphorus (Taylor, 1974), and the process is stimulated by 1,25-dihydroxy cholecalciferol (Chen et al., 1974). The amount of phosphorus absorbed is dependent on source, intestinal pH, age of the animal, and dietary levels of calcium, iron, aluminum, manganese, potassium, magnesium, and fat (Irving, 1964). Excess phosphorus is excreted primarily in the feces.

Methods employed to establish phosphorus requirements and discussion of these values relative to published data are presented in the Calcium section earlier in this chapter.

High iron levels result in the formation of insoluble iron phosphate, resulting in low phosphorus rickets (Underwood, 1977). Aluminum also forms insoluble, unavailable phosphates.

Because many forages contain inadequate levels of phosphorus to meet the requirements of growing or lactating cattle (Black et al., 1943), and because phosphorus-deficient soils are common, phosphorus deficiencies in cattle are widespread. Also, mature forages and crop residues generally contain low levels of phosphorus (Maynard et al., 1935), while the cereal grains and oilseed meals contain moderate to high levels of phosphorus. A deficiency of phosphorus results in decreased growth rates, inefficient feed utilization, and a depraved appetite (chewing of wood, soil and bones, a condition termed pica). Anestrus, low conception rate, and reduced milk production are frequently associated with low-phosphorus diets. However, Teleni et al. (1977) suggested that reproductive difficulties in beef cows may be more related to protein intake. Plasma phosphorus levels decline during phosphorus deficiencies. Phosphorus-deficient animals may have weak, fragile bones and become stiff in the joints (Preston et al., 1977).

High phosphorus intakes may cause bone resorption, elevated plasma phosphorus levels, and urinary calculi as a result of precipitation of calcium and magnesium phosphates in the kidney. Feeding increased amounts of calcium may reduce the incidence of urinary calculi in animals fed high phosphorus diets (Emerick and Embry, 1963, 1964).

In a review of availabilities to ruminants of phosphorus compounds, Peeler (1972) ranked availabilities of common sources of phosphorus as follows: dicalcium phosphate, defluorinated phosphate and bone meal, and soft phosphate. Sodium phosphates and ammonium polyphosphate are approximately equal to dicalcium phosphate in phosphorus availability. Orthophosphates are more available than meta and pyrophosphates. Oilseed meals and animal and fish products are feeds that contain large amounts of phosphorus. Phytate phosphorus is not well utilized by nonruminants, but ruminants appear to use considerable quantities of this form of phosphorus (McGillivray, 1974).

*Potassium*

Potassium (K) is the third most abundant mineral element in the animal body and the principal cation of intracellular fluid; it also is a constituent of extracellular fluid, where it influences muscle activity. Red blood cells contain approximately 25 times as much potassium as is present in plasma. Muscle and nerve cells also are high in potassium, containing over 20 times that present in interstitial fluids.

The concentration of potassium in the fat-free body of adult cattle is 78 mEq/kg (Wilde, 1962). Serum potassium concentrations in cattle are about 4.7 mEq/l (Welt et al., 1960).

Several studies have been conducted to determine potassium requirements of cattle. Variable values have been reported: the discrepancies possibly depend on amounts needed for only maintenance or for maintenance plus optimum growth or to effects of potassium on digestive function. Roberts and St. Omer (1965) concluded that the dietary potassium requirement of finishing steers was between 0.5 and 0.6 percent of the ration. A low potassium basal ration (0.08 percent potassium) was supplemented with $K_2CO_3$ to provide rations containing 0.36, 0.50, 0.67, or 0.77 percent potassium (Devlin et al., 1969). This trial indicated that the potassium requirement for finishing steers was higher than 0.51 percent but not above 0.72 percent of the diet. Clanton (1980) suggested that the potassium requirement of pregnant beef cows is between 0.5 and 0.7 percent. The requirement for potassium is higher for ruminants than for nonruminants.

Low serum potassium (hypokalemia) may be caused by malnutrition, negative nitrogen balance, gastrointestinal losses, and endocrine malfunction. Sex and age differences in potassium concentrations may be related to physiological aging or to the ratio of muscle mass of other body constituents (Welt et al., 1960). Signs of hypokalemia include anorexia, weight loss, muscle weakness, irritability, paralysis, and tetany. Evaluation of a potassium deficiency is difficult. Serum analyses were of little use in a trial with feeder lambs (Telle et al., 1964). Reduced feed consumption appears to be an early sign of inadequate dietary potassium. Changes in electrocardiogram and muscle potassium content have been used with limited success to diagnose potassium deficiency. Because reliable evaluations of a potassium deficiency are not available, dietary potassium concentration appears to be the best indicator of potassium status.

High serum potassium is not likely to occur under normal situations. If extracellular potassium is increased from 5 to 10 mEq/l, toxicity may result (Wilde, 1962). After periods of moderately high potassium intake, animals can survive potassium intakes that would otherwise be lethal (Wright et al., 1971). High dietary levels of potassium interfere with magnesium absorption in ruminants and can cause hypomagnesemic tetany in sheep (Newton et al., 1972; Fontenot et al., 1973). Increasing the potassium level in a liquid diet from 1.2 to 5.8 percent, dry basis, resulted in the death of 3 of 8 calves (Blaxter et al., 1960). Jackson et al. (1971) noted reduced weight gains as the potassium contents of diets for lambs were increased from 0.7 to 3.0 percent. The clinical signs before death were cardiac insufficiency, edema, muscular weakness, and loss of muscular tone. No abnormalities in magnesium metabolism were observed. Increasing dietary magnesium levels may offer protection against potassium toxicity.

Livestock needs for potassium vary with amounts of protein, phosphorus, calcium, and sodium consumed. Forage crops are high in potassium, even though their potassium contents depend on the fertility of the soil in which they are grown. Diets based largely on milo, corn, or corn and cob meal, together with low-potassium hays and silages, may fall short in providing sufficient potassium for fast-growing or high-producing animals. Most high-protein feeds contain high levels of potassium. Also, Clanton (1980) has shown that beef cows grazing standing forage during winter months may be deficient in potassium. The most common source of supplemental potassium is KCl.

### *Selenium*

Selenium (Se) is similar to sulfur in its chemical properties. Interest in the biological significance of selenium was initially confined to the problem of toxicity in animals (Underwood, 1971; Ullrey, 1973).

In 1973, glutathione peroxidase was shown to be a seleno enzyme (Rotruck et al., 1973); it contains four selenium atoms (Briggs and Calloway, 1979). Sulfur-containing amino acids serve as precursors for glutathione and are therefore necessary for proper glutathione peroxidase function (Burk, 1976). It is postulated that glutathione peroxidase prevents membrane damage because of its antioxidant property (Hoekstra, 1973). Any postulates concerning the biochemical role of selenium must consider the interrelationship between selenium and vitamin E (Hoekstra, 1973). It has been conclusively shown that selenium cannot be completely replaced by vitamin E, but their functions intertwine to account for their mutual sparing effect. Selenium is also effective in reducing cadmium and mercury toxicity (Parizek et al., 1973).

Absorbed selenium is carried in the plasma (associated with protein) until it enters tissues (Moxon and Rhian, 1943; Herrman and McConnell, 1973). Selenium is excreted in feces and urine; however, fecal excretion is greater than urinary excretion in ruminants (McConnell, 1941; Underwood, 1971). Pulmonary excretion of selenium is an important excretory route when dietary intakes are high (McConnell, 1942; McConnell and Portman, 1952; Ganther et al., 1966); however, it is insignificant, at least in the rat, when dietary selenium is less than 1 ppm (Burk et al., 1972).

The selenium requirement of beef cattle depends on the amount of vitamin E in the diet, but ranges are suggested as follows: growing and finishing steers and heifers, 0.10 mg/kg dry weight diet; breeding bulls and pregnant and lactating cows, 0.05 to 0.10 mg/kg dry weight diet. The NRC (1980) suggested that 0.10 to 0.30 mg/kg dry weight of diet met requirements and that 2 mg/kg dry weight diet is the maximum tolerable level for all species.

Minimum requirements of animals vary with the form of selenium ingested and the nature of the diet, especially vitamin E content (Underwood, 1971). Selenium is found associated with dietary protein as selenoamino acids in plants (Olson et al., 1970). Selenium in animal feeds is highly variable primarily due to the selenium status of the soil (Underwood, 1971). The plant species *Astragalus* and *Stanleya*, selenium accumulators that grow mainly in seleniferous areas, can contain between 1000 and 3000 ppm selenium. Thus, grazing livestock may be adversely affected (Underwood, 1971; Briggs and Calloway, 1979).

White muscle disease, a selenium-responsive myopathy, is characterized by white muscle, heart failure, and paralysis (lameness, to an inability to stand) (Whanger et al., 1973). It is a muscular dystrophy that cannot be produced in calves on vitamin E-free diets unless the diets are high in unsaturated fats (Muth et al., 1958; Hartley and Grant, 1961). Depression of glutathione peroxidase in tissues of selenium-deficient animals may account for many of the manifestations of selenium deficiency.

Selenium was identified as a toxicant in studies begun in 1929 (Franke, 1934). General signs of toxicity include loss of appetite, loss of tail hair, sloughing of hoofs, and eventual death (NRC, 1980). Death is the result of respiratory failure along with starvation and thirst. Two types of selenium poisoning have been observed: acute, "blind staggers"; and chronic, "alkali disease" (Rosenfeld and Beath, 1964). Toxicity varies with the amounts and chemical form of selenium ingested, the duration and continuity of intake, and the nature of the diet (Underwood, 1971). Edible herbage in seleniferous areas contains 5 to 20 ppm (Underwood, 1971). Tissue levels increase with toxic intakes to a point; then excretion begins to keep pace with absorption and further accumulation does not occur (Underwood, 1971). High-protein diets and arsenic also appear to offer some protection (Levander and Baumann, 1966; Underwood, 1971) against high selenium intakes.

### *Sodium and Chlorine*

Sodium (Na) functions in maintaining osmotic pressure, acid-base balance, and body-fluid balance. This cation is also involved in nerve transmission and active transport of amino acids. Sodium is required for cellular uptake of glucose through activation of the glucose carrier protein. Chlorine (Cl) is necessary for the activation of amylase and is essential for formation of gastric hydrochloric acid. In respiration and regulation of blood pH, chlorine is transferred between plasma and erythrocytes through a process known as the chloride shift.

Sodium is the major cation of extracellular fluid and provides a majority of the alkaline reserve in plasma. The sodium content of plasma is normally 140 mEq/l. Much of the body's sodium is incorporated into crystals in bone, where it is not released until bone is resorbed. Thus, this fraction may serve as a slowly available sodium pool.

Chlorine is usually studied with sodium, as it is the major anion of the extracellular fluid. Plasma chlorine concentration is normally 107 mEq/l, which is slightly less than sodium concentration. Less than 15 percent of body chlorine is found within cells.

Sodium and chlorine are mainly absorbed from the proximal portion of the small intestine, but they may also be absorbed from the distal section of the small intestine and the large intestine. Some absorption of sodium and chlorine may occur from the rumen.

Carnivorous animals usually secure adequate sodium and chlorine in their diets. However, herbivores require supplementation, because plant materials are usually low in sodium and high in potassium. Potassium may promote sodium excretion (Hafez and Dyer, 1969).

In domestic animals, deficiencies of sodium and chlorine may occur because plants have low-sodium contents, because sodium losses caused by perspiration may occur in animals maintained in warm environments or used for hard work, and because sodium needs increase during lactation and during periods of rapid growth (Hafez and Dyer, 1969; Underwood, 1970).

Sodium requirements are generally met by supplemental sodium chloride. It is readily available and is low in cost. This, in part, may account for the lack of published requirements for chlorine in beef cattle. Sodium concentrations of 0.06 to 0.08 percent of diet dry matter for nonlactating yearlings and calves and no more than 0.1 percent dry matter for lactating beef cows (Morris and Gartner, 1971; Morris and Murphy, 1972; Morris, 1980) have been found to meet requirements. Burkhaltor et al. (1979) reported that young bulls fed diets with 0.038 percent chlorine had gains and intakes that were similar to those for young bulls fed diets that contained 0.5 percent chlorine.

Animals can be maintained for some time on low-sodium diets because of their efficient conservation mechanisms. In severe deficiencies, animals may experience muscle cramps and a craving for salt that is evident through constant licking, general weakness, and death (Hafez and Dyer, 1969). Other signs may include weight loss, decrease in milk production, and rough hair coat (Underwood, 1970).

Most animals can tolerate large quantities of dietary salt when an adequate supply of water is available (NRC, 1980). More dramatic effects of sodium toxicosis may occur if the animal's water is contaminated with dissolved salts. Addition of sodium chloride to drinking water to give 12 to 20 g/l caused anorexia, decreased water consumption, weight loss, elevated plasma potassium and sodium concentrations, depressed plasma magnesium and urea levels, and physical collapse in cattle (Weeth et al., 1960; Weeth and Haverland, 1961).

Much of the western half of the United States, and many other semiarid regions, have soils that are high in salinity and saline groundwater, which may lead to saline water intoxication. Clinical signs follow consumption of water that has more than 7000 ppm of dissolved salt and include low consumption of feed and water, mild digestive disturbances, low rates of gain, and diarrhea (Jensen and Mackey, 1979).

Sodium and chlorine are widely distributed in nature; however, feedstuffs used in livestock production contain insufficient salt to meet requirements. Meyer et al. (1950) reported sodium and chlorine contents for several feeds.

### *Sulfur*

Sulfur (S) is a component of protein, some vitamins, and several important hormones. Common amino acids that contain sulfur are methionine, cysteine, and cystine. Amino acid derivatives that contain sulfur include cystathionine, taurine, and cysteic acid. Methionine is a key amino acid, since all other sulfur compounds, except the B-vitamins thiamine and biotin, that are necessary for normal body function can be synthesized from methionine. Body functions that involve sulfur include protein synthesis and metabolism, fat and carbohydrate metabolism, blood clotting, endocrine function, and intra- and extracellular fluid acid-base balance (Baker, 1977).

Sulfur has both structural and metabolic functions; thus, it is found in virtually every tissue and organ of the body. Masters and McCance (1939) showed that muscle has a fairly constant nitrogen to sulfur ratio of 15.3:1. The total body content of sulfur is approximately 0.15 percent.

The microbial population of the rumen has the ability to convert inorganic sulfur into organic sulfur compounds that can be utilized by the animal. Block et al. (1951) concluded that sodium sulfate was converted in the rumen to cystine and methionine and then incorporated into microbial protein. The use of elemental sulfur by microbes has been demonstrated by Saville et al. (1975). The availability of sulfur to rumen microbes from different sources, organic and inorganic, has been ranked from most to least available by Kahlon et al. (1975) as L-methionine, calcium sulfate, ammonium sulfate, DL-methionine, sodium sulfate, sodium sulfide, elemental sulfur, and hydroxy analog of methionine.

Most diets that are fed to cattle contain adequate amounts of sulfur to meet the animal's needs, but in certain feeding regimes, supplementation with sulfur has proven beneficial. Cattle fed high-grain rations that were supplemented with nonprotein nitrogen responded to the addition of elemental sulfur (Meiske et al., 1966). Rees et al. (1974) fed cattle pangola grass and increased dry matter intakes and digestibilities when either the grass was fertilized or supplemented with sulfur.

Requirements of beef cattle for sulfur are not well defined. Most research to determine sulfur requirements of ruminants has been conducted using sheep and lactating dairy cows, both of which produce products with higher sulfur contents than do beef cattle. A diet that contained 0.106 percent sulfur met requirements of 5- to 11-week-old calves (Leibholz, 1972). The beef cow, whether in gestation or lactation, is thought to have sulfur requirements that are similar to those of finishing cattle.

The interrelationship between copper, molybdenum, and sulfur has received wide attention. Copper requirements are increased by both sulfur and molybdenum. Copper forms cupric sulfide, which is insoluble in all parts of the digestive tract. Cupric molybdate may also be formed. Cupric molybdate can be absorbed but is metabolically inactive (Dowdy and Matrone, 1968a,b). A third compound that reduces the availability of copper is unabsorbable copper thiomolydate (Huisingh et al., 1973; Dick et al., 1974).

The interrelationship between selenium and sulfur is due in part to their similar structures. Selenium can replace sulfur in some organic compounds, but the metabolic activity of the seleno-compound is less than that of the normal sulfur-containing compound (Diplock, 1976). Selenium toxicity can be counteracted by the feeding of sulfur, but the form of the sulfur is a major factor. Whanger (1970) showed that selenium absorption was decreased by sulfur compounds with the most influence being exhibited on seleno-compounds by its sulfur analog.

Signs of sulfur deficiency include reduced appetite, weight loss, weakness, excessive salivation, watery eyes, dullness, emaciation, and death (Thomas et al., 1951; Starks et al., 1953; Whanger, 1968). In a sulfur deficiency, microbial protein synthesis is reduced, and the animal shows signs of protein malnutrition. A lack of sulfur also results in a microbial population that does not utilize lactate; therefore, lactate accumulates in the rumen, blood, and urine (Whanger and Matrone, 1966, 1967). Serum sulfate levels have been suggested as an indicator of sulfur deficiency (Weir and Rendig, 1952), but blood lactate and dietary sulfur levels may be the most reliable indicators of sulfur status (Goodrich et al., 1978).

Sulfur toxicity is characterized by restlessness, diarrhea, muscular twitching, dyspnea, and in prolonged cases by inactivity followed by death (Coghlin, 1944). The cause of these signs of toxicosis is thought to be sulfide, which is produced in large quantities when high-sulfur rations are fed (Bray, 1969). Since sulfate may be absorbed readily throughout the digestive tract, excesses may lead to metabolic acidosis. The suggested maximum level for sulfur in the diet is 0.4 percent (NRC, 1980), but Bouchard and Conrad (1976) suggested a lower level (0.26 percent) for lactating dairy cows.

All feeds contain some sulfur, but the amount usually depends on the protein content of the feed. Feeds higher in protein will usually have more sulfur. Availability of the sulfur in the feed to microbial reduction in the rumen may be of as much concern as the actual amount that is present.

### *Zinc*

Zinc (Zn) has been recognized as an essential element for animals since 1935 (Bertrand and Bhattacherjee, 1935). Requirements for zinc are based on its biochemical function as both an activator and constituent of several dehydrogenases, peptidases, and phosphatases that are involved in nucleic acid metabolism, protein synthesis, and carbohydrate metabolism (Vallee, 1959; Underwood, 1956; Hsu and Anilare, 1966; Mills et al., 1969).

Zinc concentration in the body of cattle is approximately 30 ppm. Zinc is found in high concentrations in soft tissues such as the pancreas, liver, pituitary gland, kidney, and adrenal gland. Bone, teeth, hair, and the choroid and iris of the eye are also high in zinc content. In males, testicles and accessory sex glands have high zinc concentrations. Normal plasma zinc levels range from 80 to 120 $\mu g$ per 100 ml, with one-third of the zinc firmly bound to globulin and the remainder loosely bound to albumin (Vallee, 1962).

Absorption of zinc occurs primarily from the abomasum and lower small intestine, with little zinc absorbed below the cecum (Miller and Cragle, 1965). Feces is the primary route of zinc excretion. Little zinc is excreted in urine (Feaster et al., 1954). Fecal zinc includes unabsorbed zinc, zinc secreted into the gut, zinc from bile and pancreatic secretions, and zinc from desquamated epithelial cells.

Zinc requirements of cattle are not precisely defined. Results of several trials suggest requirements to be between 20 and 40 mg/kg diet dry matter (Miller et al., 1962, 1963; Mills et al., 1967). In other trials, feeding higher levels improved performance (Perry et al., 1968).

Requirements may be altered by dietary levels of cadmium, calcium, iron, magnesium, manganese, molybdenum, and selenium since these minerals affect zinc absorption and/or utilization (Van Campen and Mitchell, 1965; Holod et al., 1969; Van Campen, 1969; Suttle and Field, 1970; Ivan and Grieve, 1975). Requirements vary according to age and growth rate, since zinc absorption decreases with age and as growth rate decreases (Stake et al., 1973). Beef cows with high levels of milk production have higher requirements, since milk contains 300 to 500 mg of zinc per liter.

Zinc deficiencies have been reported in ruminants grazing forages low in zinc or high in compounds interfering with zinc utilization (Pierson, 1966; Mayland, 1975). Deficiencies are characterized by decreased performance and listlessness, followed by development of swollen feet and a dermititis that is most severe on the neck, head, and legs. Deficiencies may also result in vision impairment, excessive salivation, decreased rumen, volatile fatty acid production, and a failure of wounds to heal normally (Miller et al., 1965; Ott et al., 1965; Pierson, 1966; Mills et al., 1967). Impaired reproductive performance may occur in zinc-deficient bulls and cows (Pitts et al., 1966).

Readily available stores of zinc are small, and depletion is reflected by a rapid drop in liver and plasma zinc. Deficiencies are difficult to detect in early stages or in milder forms. Biochemical changes with promising diagnostic value are declines in zinc concentration in plasma, hair, and tissue. However, perhaps the best indicator is increased feed intake and growth after feeding supplemental zinc, since deficient cattle respond rapidly to supplemental zinc (Miller and Miller, 1962; Mills et al., 1967).

The extent of zinc tolerance is dependent on the diet, particularly concentrations of minerals that affect zinc absorption and utilization. Therefore, the threshold for zinc toxicity cannot be adequately defined. Steers have been fed diets containing 1000 ppm zinc for 13 to 18 months without marked reduction of performance (Feaster et al., 1954).

Plant species vary widely in zinc concentration, with legumes usually having higher concentrations than grasses. In general, most hays and silages contain less than 60 ppm zinc. Cereal grains normally contain between 10 and 30 ppm zinc. Protein supplements of plant origin contain 50 to 70 ppm zinc, and those of animal origin contain 90 to 100 ppm zinc. Sources of inorganic zinc that may be used to supplement cattle include acetate, carbonate, chloride, and sulfate and metallic zinc (NRC, 1980).

## VITAMINS

Cattle have physiological requirements for most vitamins required by other mammals. Furthermore, calves from adequately fed mothers have minimal stores of vitamins at birth. Synthesis by microorganisms in the rumen, supplies in natural feedstuffs, and synthesis in tissues meet most of the usual requirements. Colostrum is rich in vitamins, providing immediate protection to the newborn calf. The ability to synthesize B vitamins and vitamin K in the rumen develops rapidly when solid feed is introduced into the diet. Vitamin D is synthesized by animals exposed to direct sunlight and is found in large amounts in sun-cured forages. High-quality forages contain large amounts of vitamin A precursors and vitamin E.

### *Vitamin A*

The vitamin A requirements for beef cattle are 2200 IU per kilogram of dry feed for feedlot cattle; 2800 IU per kilogram for pregnant heifers and cows, and 3900 IU per kilogram for lactating cows and breeding bulls (Jones et al., 1938; Guilbert and Hart, 1935; Guilbert et al., 1940; Madsen et al., 1948; Church et al., 1956; Chapman et al., 1964; Cullison and Ward, 1965; Perry et al., 1965, 1968; Swanson et al., 1968; Kohlmeier and Burroughs, 1970; Meacham et al., 1970; Kirk et al., 1971; Eaton et al., 1972). These requirements are the same as those given in the fifth edition of this report (NRC, 1976). An IU is defined as 0.300 μg of vitamin A alcohol (retinol) or 0.550 μg of vitamin A palmitate. Efficiency of conversion of carotenoids to retinol is variable in beef cattle and generally lower than that for nonruminant animals (Ullrey, 1972). One milligram of β-carotene is assigned a value of 400 IU (2.5 μg β-carotene per IU). While it is common for commercial formulators to add a safety factor to these values, general practical experience with them has been satisfactory, although systematic experimental reevaluations have not been attempted.

Vitamin A is the vitamin most likely to be of practical importance in feeding cattle. Although the only well-established biochemical function of vitamin A is its role as a component of the visual purple required for dim-light vision, it is essential for normal growth, reproduction, and maintenance of healthy epithelial tissue. Vitamin A activity is supplied in natural feeds mainly by carotenoid precursors. High-quality forages provide carotenoids in large amounts but tend to be quite seasonal in availability. Few grains, except for yellow corn, contain appreciable amounts of carotenoids. Carotene is rapidly destroyed by exposure to sunlight and air, especially at high temperatures. Ensiling effectively preserves carotene, but the availability of carotene from corn silage may be low (Jordan et al., 1963; Smith et al., 1964; Miller et al., 1967).

The liver can store large amounts of vitamin A. These stores serve to prevent vitamin A deficiency during periods of suboptimal intake. Unfortunately, liver stores are highly variable and cannot be assessed accurately without taking samples by biopsy. The duration of protection afforded by liver stores can vary from none to perhaps a year or longer. Intakes necessary to establish and maintain these stores are considerably greater than the listed requirements. The stores are in a dynamic state (Frey and Jensen, 1947; Hayes et al., 1967), but factors influencing deposition and removal are not well understood. On a practical basis it is seldom safe to expect more than 2 to 4 months of protection from stored vitamin A, and cattle should be observed carefully for signs of deficiency whenever the diet is deficient.

Dietary vitamin A deficiency is most likely to occur when cattle are fed (1) high-concentrate diets; (2) bleached pasture or hay grown under drought conditions; (3) feeds that have had excess exposure to sunlight, air, and high temperature; (4) feeds that have been heavily processed or mixed with oxidizing materials such as minerals; and (5) feeds that have been stored for long periods of time. Newborn calves deprived of colostrum and cattle that have been prevented from establishing or maintaining good liver stores through exposure to drought, winter feeding without high-quality forage, or exposure to stresses such as high temperature or elevated nitrate intake are particularly susceptible. Deficiencies can be corrected by increasing carotene intake through the introduction of high-quality forage or by supplying vitamin A in the feed or by injection. Since inefficient conversion of carotene to vitamin A is often a part of the problem, administering preformed vitamin A is preferred when deficiency signs are present. Injected vitamin A is used more efficiently than oral vitamin A (Perry et al., 1967; Schelling et al., 1975), possibly because of extensive destruction of dietary vitamin A in the rumen and abomasum (Keating et al., 1964; Klatte et al., 1964; Mitchell et al., 1967).

Signs of vitamin A deficiency include reduced feed intake, rough hair coat, edema of the joints and brisket, lacrimation, xerophthalmia, night blindness, slow growth, diarrhea, convulsive seizures, improper bone growth, blindness, low conception rates, abortion, stillbirths, blind calves, abnormal semen, reduced libido, and susceptibility to respiratory and other infections (Guilbert and Hart, 1935; Jones et al., 1938; Guilbert et al., 1940; Guilbert and Rochford, 1940; Hart, 1940; Madsen and Earle, 1947; Madsen et al., 1948; Moore, 1957; Mitchell, 1967). Only nyctalopia has proven unique to vitamin A deficiency (Moore, 1939, 1941). Vitamin A deficiency should be suspected when several of these symptoms are present. Clinical verification may include ophthalmoscopic examination, liver biopsy and assay, blood assay, testing spinal fluid pressure, conjunctival smears, and response to vitamin A therapy.

The possibility that β-carotene may have a role in reproduction independent of its role as a vitamin A precursor has received considerable recent attention (Hemken and Bremel, 1982). Evaluation of these reports and their potential practical significance will remain difficult until a biochemical function is proposed for carotene and either verified or rejected.

### *Vitamin D*

The vitamin D requirement of beef cattle is 275 IU per kilogram of dry diet. The IU is defined as 0.025 μg of cholecalciferol ($D_3$) or its equivalent. Ergocalciferol ($D_2$) also is active in cattle. Beef cattle exposed to sunlight or fed sun-cured forages rarely require vitamin D supplementation.

Vitamin D is required for calcium and phosphorus absorption, normal mineralization of bone, and mobilization of calcium from bone. Research in laboratory animals (DeLuca, 1974) indicates that before serving these functions it must be metabolized to active forms. One metabolite (25-hydroxy-vitamin-$D_3$) is formed in the liver and is about four times as active as vitamin D. Another metabolite (1,25-dihydroxy-vitamin-$D_3$) formed in the kidney is about five times as active as 25-hydroxy-vitamin-$D_3$. Extension of observations on these metabolites to cattle and study of other metabolites unique to ruminants are being actively pursued (Horst and Reinhardt, 1983) and can be expected to add much to our understanding of vitamin D nutrition. Degradation of vitamin D in the rumen (Parakkasi et al., 1970; Sommerfeldt et al., 1979) may be of practical significance when considering methods of vitamin D administration.

The best defined sign of vitamin D deficiency in calves is rickets, which involves failure of bone to mineralize adequately. Accompanying signs frequently include decreases in calcium and inorganic phosphorus in blood, swollen and stiff joints, anorexia, fast breathing, irritability, tetany, weakness, convulsions, and retarded growth. In older animals with a vitamin D deficiency, bones become weak and easily fractured, and posterior paralysis may accompany vertebral fractures. Calves may be born dead, weak, or deformed (Rupel et al., 1933; Wallis, 1944; Warner and Sutton, 1948; Stallings et al., 1964).

### *Vitamin E*

The vitamin E requirement has not been clearly established but is estimated to be between 15 and 60 IU per kilogram of dry diet for young calves. The IU is defined as 1 mg of dl-$\alpha$-tocopherol acetate. Normal diets apparently supply adequate amounts for adult cattle. Even diets very low in vitamin E did not affect growth, reproduction, or lactation when fed for four generations (Gullickson and Calverley, 1946).

Vitamin E is an antioxidant and has been widely used to protect and to facilitate the uptake and storage of vitamin A (Perry et al., 1968). Its action in metabolism is not clearly defined but is linked closely with selenium (Muth et al., 1958; Hoekstra, 1975). Some deficiency signs, particularly white muscle disease, may respond to either selenium or vitamin E or may require both. Vitamin E and selenium interactions are discussed in the Selenium section. Deficiencies may be precipitated or accentuated by feeding unsaturated fats. Signs of deficiency in young calves are characteristic of white muscle disease. They include general muscular dystrophy, weak leg muscles, crossover walking, impaired suckling ability due to dystrophy of tongue muscles, heart failure, and paralysis (Stafford et al., 1954; Muth et al., 1958).

### *Vitamin K*

Vitamin $K_1$ is abundant in pasture and green roughages. Vitamin $K_2$ is synthesized in large amounts in the rumen. Either effectively fulfills the vitamin K role in the blood clotting mechanism. The only practical deficiency to be reported in cattle is the "sweet clover disease" syndrome. This results from the antagonistic action of dicoumarol that is formed in moldy sweet clover hay. Dicoumarol leads to prolonged blood clotting times and has been responsible for animal death from uncontrolled hemorrhages. Mild cases can be treated effectively with vitamin K (McElroy and Goss, 1940a; Link, 1959).

### *B Vitamins*

Deficiency signs have been clearly demonstrated for thiamine (Johnson et al., 1948), riboflavin (Wiese et al., 1947), pyridoxine (Johnson et al., 1950), pantothenic acid (Sheppard and Johnson, 1957), biotin (Wiese et al., 1946), nicotinic acid (Hopper and Johnson, 1955), vitamin $B_{12}$ (Draper et al., 1952; Lassiter et al., 1953), and choline (Johnson et al., 1951) in young calves. Most of the established metabolic functions of B vitamins are important to cattle as well as to other animals. Consequently, a physiological need for most B vitamins can be assumed for cattle of all ages. However, B vitamins are abundant in milk and many other feeds, and synthesis of B vitamins by ruminal microorganisms is extensive (McElroy and Goss, 1940a,b, 1941a,b; Wegner et al., 1940, 1941; Hunt et al., 1943) and begins very soon after the introduction of dry feed into the diet (Conrad and Hibbs, 1954). As a result, practical B-vitamin deficiency is limited to situations where an antagonist is present or ruminal synthesis is limited by lack of precursors or other problems.

Vitamin $B_{12}$ is of special interest because of its role in propionate metabolism (Marston et al., 1961) and the practical incidence of vitamin $B_{12}$ deficiency as a secondary result of cobalt deficiency. Substantial areas of the United States, Australia, and New Zealand have soils without enough cobalt to produce adequate levels in plants to support optimum vitamin $B_{12}$ synthesis in the rumen (Ammerman, 1970). This is discussed in more detail in the section on cobalt.

Thiamin antimetabolites have been found in raw fish products and bracken fern (Somogyi, 1973). More recently (Loew and Dunlop, 1972; Sapienza and Brent, 1974), polioencephalomalacia (PEM) in grain-fed cattle and sheep has been linked to thiaminase activity or production of a thiamin antimetabolite in the rumen. Affected animals have responded to intravenous administration of thiamin (2.2 mg/kg of body weight). Supplementation of high-concentrate diets with thiamin has yielded inconsistent results (Grigat and Mathison, 1982, 1983).

Niacin has been reported to enhance protein synthesis by ruminal microorganisms (Riddell et al., 1980, 1981). Responses to niacin additions to diets for feedlot cattle have been variable.

Attempts to obtain responses to other B vitamins are numerous, but the overall results are considered inconclusive. While B vitamin synthesis is altered by diet, considerable change is possible without producing indications of deficiency (Hayes et al., 1966; Clifford et al., 1967).

# 3 Water

Water intake in feeds plus that consumed *ad libitum* as free water is approximately equivalent to the water requirements of cattle. The water requirement is influenced by several factors, including rate and composition of gain, pregnancy, lactation, activity, type of diet, feed intake, and environmental temperature.

Restriction of water intake reduces feed intake (Utley et al., 1970), which results in lower production. However, water restriction tends to increase apparent digestibility and nitrogen retention.

The minimum requirement of cattle for water is a reflection of that needed for body growth; for fetal growth or lactation; and of that lost by excretion in the urine, feces, or sweat or by evaporation from the lungs or skin. Anything influencing these needs or losses will influence the minimum requirement.

The amount of urine produced daily varies with the activity of the animal, air temperature, and water consumption as well as with certain other factors. The antidiuretic hormone, vasopressin, controls reabsorption of water from the kidney tubules and ducts; thus, it affects excretion of urine. Under conditions of restricted water intake, an animal may concentrate its urine to some extent by resorbing a greater amount of water than usual. While this capacity for concentration of the urine solutes is limited, it can reduce water requirements by a small amount. When an animal consumes a diet high in protein or salt or one that contains substances having a diuretic effect, the excretion of urine is increased and so is the water requirement.

The water lost in the feces depends largely on the diet. Succulent diets and diets with high mineral content contribute to more water in the feces.

The amount of water lost through evaporation from the skin or lungs is important and may even exceed that lost in the urine. If temperature and/or physical activity increase, water loss through evaporation and sweating increases.

Since feeds themselves contain some water and the oxidation of certain nutrients in feeds produces water, not all must be provided by drinking. Feeds such as silages, green chop, or growing pasture forage are usually very high in moisture content, while grains, hays, and dormant pasture forage are low. High-energy feeds produce much metabolic water, while low-energy feeds produce little. These are obvious complications in the matter of assessing water requirements. Fasting animals or those on a low-protein diet may form water from the destruction of body protein or fat, but this is of minor significance.

The results of water requirement studies conducted under varied conditions imply that thirst is a result of need and that animals drink to fill this need. The need results from an increase in the electrolyte concentration in the body fluids, which activates the thirst mechanism.

As this discussion suggests, water requirements are affected by many factors, and it is impossible to list specific requirements with accuracy. However, the major influences on water intake in beef cattle on typical rations are dry matter intake, environmental temperature, and stage and type of production. Table 6 has been designed with this in mind. It is a guide only, and it must be used with considerable judgment.

For more detailed information on toxic substances in water, refer to the National Research Council publication *Nutrients and Toxic Substances in Water for Livestock and Poultry* (1974).

# 4 Breeding Females

Energy requirements for pregnancy have been calculated using the equation given in Chapter 6. From this equation, 2.15 Mcal extra $NE_m$, for example, would be required for a pregnant cow bearing a 36-kg calf during the last 94 days of pregnancy.

Since determined values for NE requirements of lactating beef female are not available, they were assumed to be similar to those determined for dairy cattle. The requirements listed in the tables for lactating cows were based on the metabolizable energy requirements for 5 and 10 kg of milk given in *Nutrient Requirements of Dairy Cattle* (NRC, 1978) and were adjusted to a comparable $NE_m$ value assuming that the milk contains 4 percent fat. This increases the need for $NE_m$ by 0.75 Mcal/kg of milk. Fifty-five grams per day of protein have been used as a mean rate of protein deposition in the products of conception during the last third of pregnancy, assuming a 36-kg birth weight.

## NUTRIENT RELATIONSHIPS

Beef cows are managed under a variety of conditions to best utilize the feed resources available under existing environmental conditions. This variation presents a challenge in applying nutrient requirements. Since the beef cow can utilize a wide array of feed sources, production levels to optimize economic return vary depending on the feed resources. Hence, it may not be economical to feed cows to meet their nutrient requirements with all production systems.

The source of energy is generally the first consideration in determining a balanced ration for beef cows. Until the energy requirement is satisfied, protein, minerals, and vitamins may not be well utilized. The amount of energy required for different production levels will vary. Because the beef cow uses fiber as a major source of energy, the quantity of forage or feed and the quality are important.

When energy is limited, supplemental protein will be used for energy until the energy needs are met; then the remaining protein will be used to meet the protein needs (Clanton and Zimmerman, 1970). These researchers have shown, for example, that feeding high levels of low-protein (6.7 and 7.9 percent) supplements (7.2 and 8.0 Mcal DE/day) to growing replacement heifers wintered on native grass range threatened the nutritional status of the heifers. Protein was the limiting nutrient; thus, the extra supplemental energy provided no increase in weight gain; in fact, there was a decrease. When the added energy contained 13 or 16 percent protein, heifers gained weight. This demonstrated that protein, not energy, limited performance. These same relationships can be demonstrated using other nutrients. The proper relationships are difficult to establish because the quantity and quality of the diet selected by grazing animals are difficult to assess.

## COW EFFICIENCY

Much consideration has recently been given to the effect of cow size on energy requirements for efficient calf production. Anderson (1983) calculated the energy requirements for different-sized cows for maintenance, weight change, and milk production and showed that changes in cow size and weight did not affect the efficiency of milk production. Small and large cows were equally efficient. Therefore, it may be more important to feed cows on the basis of potential milk production rather than size and condition. Data collected by Lemenager et al. (1980) suggest that weight alone cannot be used to accurately determine the energy requirements of the breeds of heavier weight or greater potential milk production. Visual body condition score combined with weight predicted the relative total digestible nutrient (TDN) requirements of pregnant cows during late gestation more accurately than do weight and milk production alone. Maintenance energy requirements of cows may be influenced by milk production potential as well as body size.

## WEIGHT CHANGES AND BODY CONDITION

Aside from weight loss at parturition, weight change in a mature cow reflects body condition change (loss or gain of body fat). Weight change can be measured accurately, whereas the number scoring system (1 = thinnest and 9 = fattest) for condition change is empirical and subject to judgment. More accurate procedures are available for measuring body composition, but their use is generally limited to experimentation.

In the bred heifer, weight change is a combination of growth and condition change. This makes nutrient requirements more difficult to assess. A thin heifer needs to gain more weight during gestation than one that has a moderate or fat condition. This gain is necessary for continued growth and rebreeding in the minimum time. Condition cannot be determined by weight alone because heifers of different frame sizes differ in weight at the same condition. Condition must be considered in nutrient requirements for bred heifers.

When mature cows lose condition from inadequate energy intake prior to calving, the interval from calving to first estrus will be lengthened, resulting in calving intervals exceeding 1 year (Wiltbank et al., 1962). Inadequate energy intake after calving will lower conception rates (Wiltbank et al., 1962, 1964). The same effect has been demonstrated with bred yearling heifers (Clanton and Zimmerman, 1970; Bellows and Short, 1978). It appears desirable to have cows gain an amount of weight the last trimester equal to the weight lost at calving. This is even more important with the replacement heifer. Weight gain will not necessarily reflect increased condition. Condition is often lost prior to calving. Weight gain between calving and breeding is desirable and will improve conception rates, resulting in a shorter calving interval. Phillips and Vavra (1981) showed that cows losing weight (18 kg) the last trimester of pregnancy had as short an interval from calving to first estrus as those that gained weight (48 kg) during that period (58 versus 56 days). Both groups lost weight from calving until breeding, but there was no difference in conception rates (86 versus 84 percent, respectively) in a 60-day breeding season. Those that gained weight prior to calving lost the most weight after calving. One might have expected a higher conception rate had they gained weight following calving. Many cows do not gain weight between calving and breeding yet maintain acceptable conception rates. Cows need to be in good condition prior to calving to do this. It is costly to have cows gain weight following calving because it generally requires feeding of supplemental energy and protein. The small increase in production may not offset the increase in cost. If cows can be placed on new growth pasture forage 3 to 4 weeks prior to the breeding season, they will start gaining weight and show improved reproductive performance (Clanton et al., 1971).

Cows in good condition are more tolerant to the stresses of winter and require less maintenance energy per unit of weight than do cows in poor condition (Thompson et al., 1983). Klosterman et al. (1968) established a relationship between the height at the hooks and the weight of a cow that can be used to adjust energy requirements for cows in different conditions. The average weight (kg) to height (cm) ratio for a cow in good condition is 4.0 : 1. The adjustment in digestible energy (DE) required by mature cows in different condition can be determined using the following formula: $(4.0 - \text{weight/height}) \times 1.716 = \text{Mcal/day adjustment}$. Clanton and Zimmerman (1970) have shown that changes in wither height and heart girth circumference along with weight change can be used to separate growth from change in condition of bred heifers.

In many range areas or during periods of feed scarcity, lactating and breeding females frequently lose weight during part of the year. Weight may be regained during periods of more abundant feed. Cyclic loss and gain of weight may not be detrimental to overall calf production, depending on the length and severity of the poor feed conditions and the physiological status of the animals. Calf production should be greater if condition did not cycle, but preventing condition changes may not be economically feasible. The requirements listed in the tables for lactating and breeding females need to be adjusted according to previous or anticipated feed availability and the economics associated with management of a particular enterprise.

Weight loss at parturition should be considered when using the requirement tables. A 500-kg cow in the last third of pregnancy will weigh less later when she is lactating. Weight of the cow in early pregnancy should be used for the cow for the entire year.

## FORAGE INTAKE

Several factors that alter voluntary intake should be considered in the nutrition program for beef cows. Rumen capacity, as demonstrated by Campling and Balch

(1961), and low digestibility and rate of passage (Campling et al., 1961; Conrad et al., 1964) limit forage intake. Forage availability, use of supplements, and climatic conditions also affect intake. Other influencing factors include animal size, milk production, and reproductive status.

The range in voluntary intake of organic matter by cattle grazing native winter range forage in the Central Great Plains is 45 to 60 g/kg $W^{0.75}$ (Rittenhouse et al., 1970; Scales et al., 1974; Yates et al., 1982). In contrast, organic matter intake of native summer range forage in the same region varies from 70 to 85 g/kg $W^{0.75}$ daily (Streeter et al., 1968; Powell et al., 1982; Yates et al., 1982). Forage intake of grazing cattle is reduced if quantity or quality of pasture is not adequate (Johnstone-Wallace and Kennedy, 1944; Hennessy and Robinson, 1979; Holloway et al., 1979). In meeting nutrient requirements of grazing cattle, the condition of the range or pasture and the amount of available forage present must be considered.

Certain supplements to low-quality forage may decrease forage intake (Forbes et al., 1967; Lusby et al., 1976; Rittenhouse et al., 1970; Scales et al., 1974; Umoh and Holmes, 1974). Other supplements increase forage intake (Campling et al., 1962; Blaxter and Wilson, 1963; Clanton and Zimmerman, 1970). The primary difference in the intake response appears to be associated with the protein content of the forage and the amount of supplement fed. If the forage is low in protein, forage intake will increase when a small amount of a high-protein supplement is fed. But when more than 1 kg of supplement is fed, forage intake could be reduced by displacement.

Forage intake of grazing cattle can be greatly reduced by short periods of cold weather with snow cover (Rittenhouse et al., 1970); yet this is a time when more energy is needed to meet increased maintenance requirements (NRC, 1981). Supplemental forage or concentrate feeding should be given during such times to avoid large losses of weight.

Pregnant cows nearing parturition consume 12 to 13 percent less feed than nonpregnant cows (Campling, 1966; Jordan et al., 1973). Consumption increases rapidly following parturition. If forage quality is low, supplementing with higher-quality forage or with concentrates prior to parturition may be necessary to compensate for reduced feed intake.

Dry matter intake of beef cows is extremely variable. Daily intakes of lactating cows have ranged from 4.5 to 14.5 kg (Johnstone-Wallace and Kennedy, 1944). Quantity and quality were the major factors influencing intake. Lactating (spring calving) or gestating (fall calving) cows grazing crested wheat grass pasture during the summer in Oregon had similar intakes, 11.39 versus 11.37 kg daily (Kartchner et al., 1979). This was 3.0 and 2.8 percent of their spring body weight, respectively. Lactating cows were 34 kg lighter at the start of the grazing season. Holloway et al. (1979) observed that Angus cows that were nursing calves and grazing Kentucky-31 tall fescue (*Festuca arundinacea Schreb*) in the summer consumed 10.5 kg of dry matter per day when it had a high quality (70 percent digestible) and 8.8 kg when it was of poor quality (58 percent digestible).

Streeter et al. (1974) measured milk production and forage intake of Brown Swiss, Charolais x Angus, and Hereford cows grazing irrigated mountain meadow. Dry matter consumptions were 14.7, 12.0, 10.4 kg per head per day, respectively. Milk production in a 14-hour period was 6.0, 4.4, and 3.5 kg, respectively. Likewise, Lusby et al. (1976) found that Hereford, Hereford x Holstein, and Holstein cows fed a 1.22-kg supplement per day while nursing calves on dry winter range consumed 78, 104, and 131 g of dry matter daily per kilogram $W^{0.75}$, respectively. Daily dry matter intake during summer grazing without a supplement was 99, 107, and 144 g/kg $W^{0.75}$, respectively.

Daily dry matter intake of lactating cows was 121.3 g/kg $W^{0.75}$ in May and 97.4 g/kg $W^{0.75}$ in July when grazing Midland Bermudagrass (*Cynodon dactylon*) at El Reno, Oklahoma (Horn et al., 1979). This equates to daily intakes of 2.6 and 2.1 percent of body weight, respectively, for cows weighing 454 kg. Similar intakes (99 g/kg $W^{0.75}$) were observed by Lusby et al. (1976) with lactating Hereford cows grazing native range in June. These cows had received 1.11 kg supplements daily during the previous winter while grazing similar range forage. Cows fed 2.41 kg supplements during the winter consumed 84 g/kg $W^{0.75}$ of forage dry matter the following June, indicating possible carryover effects. On the same range, Lemenager et al. (1978) measured dry matter intake of 105 g/kg $W^{0.75}$ with nonpregnant Hereford cows during the winter.

Daily forage dry matter intake of mature Hereford cows grazing native Flint Hills pasture in Kansas ranged from 8.1 kg (1.7 percent of fall weight) in November to 16.8 kg (3.45 percent of fall weight) in June (Pruitt, 1980). Winter supplementation programs did not affect subsequent forage intake.

Feed intake of beef cows is difficult to predict because of the many variable factors, including animal, diet, and environmental stress. Dry matter intakes in the tables should be used as a guide and adjusted for specific conditions.

# 5 Special Considerations

## PROCESSING FEEDSTUFFS

Many methods are used to improve the nutritive value of feedstuffs for beef cattle. The purpose of this section is to define major effects of processing on their nutritive value for beef cattle rather than on the methods per se. Reviews of the methods are provided in the references.

### *Roughages*

Coarse chopping of long roughages, with or without wafering, does not affect nutritive value substantially and is recommended primarily to improve handling (Minson, 1963). In contrast, fine grinding of long roughages, which is usually followed by pelleting, increases feed intake by 50 percent or more (Greenhalgh and Wainman, 1972). Larger responses in intake through grinding and pelleting are associated with poorer-quality roughages and with diets where roughage is the major constituent. Furthermore, grinding and pelleting of roughage increase its intake more in young cattle than in older cattle. Grinding and pelleting of roughages depress their digestibility, by up to 5 percentage units. Digestibility is depressed most when intake of the processed material is high and when the roughage processed is grass (Campling and Milne, 1972). In contrast to depressing digestibility, grinding and pelleting improve utilization of the digestible energy, so that net energy per unit weight of the processed material exceeds the corresponding unprocessed roughage (Greenhalgh and Wainman, 1972). This effect is partly due to processing causing a higher percentage of the roughage to be digested postruminally. When artificially drying roughages, care should be exercised to avoid the browning reaction, which renders some of the protein indigestible (Goering, 1976).

In North America, many crops are preserved by ensiling. This practice may depress voluntary intake relative to other methods of preservation, such as drying, but it has a small effect on digestibility and utilization of digested energy (McDonald and Edwards, 1976). In dry and poorly packed silage, heating may depress protein digestibility (Thomas et al., 1972). Processing of forages prior to ensiling can influence nutritional value. Intake of grass silage chopped to 20 mm may be greater than the intake of unchopped material (Murdoch, 1965), and corn silage harvested at a theoretical cut of 12.7 mm or less was more digestible than corn silage chopped at a longer length (Sudweeks et al., 1979).

Alkali treatments of crop residues and wastes have been researched and reviewed (Homb et al., 1977; Kernan et al., 1977; Jackson, 1978; Sundstøl et al., 1978; Klopfenstein et al., 1979). The effectiveness of alkali treatment depends on the residue or waste being treated and the technique. Results vary substantially. Treatment with alkali increases potential digestion of cell walls. Although rates of digestion in the rumen are not altered substantially, rates of passage of indigestible material are improved (Berger et al., 1979; Coombe et al., 1979; Oji et al., 1980). Hence, voluntary intake of low-quality roughages can be improved by up to 50 percent through alkali treatment (Horton, 1978; Coombe et al., 1979; Garrett et al., 1979; Horton and Steacy, 1979; Morris and Mowat, 1980; Saenger et al., 1982). These studies have also demonstrated that digestibility of dry matter or energy may be increased by up to 10 percentage units. In diets containing 72 percent straw, $NE_m$ was increased from 0.62 to 1.03 Mcal/kg and $NE_g$ from 0.22 to 0.51 Mcal/kg through alkali treatments (Garrett et al., 1979). Improvements in intake and digestibility may be small when treated straws constitute 50 percent or less of the diet (Garrett et al., 1979). The efficacy of treating straw with alkali depends on the variety of cereal from which the straw was derived (Horton and Steacy, 1979), with greatest improvements in digestibility obtained for wheat straws, followed by barley and oats. The improvement in intake through chemical treatment may be small when treated roughage is compared with untreated roughage in the ground and pelleted form (Coombe et al., 1979; Horrisberger et al., 1979). Alkali treatment, through its heating effect, depresses the nitrogen digestibility by ruminants, even when ammonia is used (Garrett et al., 1979; Horton and Steacy, 1979; Morris and Mowat, 1980; Oji et al., 1980). Since energy availability in the rumen is enhanced by alkali treatment, supplementation of treated roughages with more extensively degraded protein sources is usually beneficial.

### *Grains*

#### INTRODUCTION

Many factors other than processing have a bearing on the nutritive value of grains and may modify the effects of processing. High intakes reduce digestibility. For example, the metabolizable energy of corn grain for dairy cows was reduced from 3.58 Mcal/kg at a maintenance level of feeding to 2.92 Mcal/kg at 2.5 times maintenance (Moe and Tyrrell, 1979). Source of grain also may have a major impact on digestibility. For example, the net energy of bird-resistant sorghum has been found to be considerably less than regular sorghum grain (Maxson et al., 1973), whereas waxy sorghum has a higher net energy (Sherrod et al., 1969). Within varieties of the same grain, total digestible nutrients (TDN) were found to vary by 7 percentage units (Parrot et al., 1969). Effect of processing may be less pronounced when available energy in the unprocessed grain is relatively high or when feed intake is relatively low. Since younger cattle can digest unprocessed grain better than older animals (Morgan and Campling, 1978), processing of grain should benefit the nutritive value of rations for yearling steers more than for calves less than a year old. Finally, response to processing grain depends on the level of roughage in the diet, and relevant details are presented for individual grains.

#### CORN

In rations containing at least 80 percent dry corn grain, equivalent DE and NE values have been reported whether the corn has been cracked, ground, or fed whole (Goodrich and Meiske, 1966; Vance et al., 1970, 1972; Preston, 1975). Steam processing and flaking increased net energy by at least 10 percent, in comparison to whole corn, when the diets incorporated inert roughages, but was without effect in an all-corn diet (Vance et al., 1970). With corn diets containing intermediate levels of roughage (20 to 35 percent), digestibility of starch in the diet was increased approximately 5 percentage units when the grain was ground or crimped as opposed to being unprocessed (Vance et al., 1972; Galyean et al., 1979). Steam processing and flaking improved energy retention in cattle from 6 to 10 percent, relative to cracked corn, when the grain was incorporated into fattening rations composed of 70 to 80 percent corn (Johnson et al., 1968). In low-roughage diets, feeding corn in the unprocessed form (whole corn grain) maximizes intake and facilitates cattle management. Steam processing and flaking should also maximize intake in diets containing either low or intermediate levels of roughage. Generally, with diets containing more than 35 percent roughage, digestibility of the corn is positively associated with fineness of grind, so that finely ground corn contains 10 percentage units more digestible energy than whole corn (Moe and Tyrrell, 1977, 1979). Feeding of corn in a fine form in these rations, however, can be detrimental to utilization of the roughage portion of the diet (Moe et al., 1973; Ørskov, 1976, 1979) and may make these diets unpalatable. Thus, fine grinding should be restricted to maximize the nutritive value of the entire diet. Coarse grinding is most desirable to combine favorable digestion of the corn and maintain nutritive value of the roughage.

In many areas of North America, corn is preserved wet as high-moisture grain. Digestible dry matter and energy of rations containing high-moisture corn are at least equal and may be as much as 5 percentage units higher than the same ration containing dry ground corn (McCaffree and Merrill, 1968; McKnight et al., 1973; Tonroy et al., 1974; Galyean et al., 1976; Macleod et al., 1976). These results are also evident for dry corn reconstituted with moisture and stored for a short period of time before feeding (Tonroy et al., 1974). One detriment to the nutritive value of high-moisture corn is that reduced dry matter intakes of diets containing this form of corn have been observed (Clark, 1975). This is most evident when the corn contains more than 30 percent moisture. A minor concern about high-moisture corn is that most, if not all, of its vitamin E may be lost during storage (Young et al., 1975).

#### SORGHUM

In low-roughage (< 20 percent) diets, steam processing and flaking have been shown to improve DE and TDN by 5 to 10 percentage units (Husted et al., 1968; Buchanan-Smith et al., 1968) and starch digestibility from 3 to 5 percentage units (McNeill et al., 1971; Hinman and Johnson, 1974). An important criterion for success in steam processing and flaking is to generate a density of 2.5 kg/hl (25 lb/bushel) or slightly less than one half that of the original grain. Reconstitution of the whole grain with water, followed by an incubation period, and grinding can improve energy and starch digestibility to the same extent as steam processing and flaking (Buchanan-Smith et al., 1968; McNeill et al., 1971; Kiesling et al., 1973). However, steam processing and flaking may be more successful than reconstitution in promoting high intake (Franks et al., 1972). Despite favorable reports on the feeding value of steam-processed, flaked sorghum grain, relative to dry processing methods (Newsom et al., 1968; Franks et al., 1972), steam processing and rolling did not improve net energy of sorghum grain relative to dry grinding (Garrett, 1965). It has been reported that the $NE_m$ and $NE_g$ values for sorghum were both increased by 8 percentage units through fine grinding as opposed to coarse rolling; thus, fine grinding may improve the value of sorghum to an extent comparable to steam processing and flaking (Brethour, 1980). In intermediate- and high-roughage diets, dry-rolled sorghum is better utilized than in low-roughage diets (Keating et al., 1965). Thus, it is unlikely that steam processing and flaking will have beneficial effects in these circumstances. The nutritive value of dry sorghum grain in low-roughage diets may be improved by heat treatments, other than steam processing and flaking, such as popping, micronizing, exploding, and roasting (Hale and Theurer, 1972). Micronizing and popping of sorghum grain can improve digestibility of starch to an extent similar to steam processing and flaking (Riggs et al., 1970; Hinman and Johnson, 1974; Croka and Wagner, 1975). These treatments may not be as successful as steam processing and flaking for promotion of high intake of low-roughage diets.

#### BARLEY

Grinding or rolling improves the digestibility and utilization of barley. $NE_m$ values of ground barley ranging from 1.69 to 1.89 Mcal/kg and $NE_g$ values from 1.03 to 1.39 Mcal/kg in all-concentrate and 25 percent roughage diets have been reported (Suleiman and Mathison, 1979). No benefit for steam processing and flaking of barley, versus dry rolling, were demonstrated in one experiment (Parrot et al., 1969). To maximize intake and minimize digestive disturbances such as bloat, it is recommended that in high- or all-concentrate diets, barley be fed with medium grind to avoid fines (Hironaka et al., 1979). High-moisture barley can have a nutritive value for cattle comparable to the dry ground or rolled form. It is also recommended that high-moisture barley be medium rather than fine grind to reduce the proportion of fines.

#### OATS

Although whole oats may be better utilized by cattle than whole barley (Morgan and Campling, 1978), rolling or grinding improves its utilization also.

#### WHEAT

Whole wheat may be efficiently utilized by cattle (Trowbridge and Moffett, 1933), but its nutritive value is improved by processing. Hale et al. (1970) reported that steam-processed and flaked wheat was well utilized by cattle provided the flakes were not thin. Fine grinding of wheat generally reduces feed intake and is extremely liable to cause acidosis, although acidosis depends on the variety of wheat fed. Garrett et al. (1966) and Garrett (1968) reported that heat treatment of wheat improved its digestibility but did not significantly improve its net energy. It can be concluded that the nutritive value of wheat is optimized by dry rolling, coarse grinding, or steam processing to produce a thick flake (Brethour, 1970).

## ENVIRONMENTAL INFLUENCES ON NUTRIENT REQUIREMENTS OF BEEF CATTLE

A subcommittee of the Committee of Animal Nutrition prepared a report, *Effect of Environment on Nutrient Requirements of Domestic Animals* (NRC, 1981b), that details how requirements for beef cattle might be altered to account for environmental stresses. A summary of the report's recommendations is presented here.

First, voluntary food intake can be significantly affected by the environment, particularly with effective ambient temperatures outside the thermoneutral zone 15° to 25°C. With high temperature and humidity, intake may be depressed by up to 30 percent. The extent of this depression is positively associated with temperature and humidity. High-temperature stress will be reduced if accompanied by low humidity and/or relief through more comfortable nighttime conditions. Intake depression through elevated temperature and humidity is more severe for high-roughage as opposed to low-roughage diets. With low temperatures, intake may be increased by up to 30 percent. The extent of this increase is negatively associated with temperature. An increase in intake caused by low temperatures should be observed when cattle remain relatively dry, but extensive precipitation and muddy conditions can depress intake by up to 30 percent in both the thermoneutral zone and at lower temperatures. Intake can also become severely restricted for beef cows on range during winter. Forage intake depressions up to 50 percent have been reported for grazing cattle following a storm period that produced cold temperatures and snow cover.

Second, availabilities of nutrients from feedstuffs can be altered by environmental temperature. Temperature and digestibility appear to be positively related. These alterations are required only for roughages because effects of temperature on digestibility of concentrates are small. DE, ME, and NE values of roughages may be modified by the following formula:

$$A = B + B(0.0010\ (T - 20)),$$

where A is the value adjusted for environmental temperature, B is the unadjusted value, and T is the effective ambient temperature (°C).

Third, the maintenance energy requirement of cattle should be adjusted for exposure to temperatures outside the thermoneutral zone. Adapted animals should have their requirements adjusted to allow for changes in basal metabolic rate and, possibly, for acute exposure to hot or cold. Unadapted animals should have their requirements adjusted for acute exposure to either hot or cold only. For adapted animals, maintenance energy expenditure decreases rectilinearly in association with increasing temperature. The following equation is used to express the maintenance energy requirement:

$$NE = a.W^{0.75},$$

where NE is the net energy required for maintenance (Mcal/day), and W is the body weight (kg).

For animals acclimated to 20°C (thermoneutral zone), the factor $a$ is taken as 0.077. For each degree Celcius prior to exposure to temperatures above or below 20°C, 0.0007 should be subtracted or added, respectively, to $a$ in the above equation. Thus, for cattle with prior exposure to temperatures of 30°, 20°, 10°, and 0°C, the value $a$ becomes 0.070, 0.077, 0.084, and 0.091, respectively. For expressing maintenance energy requirements in terms of ME or DE, tabulated values should be decreased (for heat) or increased (for cold) by 0.91 percent for each degree Celcius prior exposure above or below 20°C.

For acute heat stress, maintenance energy requirements should be adjusted according to severity. Severity may be detected by the respiration of the animal. For rapid shallow breathing the maintenance energy requirement should be increased by 7 percent, whereas for deep open-mouth panting the requirement should be increased from 11 to 25 percent.

For acute cold stress, maintenance energy expenditures should be increased according to exposure to temperatures below their lower critical temperature (LCT). Calculation of the LCT for any given animal is complex and depends on the animal's insulation and heat production. Wind speed influences insulation and is an important environmental factor. LCT varies widely for different cattle and according to environment. For example, for a 1-week-old calf exposed to dry, low wind, the LCT is estimated at +7.7°C, whereas for a yearling steer gaining 1.1 kg/day and exposed to a dry, low wind, the LCT is estimated at −34.1°C. The increase in ME required per degree Celcius below the LCT is from 1 to 3 percent. For details on calculating the increase in energy requirement due to acute cold exposure, the reader is referred to the report *Effect of Environment on Nutrient Requirements of Domestic Animals* (NRC, 1981b).

## IMPLANTS AND NONNUTRITIVE FEED ADDITIVES

Melengesterol acetate (MGA) is a feed additive marketed for feedlot heifers. MGA is a progestin and acts to suppress estrus, increase gains, and improve feed efficiency with finishing heifers. Sexually mature, nongravid heifers respond to MGA, whereas it has no effect on the performance of steers, bulls, and spayed or pregnant heifers. The approved daily feeding level is from 0.25 to 0.50 mg per head. Feeds containing MGA must be withdrawn at least 48 hours prior to slaughter.

Synovex implants are of two types. Synovex-S for steers contains 20 mg of estradiol benzoate and 200 mg of progesterone. It is approved for use in steers that weigh 182 (400 lb) to 455 kg (1000 lb). Synovex-H for use with feedlot heifers contains 20 mg of estradiol benzoate and 200 mg of testosterone. It is approved for heifers weighing 182 (400 lb) to 364 kg (800 lb). Use of these products improves rate of gain and efficiency of feed utilization. Maximum responses are obtained with a high-concentrate finishing diet. In the United States and Canada there is no withdrawal prior to slaughter.

Ralgro (Zeranol) implants are available for male and female nursing calves, grazing cattle, and cattle fed finishing diets and are not for use with breeding animals. Ralgro improves rate of gain and efficiency of feed utilization. The approved dose is 36 mg. Animals must not be implanted within 65 days of slaughter.

Estradiol is available in the United States as a timed-release implant (Compudose), active for a 200-day period. Use of this product improves rate of gain and efficiency of feed utilization by feedlot cattle. There is no withdrawal period prior to slaughter.

Antibiotics are added to diets to improve rate of gain and feed efficiency. Several antibiotics reduce the incidence of liver abscesses in cattle fed high-concentrate diets. The level for continuous feeding is 70 to 80 mg per head per day. Antibiotics are also approved at higher levels for beef cattle for the first 14 to 28 days after transport to help control shipping fever. Antibiotics that are approved for use and restrictions to their use are listed in the Feed Additives Compendium published annually by Miller Publishing Co., Minneapolis, Minnesota, for the United States, or the Compendium of Medicating Ingredient Brochures published by Agriculture Canada for Canada.

Monensin sodium is approved for use in cattle feeds at levels between 5 and 30 g per ton of complete feed (90 percent dry matter basis) or at daily feeding levels between 50 and 360 mg per day. With feedlot cattle, monensin generally improves feed efficiency but depresses feed intake, with no effect on rate of gain. Monensin is approved for use with pasture cattle at a daily feeding level of 200 mg per day for improvement in rate of gain. Monensin alters the ratio of volatile fatty acids produced in the rumen by increasing the proportion of propionic acid. Monensin may reduce fasting heat production and may increase dietary $NE_m$ values to a greater extent than it increases dietary $NE_g$ values. Monensin has also been shown to increase quantities of dietary protein that escape degradation in the rumen. In addition, retention of some minerals has been increased in monensin-fed cattle. Thus, energy, protein, and mineral requirements may be modified when monensin is fed to cattle. The same probably applies to other ionophores that may be fed to cattle, but data on the other ionophores are not available (Poos et al., 1979; Garrett, 1982; Kirk et al., 1983).

Lasalocid sodium is approved for use in cattle feeds in the United States at levels between 10 and 30 g per ton of complete feed (90 percent dry matter basis) for improvement in feed efficiency. It is approved for use at 25 to 30 g per ton for increased rate of gain.

Several products, generally classified as buffers, have been added to high-concentrate finishing diets to control low-rumen pH found when high-grain diets are fed. These products include sodium bicarbonate, dolomitic limestone, ground limestone, bentonite, and magnesium oxide. Sodium bicarbonate will apparently increase the pH of rumen contents by replacing sodium bicarbonate from saliva, which is reduced in high-concentrate rations. Sodium bicarbonate and other products may exert their beneficial effects by other methods, such as increasing rumen liquid turnover, increasing osmolality of the rumen, and increasing the pH of the lower intestinal tract. For a detailed discussion of this subject area, the reader is referred to the National Feed Ingredients Association Symposium on Buffers, Electrolytes and Neutrolytes, 1983.

The use of nonnutrient additives and implants is controlled by the Food and Drug Administration in the United States and the Food Production and Inspection Branch of Agriculture Canada. Users of controlled feed additives must follow regulations regarding their use and be aware of alterations to the regulations.

# 6 Prediction Equations for Estimating Nutrient Requirements and Feed Intake

## ENERGY

A. Maintenance requirements (mcal/day) of steers, heifers, bulls, and cows:

$$NE_m = 0.077\ W^{0.75}.$$

B. $NE_g$ (mcal/day) required (equivalent to RE) for empty body weight gain (EBG):

Medium-frame steer calves:

$$NE_g = 0.0635\ W^{0.75}\ (EBG)^{1.097}.$$

Large-frame steer calves, compensating medium-frame yearling steers, and medium-frame bull calves:

$$NE_g = 0.0562\ W^{0.75}\ (EBG)^{1.097}.$$

Large-frame bull calves and compensating large-frame yearling steers:

$$NE_g = 0.0498\ W^{0.75}\ (EBG)^{1.097}.$$

Medium-frame heifer calves:

$$NE_g = 0.0783\ W^{0.75}\ (EBG)^{1.119}.$$

Large-frame heifer calves and compensating yearling heifers:

$$NE_g = 0.0693\ W^{0.75}\ (EBG)^{1.119}.$$

Mature thin cows:

$$NE_g = 6.5 \text{ mcal/kg gain}.$$

C. $NE_g$ required for live weight gain (LWG):

Medium-frame steer calves:

$$NE_g = 0.0557\ W^{0.75}\ (LWG)^{1.097}.$$

Large-frame steer calves, compensating medium-frame yearling steers, and medium-frame bull calves:

$$NE_g = 0.0493\ W^{0.75}\ (LWG)^{1.097}.$$

Large-frame bull calves and compensating large-frame yearling steers:

$$NE_g = 0.0437\ W^{0.75}\ (LWG)^{1.097}.$$

Medium-frame heifer calves:

$$NE_g = 0.0686\ W^{0.75}\ (LWG)^{1.119}.$$

Large-frame heifer calves and compensating yearling heifers:

$$NE_g = 0.0608\ W^{0.75}\ (LWG)^{1.119}.$$

Mature thin cows:

6.2 mcal/kg gain.

D. Energy required for pregnancy (expressed as kcal $NE_m$/day):

$$NE_m = \text{calf birth weight } (0.0149 - 0.0000407t)e^{0.05883t - 0.0000804t^2}.$$

E. Energy required for lactation (expressed as $NE_m$, mcal/kg milk):

$$NE_m = 0.1\ (\%\ \text{fat}) + 0.35.$$

F. Estimation of empty body weight gain (EBG) from $NE_g$ available for gain:

Medium-frame steer calves:

$$EBG = 12.34\ NE_g^{0.9116}\ W^{-0.6837}.$$

Large-frame steer calves, compensating medium-frame yearling steers, and medium-frame bull calves:

$$EBG = 13.80\, NE_g^{0.9116}\, W^{-0.6837}.$$

Large-frame bull calves and compensating large-frame yearling steers:

$$EBG = 15.40\, NE_g^{0.9116}\, W^{-0.6837}.$$

Medium-frame heifer calves:

$$EBG = 9.74\, NE_g^{0.8936}\, W^{-0.6702}.$$

Large-frame heifer calves and compensating yearling heifers:

$$EBG = 10.86\, NE_g^{0.8936}\, W^{-0.6702}.$$

G. Estimation of live weight gain (LWG) from $NE_g$ available for gain:

Medium-frame steer calves:

$$LWG = 13.91\, NE_g^{0.9116}\, W^{-0.6837}.$$

Large-frame steer calves, compensating medium-frame yearling steers, and medium-frame bulls:

$$LWG = 15.54\, NE_g^{0.9116}\, W^{-0.6837}.$$

Large-frame bull calves and compensating large-frame yearling steers:

$$LWG = 17.35\, NE_g^{0.9116}\, W^{-0.6837}.$$

Medium-frame heifer calves:

$$LWG = 10.96\, NE_g^{0.8936}\, W^{-0.6702}.$$

Large-frame heifer calves and compensating yearling heifers:

$$LWG = 12.21\, NE_g^{0.8936}\, W^{-0.6702}.$$

## PROTEIN

Factorialized Protein Requirement:

$$CP = \frac{F + U + S + G + C + M}{D \times BV \times CE}$$

CP, Crude protein, g/day
F, Metabolic fecal protein loss = 3.34% dry matter intake
U, Endogenous urinary protein loss = $2.75W^{0.5}$
S, Scurf protein loss = $0.2W^{0.6}$
G, Tissue protein deposition (in grams) = (268 − 29.4 × energy content of gain, Mcal/kg) daily gain in kg
C, Conceptus, 55 g/day, last third of pregnancy
M, Milk protein production (in grams) = 33.5 × milk production in kg
D, True protein digestibility = 0.90
BV, Biological value = 0.66
CE, Conversion of dietary to postruminal protein = 1.0

Urea Potential:
g/kg dry feed = $11.78\, NE_m + 6.85 - 0.0357\, CP \times DEG$ (Burroughs et al., 1975)
g/kg dry feed = $31.64 - 3.558\, CP + ([945\, NE_m - 887 - 179\, NE_m^2])^{0.5}$ (Satter and Roffler, 1975)
CP, Crude protein (%)
NE, Net energy maintenance (Mcal/kg)
DEG, Ruminal degradation of protein (%)

### *Calcium and Phosphorus*

Calcium, g/day = $((0.0154\,(W_{kg}) + 0.071$ (protein gain, g/day) + 1.23 (milk/day, kg) + 0.0137 (fetal growth, g/day)) ÷ 0.5

Phosphorus, g/day = $((0.0280\,(W_{kg}) + 0.039$ (protein gain g/day) + 0.95 (milk/day, kg) + 0.0076 (fetal growth, g/day)) ÷ 0.85

## FEED INTAKE

Breeding Females:
Daily feed intake (kg dry matter) = $W^{0.75}(0.1462\, NE_m - 0.0517\, NE_m^2 - 0.0074)$.

Growing and Finishing Cattle:
Daily feed intake (kg dry matter) = $W^{0.75}(.1493\, NE_m - 0.0460\, NE_m^2 - 0.0196)$.
$NE_m$, net energy maintenance (Mcal/kg diet)

Adjustments for Frame Size:
None: Medium-frame steer calf, large-frame heifer, and medium-frame bull.
+10%: Large-frame steer calf and medium-frame yearling steer.
+5%: Large-frame bulls.
10% Reduction: Medium-frame heifers.

## Tables of Daily Requirements: Energy, Protein, Calcium, and Phosphorus

TABLE 1 Net Energy Requirements of Growing and Finishing Beef Cattle (Mcal/day)[a]

| Body Weight, kg: | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 |
|---|---|---|---|---|---|---|---|---|---|---|
| $NE_m$ Required: | 3.30 | 4.10 | 4.84 | 5.55 | 6.24 | 6.89 | 7.52 | 8.14 | 8.75 | 9.33 |
| Daily gain, kg | $NE_g$ Required | | | | | | | | | |
| *Medium-frame steer calves* | | | | | | | | | | |
| 0.2 | 0.41 | 0.50 | 0.60 | 0.69 | 0.77 | 0.85 | 0.93 | 1.01 | 1.08 | |
| 0.4 | 0.87 | 1.08 | 1.28 | 1.47 | 1.65 | 1.82 | 1.99 | 2.16 | 2.32 | |
| 0.6 | 1.36 | 1.69 | 2.00 | 2.29 | 2.57 | 2.84 | 3.11 | 3.36 | 3.61 | |
| 0.8 | 1.87 | 2.32 | 2.74 | 3.14 | 3.53 | 3.90 | 4.26 | 4.61 | 4.95 | |
| 1.0 | 2.39 | 2.96 | 3.50 | 4.02 | 4.51 | 4.98 | 5.44 | 5.89 | 6.23 | |
| 1.2 | 2.91 | 3.62 | 4.28 | 4.90 | 5.50 | 6.69 | 6.65 | 7.19 | 7.73 | |
| *Large-frame steers, compensating medium-frame yearling steers and medium-frame bulls* | | | | | | | | | | |
| 0.2 | 0.36 | 0.45 | 0.53 | 0.61 | 0.68 | 0.75 | 0.82 | 0.89 | 0.96 | 1.02 |
| 0.4 | 0.77 | 0.96 | 1.13 | 1.30 | 1.46 | 1.61 | 1.76 | 1.91 | 2.05 | 2.19 |
| 0.6 | 1.21 | 1.50 | 1.77 | 2.03 | 2.28 | 2.52 | 2.75 | 2.98 | 3.20 | 3.41 |
| 0.8 | 1.65 | 2.06 | 2.43 | 2.78 | 3.12 | 3.45 | 3.77 | 4.08 | 4.38 | 4.68 |
| 1.0 | 2.11 | 2.62 | 3.10 | 3.55 | 3.99 | 4.41 | 4.81 | 5.21 | 5.60 | 5.98 |
| 1.2 | 2.58 | 3.20 | 3.78 | 4.34 | 4.87 | 5.38 | 5.88 | 6.37 | 6.84 | 7.30 |
| 1.4 | 3.06 | 3.79 | 4.48 | 5.14 | 5.77 | 6.38 | 6.97 | 7.54 | 8.10 | 8.64 |
| 1.6 | 3.53 | 4.39 | 5.19 | 5.95 | 6.68 | 7.38 | 8.07 | 8.73 | 9.38 | 10.01 |
| *Large-frame bull calves and compensating large-frame yearling steers* | | | | | | | | | | |
| 0.2 | 0.32 | 0.40 | 0.47 | 0.54 | 0.60 | 0.67 | 0.73 | 0.79 | 0.85 | 0.91 |
| 0.4 | 0.69 | 0.85 | 1.01 | 1.15 | 1.29 | 1.43 | 1.56 | 1.69 | 1.82 | 1.94 |
| 0.6 | 1.07 | 1.33 | 1.57 | 1.80 | 2.02 | 2.23 | 2.44 | 2.64 | 2.83 | 3.02 |
| 0.8 | 1.47 | 1.82 | 2.15 | 2.47 | 2.77 | 3.06 | 3.34 | 3.62 | 3.88 | 4.15 |
| 1.0 | 1.87 | 2.32 | 2.75 | 3.15 | 3.54 | 3.91 | 4.27 | 4.62 | 4.96 | 5.30 |
| 1.2 | 2.29 | 2.84 | 3.36 | 3.85 | 4.32 | 4.77 | 5.21 | 5.64 | 6.06 | 6.47 |
| 1.4 | 2.71 | 3.36 | 3.97 | 4.56 | 5.11 | 5.65 | 6.18 | 6.68 | 7.18 | 7.66 |
| 1.6 | 3.14 | 3.89 | 4.60 | 5.28 | 5.92 | 6.55 | 7.15 | 7.74 | 8.31 | 8.87 |
| 1.8 | 3.56 | 4.43 | 5.23 | 6.00 | 6.74 | 7.45 | 8.13 | 8.80 | 9.46 | 10.10 |
| *Medium-frame heifer calves* | | | | | | | | | | |
| 0.2 | 0.49 | 0.60 | 0.71 | 0.82 | 0.92 | 1.01 | 1.11 | 1.20 | 1.29 | |
| 0.4 | 1.05 | 1.31 | 1.55 | 1.77 | 1.99 | 2.20 | 2.40 | 2.60 | 2.79 | |
| 0.6 | 1.66 | 2.06 | 2.44 | 2.79 | 3.13 | 3.46 | 3.78 | 4.10 | 4.40 | |
| 0.8 | 2.29 | 2.84 | 3.36 | 3.85 | 4.32 | 4.78 | 5.22 | 5.65 | 6.07 | |
| 1.0 | 2.94 | 3.65 | 4.31 | 4.94 | 5.55 | 6.14 | 6.70 | 7.25 | 7.79 | |
| *Large-frame heifer calves and compensating medium-frame yearling heifers* | | | | | | | | | | |
| 0.2 | 0.43 | 0.53 | 0.63 | 0.72 | 0.81 | 0.90 | 0.98 | 1.06 | 1.14 | 1.21 |
| 0.4 | 0.93 | 1.16 | 1.37 | 1.57 | 1.76 | 1.95 | 2.13 | 2.31 | 2.47 | 2.64 |
| 0.6 | 1.47 | 1.83 | 2.16 | 2.47 | 2.78 | 3.07 | 3.35 | 3.63 | 3.90 | 4.16 |
| 0.8 | 2.03 | 2.62 | 2.98 | 3.41 | 3.83 | 4.24 | 4.63 | 5.01 | 5.38 | 5.74 |
| 1.0 | 2.61 | 3.23 | 3.82 | 4.38 | 4.92 | 5.44 | 5.94 | 6.43 | 6.91 | 7.37 |
| 1.2 | 3.19 | 3.97 | 4.69 | 5.37 | 5.03 | 6.67 | 7.28 | 7.88 | 8.47 | 9.03 |

[a]Shrunk liveweight basis, see text.

TABLE 2 Protein Requirements of Growing and Finishing Cattle (g/day)[a]

| Body weight, kg: | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 |
|---|---|---|---|---|---|---|---|---|---|---|
| *Medium-frame steer calves* | | | | | | | | | | |
| Daily gain, kg | | | | | | | | | | |
| 0.2 | 343 | 399 | 450 | 499 | 545 | 590 | 633 | 675 | 715 | |
| 0.4 | 428 | 482 | 532 | 580 | 625 | 668 | 710 | 751 | 790 | |
| 0.6 | 503 | 554 | 601 | 646 | 688 | 728 | 767 | 805 | 842 | |
| 0.8 | 575 | 621 | 664 | 704 | 743 | 780 | 815 | 849 | 883 | |
| 1.0 | 642 | 682 | 720 | 755 | 789 | 821 | 852 | 882 | 911 | |
| 1.2 | 702 | 735 | 766 | 794 | 822 | 848 | 873 | 897 | 921 | |
| *Large-frame steer calves and compensating medium-frame yearling steers* | | | | | | | | | | |
| 0.2 | 361 | 421 | 476 | 529 | 579 | 627 | 673 | 719 | 762 | 805 |
| 0.4 | 441 | 499 | 552 | 603 | 651 | 697 | 742 | 785 | 827 | 867 |
| 0.6 | 522 | 576 | 628 | 676 | 722 | 766 | 809 | 850 | 890 | 930 |
| 0.8 | 598 | 650 | 698 | 743 | 786 | 828 | 867 | 906 | 944 | 980 |
| 1.0 | 671 | 718 | 762 | 804 | 843 | 881 | 918 | 953 | 988 | 1021 |
| 1.2 | 740 | 782 | 822 | 859 | 895 | 929 | 961 | 993 | 1023 | 1053 |
| 1.4 | 806 | 842 | 877 | 908 | 938 | 967 | 995 | 1022 | 1048 | 1073 |
| 1.6 | 863 | 892 | 919 | 943 | 967 | 989 | 1011 | 1031 | 1052 | 1071 |
| *Medium-frame bulls* | | | | | | | | | | |
| 0.2 | 345 | 401 | 454 | 503 | 550 | 595 | 638 | 680 | 721 | 761 |
| 0.4 | 430 | 485 | 536 | 584 | 629 | 673 | 716 | 757 | 797 | 835 |
| 0.6 | 509 | 561 | 609 | 655 | 698 | 740 | 780 | 819 | 856 | 893 |
| 0.8 | 583 | 632 | 677 | 719 | 759 | 798 | 835 | 871 | 906 | 940 |
| 1.0 | 655 | 698 | 739 | 777 | 813 | 849 | 881 | 914 | 945 | 976 |
| 1.2 | 722 | 760 | 795 | 828 | 860 | 890 | 919 | 947 | 974 | 1001 |
| 1.4 | 782 | 813 | 841 | 868 | 893 | 917 | 941 | 963 | 985 | 1006 |
| *Large-frame bull calves and compensating large-frame yearling steers* | | | | | | | | | | |
| 0.2 | 355 | 414 | 468 | 519 | 568 | 615 | 661 | 705 | 747 | 789 |
| 0.4 | 438 | 494 | 547 | 597 | 644 | 689 | 733 | 776 | 817 | 857 |
| 0.6 | 519 | 574 | 624 | 672 | 718 | 761 | 803 | 844 | 884 | 923 |
| 0.8 | 597 | 649 | 697 | 741 | 795 | 826 | 866 | 905 | 942 | 979 |
| 1.0 | 673 | 721 | 765 | 807 | 847 | 885 | 922 | 958 | 994 | 1027 |
| 1.2 | 745 | 789 | 830 | 868 | 904 | 939 | 973 | 1005 | 1037 | 1067 |
| 1.4 | 815 | 854 | 890 | 924 | 956 | 986 | 1016 | 1045 | 1072 | 1099 |
| 1.6 | 880 | 912 | 943 | 971 | 998 | 1024 | 1048 | 1072 | 1095 | 1117 |
| 1.8 | 922 | 942 | 962 | 980 | 997 | 1013 | 1028 | 1043 | 1057 | 1071 |
| *Medium-frame heifer calves* | | | | | | | | | | |
| 0.2 | 323 | 374 | 421 | 465 | 508 | 549 | 588 | 626 | 662 | |
| 0.4 | 409 | 459 | 505 | 549 | 591 | 630 | 669 | 706 | 742 | |
| 0.6 | 477 | 522 | 563 | 602 | 638 | 674 | 708 | 741 | 773 | |
| 0.8 | 537 | 574 | 608 | 640 | 670 | 700 | 728 | 755 | 781 | |
| 1.0 | 562 | 583 | 603 | 621 | 638 | 654 | 670 | 685 | 700 | |
| *Large-frame heifer calves and compensating medium-frame yearling heifers* | | | | | | | | | | |
| 0.2 | 342 | 397 | 449 | 497 | 543 | 588 | 631 | 672 | 712 | 751 |
| 0.4 | 426 | 480 | 530 | 577 | 622 | 665 | 707 | 747 | 787 | 825 |
| 0.6 | 500 | 549 | 596 | 639 | 681 | 721 | 759 | 796 | 832 | 867 |
| 0.8 | 568 | 613 | 654 | 693 | 730 | 765 | 799 | 833 | 865 | 896 |
| 1.0 | 630 | 668 | 703 | 735 | 767 | 797 | 826 | 854 | 881 | 907 |
| 1.2 | 680 | 708 | 734 | 758 | 781 | 803 | 824 | 844 | 864 | 883 |

[a]Shrunk liveweight basis, see text.

TABLE 3 Calcium and Phosphorus Requirements of Growing and Finishing Cattle (g/day)[a]

| Body Weight, kg | Mineral | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Medium-frame steer calves* | | | | | | | | | | | |
| Daily gain, kg | | | | | | | | | | | |
| 0.2 | Ca | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 19 | 20 | |
| | P | 7 | 9 | 10 | 12 | 13 | 15 | 16 | 18 | 19 | |
| 0.4 | Ca | 16 | 17 | 17 | 18 | 19 | 19 | 20 | 21 | 22 | |
| | P | 9 | 10 | 12 | 13 | 14 | 16 | 17 | 18 | 20 | |
| 0.6 | Ca | 21 | 21 | 21 | 22 | 22 | 22 | 22 | 23 | 23 | |
| | P | 11 | 12 | 13 | 14 | 15 | 17 | 18 | 19 | 20 | |
| 0.8 | Ca | 27 | 26 | 25 | 25 | 25 | 25 | 24 | 24 | 24 | |
| | P | 12 | 13 | 14 | 15 | 16 | 17 | 19 | 20 | 21 | |
| 1.0 | Ca | 32 | 31 | 29 | 29 | 28 | 27 | 26 | 26 | 25 | |
| | P | 14 | 15 | 16 | 16 | 17 | 18 | 19 | 20 | 21 | |
| 1.2 | Ca | 37 | 35 | 33 | 32 | 31 | 29 | 28 | 27 | 26 | |
| | P | 16 | 16 | 17 | 17 | 18 | 19 | 20 | 21 | 21 | |
| 1.4 | Ca | 42 | 39 | 37 | 35 | 33 | 32 | 30 | 29 | 27 | |
| | P | 17 | 18 | 18 | 19 | 19 | 20 | 20 | 21 | 22 | |
| *Large-frame steer calves, compensating medium-frame yearling steers, and medium-frame bulls* | | | | | | | | | | | |
| 0.2 | Ca | 11 | 12 | 13 | 14 | 16 | 17 | 18 | 19 | 20 | 22 |
| | P | 7 | 9 | 10 | 12 | 13 | 15 | 16 | 18 | 20 | 21 |
| 0.4 | Ca | 17 | 17 | 18 | 19 | 19 | 20 | 21 | 22 | 23 | 24 |
| | P | 9 | 10 | 12 | 13 | 15 | 16 | 17 | 19 | 20 | 22 |
| 0.6 | Ca | 22 | 22 | 23 | 23 | 23 | 24 | 24 | 24 | 25 | 25 |
| | P | 11 | 12 | 13 | 15 | 16 | 17 | 18 | 20 | 21 | 22 |
| 0.8 | Ca | 28 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 |
| | P | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 22 | 23 |
| 1.0 | Ca | 33 | 32 | 31 | 31 | 30 | 30 | 29 | 29 | 29 | 28 |
| | P | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| 1.2 | Ca | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 30 |
| | P | 16 | 17 | 18 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| 1.4 | Ca | 44 | 42 | 40 | 38 | 37 | 36 | 34 | 33 | 32 | 31 |
| | P | 18 | 18 | 19 | 20 | 20 | 21 | 22 | 22 | 23 | 24 |
| 1.6 | Ca | 49 | 47 | 44 | 42 | 40 | 38 | 37 | 35 | 34 | 32 |
| | P | 20 | 20 | 20 | 21 | 21 | 22 | 22 | 23 | 24 | 24 |
| *Large-frame bull calves and compensating large-frame yearling steers* | | | | | | | | | | | |
| 0.2 | Ca | 11 | 12 | 13 | 15 | 16 | 17 | 18 | 20 | 21 | 22 |
| | P | 7 | 9 | 10 | 12 | 13 | 15 | 17 | 18 | 20 | 21 |
| 0.4 | Ca | 17 | 18 | 19 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| | P | 9 | 11 | 12 | 13 | 15 | 16 | 18 | 19 | 21 | 22 |
| 0.6 | Ca | 23 | 23 | 23 | 24 | 24 | 25 | 25 | 26 | 27 | 27 |
| | P | 11 | 12 | 14 | 15 | 16 | 18 | 19 | 20 | 22 | 23 |
| 0.8 | Ca | 28 | 28 | 28 | 28 | 28 | 29 | 29 | 29 | 29 | 30 |
| | P | 13 | 14 | 15 | 16 | 18 | 19 | 20 | 21 | 22 | 24 |
| 1.0 | Ca | 34 | 34 | 33 | 33 | 32 | 32 | 32 | 32 | 32 | 32 |
| | P | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| 1.2 | Ca | 40 | 39 | 38 | 37 | 36 | 36 | 35 | 35 | 34 | 34 |
| | P | 17 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| 1.4 | Ca | 45 | 44 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 36 |
| | P | 18 | 19 | 20 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| 1.6 | Ca | 51 | 49 | 47 | 45 | 44 | 42 | 41 | 40 | 39 | 38 |
| | P | 20 | 21 | 21 | 22 | 23 | 23 | 24 | 25 | 25 | 26 |
| 1.8 | Ca | 56 | 54 | 51 | 49 | 47 | 45 | 44 | 42 | 41 | 39 |
| | P | 22 | 22 | 22 | 23 | 23 | 24 | 25 | 25 | 26 | 26 |

TABLE 3 Calcium and Phosphorus Requirements of Growing and Finishing Cattle (g/day)[a]—*Continued*

| Body Weight, kg | Mineral | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Medium-frame heifer calves* | | | | | | | | | | | |
| 0.2 | Ca | 10 | 11 | 12 | 13 | 14 | 16 | 17 | 18 | 19 | |
| | P | 7 | 9 | 10 | 11 | 13 | 14 | 16 | 17 | 19 | |
| 0.4 | Ca | 15 | 16 | 16 | 16 | 17 | 17 | 18 | 19 | 19 | |
| | P | 9 | 10 | 11 | 12 | 14 | 15 | 16 | 18 | 19 | |
| 0.6 | Ca | 20 | 20 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | |
| | P | 10 | 11 | 12 | 13 | 14 | 16 | 17 | 18 | 19 | |
| 0.8 | Ca | 25 | 23 | 23 | 22 | 21 | 20 | 20 | 19 | 19 | |
| | P | 12 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | |
| 1.0 | Ca | 29 | 27 | 26 | 24 | 23 | 22 | 20 | 19 | 19 | |
| | P | 13 | 14 | 14 | 15 | 16 | 16 | 17 | 18 | 19 | |
| *Large-frame heifer calves and compensating medium-frame yearling heifers* | | | | | | | | | | | |
| 0.2 | Ca | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 20 | 21 |
| | P | 7 | 9 | 10 | 12 | 13 | 15 | 16 | 18 | 19 | 21 |
| 0.4 | Ca | 16 | 16 | 17 | 17 | 18 | 19 | 19 | 20 | 21 | 22 |
| | P | 9 | 10 | 11 | 13 | 14 | 15 | 17 | 18 | 20 | 21 |
| 0.6 | Ca | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 22 | 22 |
| | P | 10 | 12 | 13 | 14 | 15 | 16 | 17 | 19 | 20 | 21 |
| 0.8 | Ca | 26 | 25 | 24 | 24 | 23 | 23 | 23 | 22 | 22 | 22 |
| | P | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| 1.0 | Ca | 31 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 23 | 22 |
| | P | 14 | 14 | 15 | 16 | 17 | 18 | 18 | 19 | 20 | 21 |
| 1.2 | Ca | 35 | 33 | 31 | 30 | 28 | 27 | 25 | 24 | 23 | 22 |
| | P | 15 | 16 | 16 | 17 | 17 | 18 | 19 | 20 | 20 | 21 |

[a]Shrunk liveweight basis, see text.

TABLE 4 Mineral Requirements and Maximum Tolerable Levels for Beef Cattle

| Mineral | Requirement: Suggested Value | Requirement: Range[a] | Maximum Tolerable Level[b] |
|---|---|---|---|
| Calcium, % | — | See Tables 3 and 7. | 2 |
| Cobalt, ppm | 0.10 | 0.07 to 0.11 | 5 |
| Copper, ppm | 8 | 4 to 10 | 115 |
| Iodine, ppm | 0.5 | 0.20 to 2.0 | 50 |
| Iron, ppm | 50 | 50 to 100 | 1000 |
| Magnesium, % | 0.10 | 0.05 to 0.25 | 0.40 |
| Manganese, ppm | 40 | 20 to 50 | 1000 |
| Molybdenum, ppm | — | — | 6 |
| Phosphorus, % | — | See Tables 3 and 7. | 1 |
| Potassium, % | 0.65 | 0.5 to 0.7 | 3 |
| Selenium, ppm | 0.20 | 0.05 to 0.30 | 2 |
| Sodium, % | 0.08 | 0.06 to 0.10 | 10[c] |
| Chlorine, % | — | — | — |
| Sulfur, % | 0.10 | 0.08 to 0.15 | 0.40 |
| Zinc, ppm | 30 | 20 to 40 | 500 |

[a]The listing of a range in which requirements are likely to be met recognizes that requirements for most minerals are affected by a variety of dietary and animal (body weight, sex, rate of gain) factors. Thus, it may be better to evaluate rations based on a range of mineral requirements and for content of interfering substances than to meet a specific dietary value.

[b]From NRC (1980).

[c]10% sodium chloride.

TABLE 5 Maximum Tolerable Levels of Certain Toxic Elements[a]

| Element | Maximum Tolerable Level, ppm |
|---|---|
| Aluminum | 1,000 |
| Arsenic | 50 (100 for organic forms) |
| Bromine | 200 |
| Cadmium | 00.5 |
| Fluorine | 20 to 100 |
| Lead | 30 |
| Mercury | 2 |
| Strontium | 2,000 |

[a]NRC (1980), Table 4, Mineral Requirements and Maximum Tolerable Levels for Beef Cattle.

TABLE 6 Approximate Total Daily Water Intake of Beef Cattle[a]

| Weight | | Temperature in °F (°C)[b] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 40 (4.4) | | 50 (10.0) | | 60 (14.4) | | 70 (21.1) | | 80 (26.6) | | 90 (32.2) | |
| kg | lb | liter | gal | liter | gal | liter | gal | liter | gal | liter | gal | liter | gal |
| *Growing heifers, steers, and bulls* | | | | | | | | | | | | | |
| 182 | 400 | 15.1 | 4.0 | 16.3 | 4.3 | 18.9 | 5.0 | 22.0 | 5.8 | 25.4 | 6.7 | 36.0 | 9.5 |
| 273 | 600 | 20.1 | 5.3 | 22.0 | 5.8 | 25.0 | 6.6 | 29.5 | 7.8 | 33.7 | 8.9 | 48.1 | 12.7 |
| 364 | 800 | 23.8 | 6.3 | 25.7 | 6.8 | 29.9 | 7.9 | 34.8 | 9.2 | 40.1 | 10.6 | 56.8 | 15.0 |
| *Finishing cattle* | | | | | | | | | | | | | |
| 273 | 600 | 22.7 | 6.0 | 24.6 | 6.5 | 28.0 | 7.4 | 32.9 | 8.7 | 37.9 | 10.0 | 54.1 | 14.3 |
| 364 | 800 | 27.6 | 7.3 | 29.9 | 7.9 | 34.4 | 9.1 | 40.5 | 10.7 | 46.6 | 12.3 | 65.9 | 17.4 |
| 454 | 1000 | 32.9 | 8.7 | 35.6 | 9.4 | 40.9 | 10.8 | 47.7 | 12.6 | 54.9 | 14.5 | 78.0 | 20.6 |
| *Wintering pregnant cows*[c] | | | | | | | | | | | | | |
| 409 | 900 | 25.4 | 6.7 | 27.3 | 7.2 | 31.4 | 8.3 | 36.7 | 9.7 | — | — | — | — |
| 500 | 1100 | 22.7 | 6.0 | 24.6 | 6.5 | 28.0 | 7.4 | 32.9 | 8.7 | — | — | — | — |
| *Lactating cows* | | | | | | | | | | | | | |
| 409 + | 900 + | 43.1 | 11.4 | 47.7 | 12.6 | 54.9 | 14.5 | 64.0 | 16.9 | 67.8 | 17.9 | 61.3 | 16.2 |
| *Mature bulls* | | | | | | | | | | | | | |
| 636 | 1400 | 30.3 | 8.0 | 32.6 | 8.6 | 37.5 | 9.9 | 44.3 | 11.7 | 50.7 | 13.4 | 71.9 | 19.0 |
| 727 + | 1600 + | 32.9 | 8.7 | 35.6 | 9.4 | 40.9 | 10.8 | 47.7 | 12.6 | 54.9 | 14.5 | 78.0 | 20.6 |

[a] Winchester and Morris (1956).

[b] Water intake of a given class of cattle in a specific management regime is a function of dry matter intake and ambient temperature. Water intake is quite constant up to 40°F (4.4°C).

[c] Dry matter intake has a major influence on water intake. Heavier cows are assumed to be higher in body condition and to require less dry matter and, thus, less water intake.

TABLE 7 Nutrient Requirements of Breeding Cattle (metric)

| | | | Energy | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Daily | | | | In Diet DM | | | | Total Protein | | Calcium | | Phosphorus | | Vitamin A[d] |
| Weight[a] (kg) | Daily Gain[b] (kg) | Daily DM[c] (kg) | ME (Mcal) | TDN (kg) | $NE_m$ (Mcal) | $NE_g$ (Mcal) | ME (Mcal/kg) | TDN (%) | $NE_m$ (Mcal/kg) | $NE_g$ (Mcal/kg) | Daily (g) | In Diet DM (%) | Daily (g) | In Diet DM (%) | Daily (g) | In Diet DM (%) | Daily (1000's IU) |
| *Pregnant yearling heifers—Last third of pregnancy* | | | | | | | | | | | | | | | | | |
| 325 | 0.4 | 7.1 | 14.2 | 3.9 | 8.04 | NA[e] | 2.00 | 55.2 | 1.15 | NA[e] | 591 | 8.4 | 19 | 0.27 | 14 | 0.20 | 20 |
| 325 | 0.6 | 7.3 | 15.7 | 4.3 | 8.04 | 0.77 | 2.15 | 59.3 | 1.29 | 0.72 | 649 | 8.9 | 23 | 0.32 | 15 | 0.21 | 20 |
| 325 | 0.8 | 7.3 | 17.2 | 4.8 | 8.04 | 1.67 | 2.35 | 64.9 | 1.47 | 0.88 | 697 | 9.5 | 27 | 0.37 | 16 | 0.22 | 20 |
| 350 | 0.4 | 7.5 | 14.8 | 4.1 | 8.38 | NA | 1.99 | 55.0 | 1.14 | NA | 616 | 8.3 | 20 | 0.27 | 15 | 0.21 | 21 |
| 350 | 0.6 | 7.7 | 16.5 | 4.6 | 8.38 | 0.81 | 2.14 | 59.1 | 1.28 | 0.71 | 674 | 8.8 | 24 | 0.32 | 16 | 0.21 | 22 |
| 350 | 0.8 | 7.8 | 18.1 | 5.0 | 8.38 | 1.76 | 2.34 | 64.6 | 1.46 | 0.88 | 720 | 9.3 | 27 | 0.35 | 17 | 0.22 | 22 |
| 375 | 0.4 | 7.8 | 15.5 | 4.3 | 8.71 | NA | 1.98 | 54.7 | 1.13 | NA | 641 | 8.2 | 21 | 0.27 | 15 | 0.19 | 22 |
| 375 | 0.6 | 8.1 | 17.2 | 4.8 | 8.71 | 0.86 | 2.13 | 58.8 | 1.27 | 0.70 | 697 | 8.6 | 25 | 0.31 | 17 | 0.21 | 23 |
| 375 | 0.8 | 8.2 | 19.0 | 5.2 | 8.71 | 1.86 | 2.32 | 64.1 | 1.45 | 0.86 | 743 | 9.1 | 27 | 0.33 | 18 | 0.22 | 23 |
| 400 | 0.4 | 8.2 | 16.1 | 4.5 | 9.04 | NA | 1.97 | 54.4 | 1.12 | NA | 664 | 8.1 | 22 | 0.27 | 16 | 0.20 | 23 |
| 400 | 0.6 | 8.5 | 18.0 | 5.0 | 9.04 | 0.90 | 2.12 | 58.6 | 1.26 | 0.69 | 721 | 8.5 | 25 | 0.30 | 18 | 0.21 | 24 |
| 400 | 0.8 | 8.6 | 19.8 | 5.5 | 9.04 | 1.95 | 2.31 | 63.8 | 1.44 | 0.85 | 764 | 8.9 | 28 | 0.33 | 18 | 0.20 | 24 |
| 425 | 0.4 | 8.6 | 16.8 | 4.6 | 9.36 | NA | 1.96 | 54.1 | 1.11 | NA | 687 | 8.0 | 23 | 0.27 | 17 | 0.20 | 24 |
| 425 | 0.6 | 8.9 | 18.7 | 5.2 | 9.36 | 0.94 | 2.11 | 58.3 | 1.25 | 0.69 | 743 | 8.4 | 26 | 0.30 | 18 | 0.20 | 25 |
| 425 | 0.8 | 9.0 | 20.7 | 5.7 | 9.36 | 2.04 | 2.30 | 63.5 | 1.43 | 0.84 | 786 | 8.8 | 28 | 0.31 | 19 | 0.21 | 25 |
| 450 | 0.4 | 8.9 | 17.3 | 4.8 | 9.67 | NA | 1.95 | 53.9 | 1.10 | NA | 710 | 8.0 | 23 | 0.26 | 18 | 0.20 | 25 |
| 450 | 0.6 | 9.2 | 19.4 | 5.4 | 9.67 | 0.98 | 2.10 | 58.0 | 1.25 | 0.68 | 765 | 8.3 | 26 | 0.29 | 19 | 0.21 | 26 |
| 450 | 0.8 | 9.4 | 21.5 | 5.9 | 9.67 | 2.13 | 2.29 | 63.3 | 1.42 | 0.84 | 807 | 8.6 | 28 | 0.30 | 20 | 0.21 | 26 |
| *Dry pregnant mature cows—Middle third of pregnancy* | | | | | | | | | | | | | | | | | |
| 350 | 0.0 | 6.8 | 11.9 | 3.3 | 6.23 | NA | 1.76 | 48.6 | 0.92 | NA | 478 | 7.1 | 12 | 0.16 | 12 | 0.18 | 19 |
| 400 | 0.0 | 7.5 | 13.1 | 3.6 | 6.89 | NA | 1.76 | 48.6 | 0.92 | NA | 525 | 7.0 | 13 | 0.17 | 13 | 0.17 | 21 |
| 450 | 0.0 | 8.2 | 14.3 | 4.0 | 7.52 | NA | 1.76 | 48.6 | 0.92 | NA | 570 | 7.0 | 15 | 0.17 | 15 | 0.18 | 23 |
| 500 | 0.0 | 8.8 | 15.5 | 4.3 | 8.14 | NA | 1.76 | 48.6 | 0.92 | NA | 614 | 7.0 | 17 | 0.19 | 17 | 0.19 | 25 |
| 550 | 0.0 | 9.5 | 16.7 | 4.6 | 8.75 | NA | 1.76 | 48.6 | 0.92 | NA | 657 | 6.9 | 18 | 0.19 | 18 | 0.19 | 27 |
| 600 | 0.0 | 10.1 | 17.8 | 4.9 | 9.33 | NA | 1.76 | 48.6 | 0.92 | NA | 698 | 6.9 | 20 | 0.20 | 20 | 0.20 | 28 |
| 650 | 0.0 | 10.7 | 18.9 | 5.2 | 9.91 | NA | 1.76 | 48.6 | 0.92 | NA | 739 | 6.9 | 22 | 0.21 | 22 | 0.21 | 30 |
| *Dry pregnant mature cows—Last third of pregnancy* | | | | | | | | | | | | | | | | | |
| 350 | 0.4 | 7.4 | 14.7 | 4.1 | 8.38 | NA | 1.98 | 54.7 | 1.13 | NA | 609 | 8.2 | 20 | 0.27 | 15 | 0.20 | 21 |
| 400 | 0.4 | 8.2 | 16.0 | 4.4 | 9.04 | NA | 1.96 | 54.1 | 1.11 | NA | 657 | 8.0 | 22 | 0.27 | 16 | 0.20 | 23 |
| 450 | 0.4 | 8.9 | 17.2 | 4.8 | 9.67 | NA | 1.94 | 53.6 | 1.10 | NA | 703 | 7.9 | 23 | 0.26 | 18 | 0.21 | 24 |
| 500 | 0.4 | 9.5 | 18.3 | 5.1 | 10.29 | NA | 1.92 | 53.1 | 1.08 | NA | 746 | 7.8 | 25 | 0.26 | 20 | 0.21 | 27 |
| 550 | 0.4 | 10.2 | 19.5 | 5.4 | 10.90 | NA | 1.91 | 52.8 | 1.07 | NA | 790 | 7.8 | 26 | 0.25 | 21 | 0.21 | 29 |
| 600 | 0.4 | 10.8 | 20.6 | 5.7 | 11.48 | NA | 1.90 | 52.5 | 1.06 | NA | 832 | 7.7 | 28 | 0.26 | 23 | 0.21 | 30 |
| 650 | 0.4 | 11.5 | 21.7 | 6.0 | 12.06 | NA | 1.89 | 52.2 | 1.05 | NA | 872 | 7.6 | 30 | 0.26 | 25 | 0.22 | 32 |
| *Two-year-old heifers nursing calves—First 3-4 months postpartum—5.0 kg milk/day* | | | | | | | | | | | | | | | | | |
| 300 | 0.2 | 6.9 | 16.6 | 4.6 | 9.30[f] | 0.72 | 2.41 | 66.6 | 1.53 | 0.93 | 814[g] | 11.8 | 26 | 0.38 | 17 | 0.25 | 27 |
| 325 | 0.2 | 7.3 | 17.4 | 4.8 | 9.64[f] | 0.77 | 2.37 | 65.5 | 1.49 | 0.90 | 841[g] | 11.5 | 27 | 0.37 | 18 | 0.25 | 28 |
| 350 | 0.2 | 7.8 | 18.1 | 5.0 | 9.98[f] | 0.81 | 2.34 | 64.6 | 1.46 | 0.88 | 866[g] | 11.2 | 27 | 0.35 | 19 | 0.24 | 30 |
| 375 | 0.2 | 8.2 | 18.9 | 5.2 | 10.31[f] | 0.86 | 2.31 | 63.8 | 1.44 | 0.85 | 892[g] | 10.9 | 28 | 0.34 | 19 | 0.23 | 32 |
| 400 | 0.2 | 8.6 | 19.7 | 5.4 | 10.64[f] | 0.90 | 2.29 | 63.3 | 1.42 | 0.84 | 916[g] | 10.7 | 28 | 0.33 | 20 | 0.23 | 34 |
| 425 | 0.2 | 9.0 | 20.4 | 5.6 | 10.96[f] | 0.94 | 2.27 | 62.7 | 1.40 | 0.82 | 939[g] | 10.5 | 29 | 0.32 | 21 | 0.23 | 35 |
| 450 | 0.2 | 9.4 | 21.1 | 5.8 | 11.27[f] | 0.98 | 2.25 | 62.2 | 1.38 | 0.80 | 963[g] | 10.3 | 29 | 0.31 | 22 | 0.23 | 37 |

**TABLE 7 Nutrient Requirements of Breeding Cattle (metric)—*Continued***

| | | | Energy | | | | | | | | Total Protein | | Calcium | | Phosphorus | | Vitamin A[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Daily | | | | In Diet DM | | | | | | | | | | |
| Weight[a] (kg) | Daily Gain[b] (kg) | Daily DM[c] (kg) | ME (Mcal) | TDN (kg) | $NE_m$ (Mcal) | $NE_g$ (Mcal) | ME (Mcal/kg) | TDN (%) | $NE_m$ (Mcal/kg) | $NE_g$ (Mcal/kg) | Daily (g) | In Diet DM (%) | Daily (g) | In Diet DM (%) | Daily (g) | In Diet DM (%) | Daily (1000's IU) |
| *Cows nursing calves—Average milking ability—First 3-4 months postpartum—5.0 kg milk/day* | | | | | | | | | | | | | | | | | |
| 350 | 0.0 | 7.7 | 16.6 | 4.6 | 9.98[f] | NA | 2.15 | 59.4 | 1.29 | NA | 814[g] | 10.6 | 23 | 0.30 | 18 | 0.23 | 30 |
| 400 | 0.0 | 8.5 | 17.9 | 4.9 | 10.64[f] | NA | 2.11 | 58.3 | 1.25 | NA | 864[g] | 10.2 | 25 | 0.29 | 19 | 0.22 | 33 |
| 450 | 0.0 | 9.2 | 19.1 | 5.3 | 11.27[f] | NA | 2.08 | 57.5 | 1.23 | NA | 911[g] | 9.9 | 26 | 0.28 | 21 | 0.23 | 36 |
| 500 | 0.0 | 9.9 | 20.3 | 5.6 | 11.89[f] | NA | 2.05 | 56.6 | 1.20 | NA | 957[g] | 9.7 | 28 | 0.28 | 22 | 0.22 | 39 |
| 550 | 0.0 | 10.6 | 21.5 | 5.9 | 12.50[f] | NA | 2.03 | 56.1 | 1.18 | NA | 1001[g] | 9.5 | 29 | 0.27 | 24 | 0.23 | 41 |
| 600 | 0.0 | 11.2 | 22.6 | 6.2 | 13.08[f] | NA | 2.01 | 55.5 | 1.16 | NA | 1044[g] | 9.3 | 31 | 0.28 | 26 | 0.23 | 44 |
| 650 | 0.0 | 11.9 | 23.9 | 6.6 | 13.66[f] | NA | 2.00 | 55.3 | 1.15 | NA | 1086[g] | 9.1 | 33 | 0.28 | 27 | 0.23 | 46 |
| *Cows nursing calves—Superior milking ability—First 3-4 months postpartum—10.0 kg milk/day* | | | | | | | | | | | | | | | | | |
| 350 | 0.0 | 6.2 | 18.5 | 5.1 | 13.73[f] | NA | 3.00 | 82.9 | 2.03 | NA | 1009[g] | 16.4 | 36 | 0.58 | 24 | 0.39 | 24 |
| 400 | 0.0 | 7.6 | 21.4 | 5.9 | 14.39[f] | NA | 2.80 | 77.4 | 1.86 | NA | 1099[g] | 14.4 | 37 | 0.49 | 25 | 0.33 | 30 |
| 450 | 0.0 | 9.1 | 23.2 | 6.4 | 15.02[f] | NA | 2.56 | 70.7 | 1.66 | NA | 1186[g] | 13.1 | 39 | 0.43 | 26 | 0.29 | 35 |
| 500 | 0.0 | 10.0 | 24.6 | 6.8 | 15.64[f] | NA | 2.45 | 67.7 | 1.56 | NA | 1246[g] | 12.4 | 40 | 0.40 | 28 | 0.28 | 39 |
| 550 | 0.0 | 10.9 | 25.8 | 7.1 | 16.25[f] | NA | 2.38 | 65.8 | 1.50 | NA | 1299[g] | 12.0 | 42 | 0.39 | 30 | 0.27 | 42 |
| 600 | 0.0 | 11.6 | 27.0 | 7.5 | 16.83[f] | NA | 2.32 | 64.1 | 1.45 | NA | 1348[g] | 11.6 | 43 | 0.37 | 31 | 0.27 | 45 |
| 650 | 0.0 | 12.4 | 28.2 | 7.8 | 17.41[f] | NA | 2.28 | 63.0 | 1.41 | NA | 1394[g] | 11.3 | 45 | 0.36 | 33 | 0.26 | 48 |
| *Bulls, maintenance and regaining body condition* | | | | | | | | | | | | | | | | | |
| <650 | For growth and development use requirements for bulls in Tables 1, 2, and 3. | | | | | | | | | | | | | | | | |
| 650 | 0.4 | 12.3 | 24.3 | 6.7 | 9.91 | 2.06 | 1.98 | 54.8 | 1.13 | 0.57 | 904 | 7.4 | 25 | 0.20 | 23 | 0.19 | 48 |
| 650 | 0.6 | 12.6 | 26.7 | 7.4 | 9.91 | 3.21 | 2.11 | 58.4 | 1.25 | 0.69 | 957 | 7.6 | 27 | 0.21 | 24 | 0.19 | 49 |
| 650 | 0.8 | 12.8 | 28.7 | 7.9 | 9.91 | 4.40 | 2.24 | 62.0 | 1.37 | 0.79 | 998 | 7.8 | 29 | 0.23 | 25 | 0.20 | 50 |
| 700 | 0.4 | 13.0 | 25.7 | 7.1 | 10.48 | 2.18 | 1.98 | 54.8 | 1.13 | 0.57 | 942 | 7.3 | 26 | 0.20 | 25 | 0.20 | 51 |
| 700 | 0.6 | 13.4 | 28.2 | 7.8 | 10.48 | 3.40 | 2.11 | 58.4 | 1.25 | 0.69 | 994 | 7.4 | 29 | 0.22 | 26 | 0.20 | 52 |
| 700 | 0.8 | 13.5 | 30.3 | 8.4 | 10.48 | 4.66 | 2.24 | 62.0 | 1.37 | 0.79 | 1032 | 7.6 | 30 | 0.22 | 26 | 0.19 | 53 |
| 800 | 0.0 | 12.9 | 22.6 | 6.3 | 11.58 | NA | 1.75 | 48.4 | 0.91 | NA | 882 | 6.8 | 27 | 0.21 | 27 | 0.21 | 50 |
| 800 | 0.2 | 13.7 | 25.5 | 7.1 | 11.58 | 1.12 | 1.86 | 51.5 | 1.02 | 0.47 | 956 | 7.0 | 27 | 0.20 | 27 | 0.20 | 53 |
| 900 | 0.0 | 14.1 | 24.7 | 6.8 | 12.65 | NA | 1.75 | 48.4 | 0.91 | NA | 958 | 6.8 | 30 | 0.21 | 30 | 0.21 | 55 |
| 900 | 0.2 | 15.0 | 27.9 | 7.7 | 12.65 | 1.23 | 1.86 | 51.5 | 1.02 | 0.47 | 1031 | 6.9 | 31 | 0.21 | 31 | 0.21 | 58 |
| 1000 | 0.0 | 15.3 | 26.8 | 7.4 | 13.69 | NA | 1.75 | 48.4 | 0.91 | NA | 1032 | 6.8 | 33 | 0.22 | 33 | 0.22 | 60 |

[a]Average weight for a feeding period.

[b]Approximately 0.4 ± 0.1 kg of weight gain/day over the last third of pregnancy is accounted for by the products of conception. Daily 2.15 Mcal of $NE_m$ and 55 g of protein are provided for this requirement for a calf with a birth weight of 36 kg.

[c]Dry matter consumption should vary depending on the energy concentration of the diet and environmental conditions. These intakes are based on the energy concentration shown in the table and assuming a thermoneutral environment without snow or mud conditions. If the energy concentrations of the diet to be fed exceed the tabular value, limit feeding may be required.

[d]Vitamin A requirements per kilogram of diet are 2800 IU for pregnant heifers and cows and 3900 IU for lactating cows and breeding bulls.

[e]Not applicable.

[f]Includes .75 Mcal $NE_m$/kg of milk produced.

[g]Includes 33.5 g protein/kg of milk produced.

# 7 Composition of Feeds and Mineral Supplements

Table 8 gives the composition of feeds commonly used for beef cattle. Some names have been shortened and the listing of feeds is slightly reorganized compared with the previous edition of this report. Mineral supplements are listed in a separate table. International Feed Numbers (IFNs) have been retained. For a complete nomenclature of the feeds appearing in Table 8, the reader is referred to the third revision of *United States-Canadian Tables of Feed Composition* (NRC, 1982), which also contains a table of weight-unit conversion factors.

The energy values in Table 8 were calculated as follows (Garrett, 1980):

$$ME = 0.82\ DE.$$

$$NE_m = 1.37\ ME - 0.138\ ME^2 + 0.0105\ ME^3 - 1.12.$$

$$NE_g = 1.42\ ME - 0.174\ ME^2 + 0.0122\ ME^3 - 1.65.$$

Additional feeds may be found in the third revision of *United States-Canadian Tables of Feed Composition*. If those feeds are to be used with prediction equations in this report, the ME and NE values need to be recalculated using the above equations. For some feedstuffs, energy values are not available from digestibility trials. Digestibility energy values may be estimated from the following formula:

$$DE\ (Mcal/kg) = 0.0504\ CP\% + 0.0770\ EE\% + 0.0200\ CF\% + 0.000377\ NFE^2\% + 0.0110\ NFE\% - 0.152.$$

This formula and a listing of unusual and by-product feeds for cattle are included in Western Regional Extension Publication Number 39, Cooperative Extension Service, University of California, Berkeley, 94720.

It should be realized that the values given in Table 8 are the best estimate of the composition of that particular feed for beef cattle. Many factors affect the composition of feeds, such as soil conditions and climate, and these should be taken into consideration.

Where data are available, plant cell constituents are given, because of the increasing use of these values in dietary formulations. When available, values are also given for crude fiber.

Table 9 lists the minerals commonly used in dietary formulations for beef cattle. Both the feed composition and mineral tables are expressed on a dry matter basis.

The vitamin A activity shown in Table 8 is based on the equivalence of 1 mg of $\beta$-carotene to 400 IU of vitamin A.

TABLE 8 Composition of Some Beef Cattle Feeds

| | | | | Dry Basis (100% Dry Matter) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Entry Number | Feed Name Description | International Feed Number[a] | Dry Matter (%) | DE (Mcal/kg) | ME (Mcal/kg) | $NE_m$ (Mcal/kg) | $NE_g$ (Mcal/kg) | TDN (%) | Crude Protein (%) | Ether Extract (%) | Ash (%) | Crude Fiber (%) | Cell Walls (%) |
| | ALFALFA *Medicago sativa* | | | | | | | | | | | | |
| 001 | fresh, late vegetative | 2-00-181 | 21 | 2.78 | 2.28 | 1.41 | 0.83 | 63 | 20.0 | 2.7 | 9.8 | 23.0 | 38 |
| 002 | fresh, early bloom | 2-00-184 | 23 | 2.65 | 2.17 | 1.31 | 0.74 | 60 | 19.0 | 3.1 | 9.5 | 25.0 | 40 |
| 003 | fresh, midbloom | 2-00-185 | 24 | 2.56 | 2.10 | 1.24 | 0.68 | 58 | 18.3 | 2.6 | 8.7 | 28.0 | 46 |
| 004 | fresh, full bloom | 2-00-188 | 25 | 2.43 | 1.99 | 1.14 | 0.58 | 55 | 14.0 | 2.8 | 8.5 | 31.0 | 52 |
| 005 | hay, sun-cured, early bloom | 1-00-059 | 90 | 2.65 | 2.17 | 1.31 | 0.74 | 60 | 18.0 | 3.0 | 9.6 | 23.0 | 42 |
| 006 | hay, sun-cured, midbloom | 1-00-063 | 90 | 2.56 | 2.10 | 1.24 | 0.68 | 58 | 17.0 | 2.6 | 9.1 | 26.0 | 46 |
| 007 | hay, sun-cured, late bloom | 1-20-681 | 90 | 2.29 | 1.88 | 1.04 | 0.49 | 52 | 14.0 | 1.8 | 7.8 | 32.0 | 52 |
| 008 | hay, sun-cured, mature | 1-00-071 | 91 | 2.21 | 1.81 | 0.97 | 0.42 | 50 | 12.9 | 1.3 | 7.5 | 37.7 | 58 |
| 009 | meal dehydrated, 17% protein | 1-00-023 | 92 | 2.69 | 2.21 | 1.34 | 0.77 | 61 | 18.9 | 3.0 | 10.6 | 26.2 | 45 |
| 010 | silage wilted, early bloom | 3-00-216 | 35 | 2.65 | 2.17 | 1.31 | 0.74 | 60 | 17.0 | 3.2 | 8.2 | 28.0 | 43 |
| 011 | silage wilted, midbloom | 3-00-217 | 38 | 2.56 | 2.10 | 1.24 | 0.68 | 58 | 15.5 | 3.1 | 7.9 | 30.0 | 47 |
| 012 | silage wilted, full bloom | 3-00-218 | 45 | 2.43 | 1.99 | 1.14 | 0.58 | 55 | 14.0 | 2.7 | 7.7 | 33.2 | 51 |
| | ALMOND *Prunus amygdalus* | | | | | | | | | | | | |
| 013 | hulls | 4-00-359 | 90 | 2.43 | 1.99 | 1.14 | 0.58 | 55 | 2.1 | 3.0 | 6.5 | 15.0 | 32 |
| | APPLE *Malus* spp | | | | | | | | | | | | |
| 014 | pomace oat hulls added, dehydrated | 4-28-096 | 89 | 2.47 | 2.03 | 1.18 | 0.61 | 56 | 5.1 | 5.2 | 3.5 | 20.0 | — |
| | BAHIAGRASS *Paspalum notatum* | | | | | | | | | | | | |
| 015 | fresh | 2-00-464 | 30 | 2.38 | 1.95 | 1.11 | 0.55 | 54 | 8.9 | 1.6 | 11.1 | 30.4 | 68 |
| 016 | hay, sun-cured | 1-00-462 | 91 | 2.25 | 1.84 | 1.00 | 0.45 | 51 | 8.2 | 2.1 | 6.4 | 32.0 | 72 |
| | BAKERY | | | | | | | | | | | | |
| 017 | waste, dehydrated (dried bakery product) | 4-00-466 | 92 | 3.92 | 3.22 | 2.21 | 1.52 | 89 | 10.7 | 12.7 | 4.4 | 1.3 | — |
| | BARLEY *Hordeum vulgare* | | | | | | | | | | | | |
| 018 | grain | 4-00-549 | 88 | 3.70 | 3.04 | 2.06 | 1.40 | 84 | 13.5 | 2.1 | 2.6 | 5.7 | 19 |
| 019 | grain, pacific coast | 4-07-939 | 89 | 3.79 | 3.11 | 2.12 | 1.45 | 86 | 10.8 | 2.0 | 3.1 | 7.1 | 21 |
| 020 | grain screenings | 4-00-542 | 89 | 3.53 | 2.89 | 1.94 | 1.30 | 80 | 13.1 | 2.6 | 3.4 | 9.6 | — |
| 021 | hay, sun-cured | 1-00-495 | 87 | 2.47 | 2.03 | 1.18 | 0.61 | 56 | 8.7 | 2.1 | 7.6 | 27.5 | — |
| 022 | silage | 3-00-512 | 31 | 2.25 | 1.84 | 1.00 | 0.45 | 51 | 10.3 | 3.9 | 10.2 | 30.0 | — |
| 023 | straw | 1-00-498 | 91 | 1.76 | 1.45 | 0.60 | 0.08 | 40 | 4.3 | 1.9 | 7.1 | 42.0 | 80 |
| | BEAN, NAVY *Phaseolus vulgaris* | | | | | | | | | | | | |
| 024 | seeds | 5-00-623 | 89 | 3.70 | 3.04 | 2.06 | 1.40 | 84 | 25.3 | 1.5 | 5.2 | 5.0 | — |
| | BEET, MANGEL *Beta vulgaris macrorrhiza* | | | | | | | | | | | | |
| 025 | roots, fresh | 4-00-637 | 11 | 3.53 | 2.89 | 1.94 | 1.30 | 80 | 11.8 | 0.7 | 9.6 | 7.4 | — |
| | BEET, SUGAR *Beta vulgaris altissima* | | | | | | | | | | | | |
| 026 | aerial part with crowns, silage | 3-00-660 | 22 | 2.25 | 1.84 | 1.00 | 0.45 | 51 | 13.4 | 2.8 | 32.5 | 13.7 | — |
| | MOLASSES—SEE MOLASSES AND SYRUP | | | | | | | | | | | | |
| 027 | pulp, dehydrated | 4-00-669 | 91 | 3.26 | 2.68 | 1.76 | 1.14 | 74 | 9.7 | 0.6 | 5.4 | 19.8 | 54 |
| 028 | pulp, wet | 4-00-671 | 11 | 3.17 | 2.60 | 1.70 | 1.08 | 72 | 11.2 | 2.1 | 4.7 | 28.1 | — |
| 029 | pulp with molasses, dehydrated | 4-00-672 | 92 | 3.35 | 2.75 | 1.82 | 1.19 | 76 | 10.1 | 0.6 | 6.1 | 16.5 | 44 |
| | BERMUDAGRASS *Cynodon dactylon* | | | | | | | | | | | | |
| 030 | fresh | 2-00-712 | 34 | 2.65 | 2.17 | 1.31 | 0.74 | 60 | 12.0 | 2.2 | 10.2 | 26.4 | — |
| 031 | hay, sun-cured | 1-00-703 | 91 | 2.03 | 1.66 | 0.83 | 0.29 | 46 | 9.8 | 2.0 | 9.2 | 30.4 | — |
| | BERMUDAGRASS, COASTAL *Cynodon dactylon* | | | | | | | | | | | | |
| 032 | fresh | 2-00-719 | 29 | 2.82 | 2.31 | 1.44 | 0.86 | 64 | 15.0 | 3.8 | 6.3 | 28.4 | — |
| 033 | hay, sun-cured | 1-00-716 | 90 | 2.16 | 1.77 | 0.93 | 0.39 | 49 | 6.0 | 2.3 | 6.6 | 30.7 | 78 |
| | BLUEGRASS, CANADA *Poa compressa* | | | | | | | | | | | | |
| 034 | fresh, early vegetative | 2-00-763 | 26 | 3.13 | 2.57 | 1.67 | 1.06 | 71 | 18.7 | 3.7 | 9.1 | 25.5 | — |
| 035 | hay, sun-cured, late vegetative | 1-20-889 | 97 | 2.12 | 1.74 | 0.90 | 0.35 | 48 | — | — | — | — | — |
| | BLUEGRASS, KENTUCKY *Poa pratensis* | | | | | | | | | | | | |
| 036 | fresh, early vegetative | 2-00-777 | 31 | 3.17 | 2.60 | 1.70 | 1.08 | 72 | 17.4 | 3.6 | 9.4 | 25.3 | 55 |
| 037 | fresh, mature | 2-00-784 | 42 | 2.47 | 2.03 | 1.18 | 0.61 | 56 | 9.5 | 3.1 | 6.2 | 32.2 | 69 |
| 038 | hay, sun-cured | 1-00-776 | 89 | 2.47 | 2.03 | 1.18 | 0.61 | 56 | 13.0 | 3.5 | 6.6 | 31.0 | — |
| 039 | hay, sun-cured, full bloom | 1-00-772 | 92 | 2.12 | 1.74 | 0.90 | 0.35 | 48 | 8.9 | 3.3 | 5.9 | 32.5 | — |
| | BLUESTEM *Andropogon* spp | | | | | | | | | | | | |
| 040 | fresh, early vegetative | 2-00-821 | 27 | 3.00 | 2.46 | 1.57 | 0.97 | 68 | 12.8 | 2.8 | 8.9 | 24.9 | — |
| 041 | fresh, mature | 2-00-825 | 59 | 2.34 | 1.92 | 1.07 | 0.52 | 53 | 5.8 | 2.4 | 5.6 | 34.2 | — |
| | BREWERS | | | | | | | | | | | | |
| 042 | grains, dehydrated | 5-02-141 | 92 | 2.91 | 2.39 | 1.51 | 0.91 | 66 | 29.4 | 7.2 | 3.9 | 14.4 | 46 |
| 043 | grains, wet | 5-02-142 | 21 | 2.91 | 2.39 | 1.51 | 0.91 | 66 | 23.2 | 6.5 | 4.8 | 15.3 | 42 |
| | BROME *Bromus* spp | | | | | | | | | | | | |
| 044 | fresh, early vegetative | 2-00-892 | 34 | 3.26 | 2.68 | 1.76 | 1.14 | 74 | 18.0 | 3.7 | 10.7 | 24.0 | 56 |
| 045 | hay, sun-cured, late vegetative | 1-00-887 | 88 | 2.65 | 2.17 | 1.31 | 0.74 | 60 | 16.0 | 2.6 | 9.4 | 30.0 | 65 |
| 046 | hay, sun-cured, late bloom | 1-00-888 | 89 | 2.43 | 1.99 | 1.14 | 0.58 | 55 | 10.0 | 2.3 | 8.4 | 37.0 | 68 |
| | BROME, SMOOTH *Bromus inermis* | | | | | | | | | | | | |
| 047 | fresh, early vegetative | 2-00-956 | 30 | 3.22 | 2.64 | 1.73 | 1.11 | 73 | 21.3 | 4.2 | 10.1 | 22.8 | 49 |
| 048 | fresh, mature | 2-08-364 | 55 | 2.34 | 1.92 | 1.07 | 0.52 | 53 | 6.0 | 2.4 | 6.9 | 34.8 | — |
| 049 | hay, sun-cured, midbloom | 1-05-633 | 90 | 2.47 | 2.03 | 1.18 | 0.61 | 56 | 14.6 | 2.6 | 10.0 | 31.8 | 61 |

| Entry Number | Acid Detergent Fiber (%) | Hemicellulose (%) | Cellulose (%) | Lignin (%) | Calcium (%) | Chlorine (%) | Magnesium (%) | Phosphorus (%) | Potassium (%) | Sodium (%) | Sulfur (%) | Cobalt (mg/kg) | Copper (mg/kg) | Iodine (mg/kg) | Iron (mg/kg) | Manganese (mg/kg) | Selenium (mg/kg) | Zinc (mg/kg) | Carotene (Provitamin A) Vitamin A Activity (1000 IU/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 001 | 29 | 7 | 22 | 7 | 2.19 | 0.44 | 0.27 | 0.33 | 2.14 | 0.21 | 0.48 | 0.17 | 11 | — | 111 | 41 | — | — | — |
| 002 | 31 | 8 | 23 | 7 | 2.33 | — | — | 0.31 | 1.92 | — | — | — | — | — | — | — | — | — | 69.8 |
| 003 | 35 | 10 | 26 | 9 | 2.01 | 0.45 | 0.26 | 0.28 | 2.06 | 0.16 | 0.29 | — | — | — | — | — | — | — | 56.7 |
| 004 | 37 | 13 | 27 | 10 | 1.53 | 0.43 | 0.27 | 0.27 | 2.13 | 0.15 | 0.31 | — | — | — | 430 | 155 | — | — | — |
| 005 | 31 | 9 | 24 | 8 | 1.41 | 0.38 | 0.33 | 0.22 | 2.52 | 0.14 | 0.28 | 0.16 | 11 | — | 192 | 31 | 0.54 | 25 | 56.1 |
| 006 | 35 | 10 | 26 | 9 | 1.41 | 0.38 | 0.31 | 0.24 | 1.71 | 0.12 | 0.28 | 0.36 | 14 | — | 134 | 28 | — | 23 | 13.3 |
| 007 | 39 | 12 | 26 | 12 | 1.43 | — | 0.14 | 0.25 | 2.45 | — | — | — | 14 | — | 170 | 43 | — | 31 | — |
| 008 | 44 | 13 | 29 | 14 | 1.13 | — | 0.27 | 0.18 | 1.78 | 0.08 | 0.25 | 0.09 | 14 | — | 153 | 44 | — | 24 | 4.6 |
| 009 | 35 | — | 24 | 11 | 1.52 | 0.52 | 0.32 | 0.25 | 2.60 | 0.11 | 0.24 | 0.33 | 11 | 0.16 | 441 | 34 | 0.37 | 21 | 52.4 |
| 010 | 33 | 9 | 23 | 10 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 011 | 35 | 10 | 24 | 11 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 012 | 38 | 12 | 25 | 12 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 013 | 28 | — | — | 9 | 0.23 | — | — | 0.11 | 0.53 | — | 0.11 | — | — | — | — | — | — | — | — |
| 014 | 45 | — | — | 14 | 0.13 | — | 0.07 | 0.12 | 0.49 | 0.14 | 0.02 | — | — | — | 299 | 8 | — | — | — |
| 015 | 38 | — | — | 7 | 0.46 | — | 0.25 | 0.22 | 1.45 | — | — | — | — | — | — | — | — | — | 73.0 |
| 016 | 41 | 30 | 32 | 8 | 0.50 | — | 0.19 | 0.22 | — | — | — | — | — | — | 60 | — | — | — | — |
| 017 | 2 | — | — | — | 0.14 | 1.61 | 0.26 | 0.26 | 0.53 | 1.24 | 0.02 | 1.05 | 5 | — | 31 | 71 | — | 16 | 1.9 |
| 018 | 7 | — | 5 | 2 | 0.05 | 0.18 | 0.15 | 0.38 | 0.47 | 0.03 | 0.17 | 0.10 | 9 | 0.05 | 85 | 18 | 0.22 | 19 | 0.9 |
| 019 | 9 | — | — | — | 0.06 | 0.17 | 0.14 | 0.39 | 0.58 | 0.02 | 0.16 | 0.10 | 9 | — | 97 | 18 | 0.11 | 17 | — |
| 020 | — | — | — | — | 0.34 | — | 0.14 | 0.33 | 0.75 | 0.02 | 0.15 | — | — | — | 60 | — | — | — | — |
| 021 | — | — | — | — | 0.23 | — | 0.18 | 0.26 | 1.18 | 0.14 | 0.17 | 0.07 | 24 | — | 101 | 27 | 0.16 | 48 | 21.0 |
| 022 | — | — | — | — | 0.34 | — | 0.13 | 0.28 | 2.01 | 0.01 | 0.11 | 0.67 | 5 | — | 274 | 79 | 0.09 | 22 | 10.2 |
| 023 | 49 | 44 | 37 | 11 | 0.30 | 0.67 | 0.23 | 0.07 | 2.37 | 0.14 | 0.17 | 0.07 | 5 | — | 201 | 17 | — | 7 | 0.9 |
| 024 | — | — | — | — | 0.18 | 0.06 | 0.15 | 0.59 | 1.47 | 0.05 | 0.26 | — | 11 | — | 110 | 24 | — | — | — |
| 025 | — | — | — | — | 0.18 | 1.41 | 0.20 | 0.22 | 2.30 | 0.63 | 0.20 | — | 6 | — | 154 | — | — | — | 0.4 |
| 026 | — | — | — | — | 1.56 | — | 1.07 | 0.29 | 5.74 | 0.54 | 0.57 | — | — | — | 200 | — | — | — | — |
| 027 | 33 | — | — | 2 | 0.69 | 0.04 | 0.27 | 0.10 | 0.20 | 0.21 | 0.22 | 0.08 | 14 | — | 329 | 38 | — | 1 | 0.1 |
| 028 | — | — | — | — | 0.87 | — | 0.22 | 0.10 | 0.19 | 0.19 | 0.22 | — | — | — | 330 | — | — | 1 | — |
| 029 | 25 | — | — | 3 | 0.61 | — | 0.16 | 0.10 | 1.78 | 0.53 | 0.42 | 0.23 | 16 | — | 207 | 27 | — | 2 | 0.1 |
| 030 | — | — | — | — | 0.53 | — | 0.17 | 0.21 | 1.70 | — | — | 0.08 | 6 | — | — | — | — | — | 124.1 |
| 031 | — | — | — | — | 0.47 | — | 0.17 | 0.17 | 1.53 | 0.08 | 0.21 | 0.12 | — | 0.12 | 290 | — | — | — | 23 |
| 032 | — | — | — | — | 0.49 | — | — | 0.27 | — | — | — | — | — | — | — | — | — | — | 132.2 |
| 033 | 38 | — | — | 6 | 0.43 | — | 0.17 | 0.20 | 1.61 | 0.44 | 0.21 | — | — | — | 300 | — | — | 11 | 41.8 |
| 034 | — | — | — | — | 0.39 | — | 0.16 | 0.39 | 2.04 | 0.14 | 0.17 | — | — | — | 300 | — | — | — | 160 |
| 035 | — | — | — | — | 0.30 | — | 0.33 | 0.29 | 1.59 | 0.11 | 0.13 | — | — | — | — | — | — | — | 135.0 |
| 036 | 29 | — | 26 | 3 | 0.50 | — | 0.18 | 0.44 | 2.27 | 0.14 | 0.17 | — | — | — | 300 | — | — | — | 192.8 |
| 037 | 40 | 21 | 34 | 6 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 36.7 |
| 038 | — | — | — | — | 0.33 | 0.53 | 0.16 | 0.25 | 1.69 | 0.13 | 0.16 | — | 10 | — | 293 | 70 | — | — | — |
| 039 | — | — | — | — | 0.26 | — | — | 0.27 | 1.52 | — | — | — | — | — | — | — | — | — | — |
| 040 | — | — | — | — | 0.63 | — | — | 0.20 | 1.72 | — | — | — | 47 | — | 895 | 106 | — | — | 87.7 |
| 041 | — | — | — | — | 0.40 | — | 0.06 | 0.12 | 0.51 | — | — | — | 26 | — | 1075 | 61 | — | — | — |
| 042 | 24 | — | — | 6 | 0.33 | 0.17 | 0.16 | 0.55 | 0.09 | 0.23 | 0.32 | 0.08 | 23 | 0.07 | 266 | 40 | 0.76 | 30 | — |
| 043 | 23 | — | — | 5 | 0.33 | 0.17 | 0.16 | 0.55 | 0.09 | 0.23 | 0.32 | 0.10 | 23 | 0.07 | 266 | 40 | 0.76 | 30 | — |
| 044 | 31 | — | 27 | 3 | 0.50 | — | 0.18 | 0.30 | 2.30 | 0.02 | 0.20 | — | — | — | 200 | — | — | — | 183.8 |
| 045 | 35 | — | 32 | 4 | 0.32 | — | 0.09 | 0.37 | 2.32 | 0.02 | 0.20 | — | — | — | — | — | — | — | 26.0 |
| 046 | 43 | — | 36 | 8 | 0.30 | — | 0.09 | 0.35 | 2.32 | 0.02 | 0.20 | — | — | — | — | — | — | — | 15.0 |
| 047 | 27 | 22 | 20 | 4 | 0.55 | — | 0.32 | 0.45 | 3.16 | — | — | — | — | — | — | — | — | — | 233.2 |
| 048 | — | — | — | — | 0.26 | — | — | 0.16 | — | — | — | — | 2 | — | — | — | — | — | — |
| 049 | 37 | 22 | 31 | 4 | 0.29 | — | 0.10 | 0.28 | 1.99 | 0.01 | — | 0.58 | 25 | — | 91 | 40 | — | 30 | — |

TABLE 8 Composition of Some Beef Cattle Feeds—*Continued*

| Entry Number | Feed Name Description | International Feed Number[a] | Dry Matter (%) | Dry Basis (100% Dry Matter) DE (Mcal/kg) | ME (Mcal/kg) | $NE_m$ (Mcal/kg) | $NE_g$ (Mcal/kg) | TDN (%) | Crude Protein (%) | Ether Extract (%) | Ash (%) | Crude Fiber (%) | Cell Walls (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BUCKWHEAT, COMMON *Fagopyrum sagittatum* | | | | | | | | | | | | |
| 050 | grain | 4-00-994 | 88 | 3.17 | 2.60 | 1.70 | 1.08 | 72 | 12.5 | 2.8 | 2.3 | 11.8 | — |
| | BUFFALOGRASS *Buchloe dactyloides* | | | | | | | | | | | | |
| 051 | fresh | 2-01-010 | 46 | 2.47 | 2.03 | 1.18 | 0.61 | 56 | 10.3 | 1.9 | 12.4 | 26.7 | 74 |
| | CANARYGRASS, REED *Phalaris arundinacea* | | | | | | | | | | | | |
| 052 | fresh | 2-01-113 | 27 | 2.65 | 2.17 | 1.31 | 0.74 | 60 | 11.6 | 3.5 | 8.3 | 29.5 | 46 |
| 053 | hay, sun-cured | 1-01-104 | 91 | 2.43 | 1.99 | 1.14 | 0.58 | 55 | 10.3 | 3.1 | 7.9 | 33.0 | 64 |
| | CARROT *Daucus* spp | | | | | | | | | | | | |
| 054 | roots, fresh | 4-01-145 | 12 | 3.70 | 3.04 | 2.06 | 1.40 | 84 | 9.9 | 1.4 | 8.2 | 9.7 | 9 |
| | CASSAVA, COMMON *Manihot esculenta* | | | | | | | | | | | | |
| 055 | tubers, meal | 4-09-598 | 88 | 3.75 | 3.07 | 2.09 | 1.43 | 85 | 2.6 | 0.8 | 3.3 | 5.2 | — |
| 056 | tubers, fresh | 4-09-599 | 37 | 3.53 | 2.89 | 1.94 | 1.30 | 80 | 3.6 | 1.0 | 3.9 | 4.6 | — |
| | CATTLE *Bos taurus* | | | | | | | | | | | | |
| 057 | manure, dehydrated, all forage | 1-28-274 | 92 | 1.10 | 0.90 | 0.01 | — | 25 | 17.0 | — | — | — | 69 |
| 058 | manure, dehydrated (high concentrate) | 1-28-213 | 92 | 1.90 | 1.56 | 0.72 | 0.18 | 43 | 25.0 | — | 19.8 | — | 32 |
| 059 | manure, dehydrated, forage and concentrate | 1-28-214 | 92 | 1.32 | 1.09 | 0.22 | — | 30 | 17 | 2.8 | 5.4 | 31.4 | 58 |
| | CEREALS | | | | | | | | | | | | |
| 060 | grain screenings | 4-02-156 | 90 | 3.00 | 2.46 | 1.57 | 0.97 | 68 | 13.4 | 4.1 | 6.0 | 13.4 | — |
| 061 | grain screenings refuse | 4-02-151 | 91 | 2.65 | 2.17 | 1.31 | 0.74 | 60 | 14.1 | 4.9 | 9.8 | 18.7 | — |
| 062 | grain screenings, uncleaned | 4-02-153 | 92 | 2.87 | 2.35 | 1.47 | 0.88 | 65 | 15.1 | 5.9 | 9.3 | 18.6 | — |
| | CITRUS *Citrus* spp | | | | | | | | | | | | |
| 063 | pulp, silage | 4-01-234 | 21 | 3.88 | 3.18 | 2.18 | 1.50 | 88 | 7.3 | 9.7 | 5.5 | 15.6 | — |
| 064 | pulp without fines, dehydrated (dried citrus pulp) | 4-01-237 | 91 | 3.62 | 2.97 | 2.00 | 1.35 | 82 | 6.7 | 3.7 | 6.6 | 12.7 | 23 |
| | CLOVER, ALSIKE *Trifolium hybridum* | | | | | | | | | | | | |
| 065 | fresh, early vegetative | 2-01-314 | 19 | 2.91 | 2.39 | 1.51 | 0.91 | 66 | 24.1 | 3.2 | 12.8 | 17.5 | — |
| 066 | hay, sun-cured | 1-01-313 | 88 | 2.56 | 2.10 | 1.24 | 0.68 | 58 | 14.9 | 3.0 | 8.7 | 30.1 | — |
| | CLOVER, CRIMSON *Trifolium incarnatum* | | | | | | | | | | | | |
| 067 | fresh, early vegetative | 2-20-890 | 18 | 2.78 | 2.28 | 1.41 | 0.83 | 63 | 17.0 | — | — | 28.0 | — |
| 068 | hay, sun-cured | 1-01-328 | 87 | 2.51 | 2.06 | 1.21 | 0.64 | 57 | 18.4 | 2.4 | 11.0 | 30.1 | — |
| | CLOVER, LADINO *Trifolium repens* | | | | | | | | | | | | |
| 069 | fresh, early vegetative | 2-01-380 | 19 | 3.00 | 2.46 | 1.57 | 0.97 | 68 | 27.2 | 2.5 | 13.5 | 14.0 | — |
| 070 | hay, sun-cured | 1-01-378 | 90 | 2.65 | 2.17 | 1.31 | 0.74 | 60 | 22.0 | 2.7 | 10.1 | 21.2 | 36 |
| | CLOVER, RED *Trifolium pratense* | | | | | | | | | | | | |
| 071 | fresh, early bloom | 2-01-428 | 20 | 3.04 | 2.50 | 1.60 | 1.00 | 69 | 19.4 | 5.0 | 10.2 | 23.2 | — |
| 072 | fresh, full bloom | 2-01-429 | 26 | 2.82 | 2.31 | 1.44 | 0.86 | 64 | 14.6 | 2.9 | 7.8 | 26.1 | — |
| 073 | fresh, regrowth early vegetative | 2-28-255 | 18 | 3.00 | 2.46 | 1.57 | 0.97 | 68 | 21.0 | — | — | — | — |
| 074 | hay, sun-cured | 1-01-415 | 89 | 2.43 | 1.99 | 1.14 | 0.58 | 55 | 16.0 | 2.8 | 8.5 | 28.8 | 56 |
| | COCONUT *Cocos nucifera* | | | | | | | | | | | | |
| 075 | kernels with coats, meal mechanical extracted (copra meal) | 5-01-572 | 92 | 3.62 | 2.97 | 2.00 | 1.35 | 82 | 22.4 | 6.9 | 7.3 | 12.8 | — |
| 076 | kernels with coats, meal solvent extracted (copra meal) | 5-01-573 | 91 | 3.31 | 2.71 | 1.79 | 1.16 | 75 | 23.4 | 3.9 | 6.6 | 15.4 | — |
| | CORN, DENT YELLOW *Zea mays indentata* | | | | | | | | | | | | |
| 077 | aerial part with ears, sun-cured (fodder) | 1-28-231 | 81 | 2.87 | 2.35 | 1.47 | 0.88 | 65 | 8.9 | 2.4 | 6.8 | 25.2 | 55 |
| 078 | aerial part with ears, sun-cured, mature (fodder) | 1-28-232 | 82 | 3.04 | 2.50 | 1.60 | 1.00 | 69 | 8.0 | 2.3 | 5.4 | 22.6 | — |
| 079 | aerial part without ears, without husks, sun-cured (stover) (straw) | 1-28-233 | 85 | 2.21 | 1.81 | 0.97 | 0.42 | 50 | 6.6 | 1.3 | 7.2 | 34.4 | 67 |
| 080 | cobs, ground | 1-28-234 | 90 | 2.21 | 1.81 | 0.97 | 0.42 | 50 | 3.2 | 0.7 | 1.7 | 36.2 | 89 |
| 081 | distillers grains, dehydrated | 5-28-235 | 94 | 3.79 | 3.11 | 2.12 | 1.45 | 86 | 23.0 | 9.8 | 2.4 | 12.1 | 43 |
| 082 | distillers grains with solubles, dehydrated | 5-28-236 | 92 | 3.88 | 3.18 | 2.18 | 1.50 | 88 | 25.0 | 10.3 | 4.8 | 9.9 | 44 |
| 083 | distillers solubles, dehydrated | 5-28-237 | 93 | 3.88 | 3.18 | 2.18 | 1.50 | 88 | 29.7 | 9.2 | 7.8 | 5.0 | 23 |
| 084 | ears, ground (corn and cob meal) | 4-28-238 | 87 | 3.66 | 3.00 | 2.03 | 1.37 | 83 | 9.0 | 3.7 | 1.9 | 9.4 | — |
| 085 | ears with husks, silage | 4-28-239 | 44 | 3.26 | 2.68 | 1.76 | 1.14 | 74 | 8.9 | 3.8 | 2.8 | 11.6 | — |
| 086 | gluten, meal | 5-28-241 | 91 | 3.79 | 3.11 | 2.12 | 1.45 | 86 | 46.8 | 2.4 | 3.4 | 4.8 | 37 |
| 087 | gluten, meal 60% protein | 5-28-242 | 90 | 3.92 | 3.22 | 2.21 | 1.52 | 89 | 67.2 | 2.4 | 1.8 | 2.2 | 14 |
| 088 | gluten with bran (corn gluten feed) | 5-28-243 | 90 | 3.66 | 3.00 | 2.03 | 1.37 | 83 | 25.6 | 2.4 | 7.5 | 9.7 | — |
| 089 | grain, grade 2, 69.5 kg/hl | 4-02-931 | 88 | 3.97 | 3.25 | 2.24 | 1.55 | 90 | 10.1 | 4.2 | 1.4 | 2.2 | — |
| 090 | grain, flaked | 4-28-244 | 86 | 4.19 | 3.44 | 2.38 | 1.67 | 95 | 11.2 | 2.2 | 1.0 | 0.7 | — |
| 091 | grain, high moisture | 4-20-770 | 72 | 4.10 | 3.36 | 2.33 | 1.62 | 93 | 10.7 | 4.3 | 1.6 | 2.6 | — |
| 092 | grits by-product (hominy feed) | 4-03-011 | 90 | 4.14 | 3.40 | 2.35 | 1.65 | 94 | 11.5 | 7.7 | 3.1 | 6.7 | 55 |

| Entry Number | Acid Detergent Fiber (%) | Hemicellulose (%) | Cellulose (%) | Lignin (%) | Calcium (%) | Chlorine (%) | Magnesium (%) | Phosphorus (%) | Potassium (%) | Sodium (%) | Sulfur (%) | Cobalt (mg/kg) | Copper (mg/kg) | Iodine (mg/kg) | Iron (mg/kg) | Manganese (mg/kg) | Selenium (mg/kg) | Zinc (mg/kg) | Carotene (Provitamin A) Vitamin A Activity (1000 IU/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 050 | — | — | — | — | 0.11 | 0.05 | 0.12 | 0.37 | 0.51 | 0.06 | 0.16 | 0.06 | 11 | — | 50 | 38 | — | 10 | — |
| 051 | 36 | — | — | 6 | 0.57 | — | 0.14 | 0.21 | 0.71 | — | — | — | — | — | — | — | — | — | 37.5 |
| 052 | 28 | 20 | 22 | 4 | 0.41 | — | — | 0.35 | 3.64 | — | — | — | — | — | — | — | — | — | — |
| 053 | 30 | 23 | 26 | 4 | 0.38 | — | 0.29 | 0.25 | 2.76 | 0.14 | — | 0.02 | 12 | — | 150 | 118 | — | — | 10.3 |
| 054 | 8 | — | 7 | 0 | 0.40 | 0.50 | 0.20 | 0.35 | 2.80 | 1.04 | 0.17 | — | 10 | — | 120 | 31 | — | — | 271.0 |
| 055 | — | — | — | — | 0.28 | — | — | 0.19 | 0.26 | — | — | — | — | — | 9 | 20 | — | — | — |
| 056 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 057 | 46 | — | — | 27 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 058 | 26 | — | — | 5 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 059 | 34 | 26 | 30 | 7 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 060 | — | — | — | — | 0.37 | — | 0.14 | 0.39 | 0.34 | 0.45 | — | — | — | — | — | 49 | — | — | — |
| 061 | — | — | — | — | 0.32 | — | 0.24 | 0.37 | 0.20 | 0.28 | 0.33 | — | — | — | 270 | — | 0.72 | — | — |
| 062 | — | — | — | — | 0.40 | — | 0.23 | 0.45 | 0.20 | 0.28 | 0.33 | — | 5 | — | 270 | — | 0.87 | 37 | — |
| 063 | — | — | — | — | 2.04 | — | 0.16 | 0.15 | 0.62 | 0.09 | 0.02 | — | — | — | 160 | — | — | 16 | — |
| 064 | 22 | — | — | 3 | 1.84 | — | 0.17 | 0.12 | 0.79 | 0.09 | 0.08 | 0.16 | 6 | — | 378 | 7 | — | 15 | 0.1 |
| 065 | — | — | — | — | 1.19 | — | 0.34 | 0.42 | 2.31 | — | — | — | — | — | — | — | — | — | 154.0 |
| 066 | — | 13 | — | — | 1.29 | 0.78 | 0.41 | 0.26 | 2.46 | 0.46 | 0.19 | — | 6 | — | 260 | 69 | — | — | 74.8 |
| 067 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 95.0 |
| 068 | — | — | — | — | 1.40 | 0.63 | 0.28 | 0.22 | 2.40 | 0.39 | 0.28 | — | — | 0.07 | 700 | 171 | — | — | 9.0 |
| 069 | — | — | — | — | 1.93 | — | 0.42 | 0.35 | — | 0.12 | 0.16 | — | — | — | — | — | — | — | 141.0 |
| 070 | 32 | — | — | 7 | 1.35 | 0.30 | 0.48 | 0.31 | 2.62 | 0.13 | 0.21 | 0.16 | 10 | 0.30 | 413 | 95 | — | 17 | 33.4 |
| 071 | — | — | — | — | 2.26 | — | 0.51 | 0.38 | 2.49 | 0.20 | 0.17 | — | — | — | 300 | — | — | — | 99.0 |
| 072 | — | — | — | — | 1.01 | — | 0.51 | 0.27 | 1.96 | 0.20 | 0.17 | — | — | — | 300 | — | — | — | 83.0 |
| 073 | — | — | — | — | 1.64 | — | 0.51 | 0.36 | 2.44 | 0.20 | 0.17 | — | — | — | 300 | — | — | — | — |
| 074 | 36 | 9 | 26 | 10 | 1.53 | 0.32 | 0.43 | 0.25 | 1.62 | 0.19 | 0.17 | 0.16 | 11 | 0.25 | 184 | 73 | — | 17 | 7.9 |
| 075 | — | — | — | — | 0.22 | — | 0.33 | 0.66 | 1.62 | 0.04 | 0.36 | 0.14 | 15 | — | 1651 | 71 | — | 53 | — |
| 076 | — | — | — | — | 0.19 | 0.03 | 0.36 | 0.66 | 1.63 | 0.04 | 0.37 | 0.14 | 10 | — | 750 | 72 | — | — | — |
| 077 | 33 | — | 28 | 3 | 0.50 | 0.19 | 0.29 | 0.25 | 0.93 | 0.03 | 0.14 | — | 8 | — | 100 | 68 | — | — | 1.8 |
| 078 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 079 | 39 | — | 25 | 11 | 0.57 | — | 0.40 | 0.10 | 1.45 | 0.07 | 0.17 | — | 5 | — | 210 | 136 | — | — | 1.8 |
| 080 | 35 | — | 28 | 7 | 0.12 | — | 0.07 | 0.04 | 0.87 | 0.47 | 0.47 | 0.13 | 7 | — | 230 | 6 | — | — | 0.3 |
| 081 | — | — | — | — | 0.11 | 0.08 | 0.07 | 0.43 | 0.18 | 0.10 | 0.46 | 0.09 | 48 | 0.05 | 223 | 23 | 0.48 | 35 | 1.3 |
| 082 | 18 | — | 14 | 4 | 0.15 | 0.18 | 0.18 | 0.71 | 0.44 | 0.57 | 0.33 | 0.18 | 58 | — | 259 | 25 | 0.42 | — | 1.4 |
| 083 | 7 | — | 6 | 1 | 0.35 | 0.28 | 0.65 | 1.37 | 1.80 | 0.25 | 0.40 | 0.21 | 89 | 0.12 | 610 | 80 | 0.36 | 92 | 0.3 |
| 084 | — | — | — | — | 0.07 | 0.05 | 0.14 | 0.27 | 0.53 | 0.02 | 0.16 | 0.31 | 8 | 0.03 | 91 | 14 | 0.09 | 14 | 1.5 |
| 085 | — | — | — | — | 0.10 | — | 0.12 | 0.29 | 0.49 | 0.01 | 0.13 | — | — | — | 80 | — | — | — | 3.1 |
| 086 | 9 | — | 8 | 1 | 0.16 | 0.07 | 0.06 | 0.50 | 0.03 | 0.10 | 0.39 | 0.08 | 30 | — | 423 | 8 | 1.11 | 190 | 7.1 |
| 087 | 5 | — | 4 | 1 | 0.08 | 0.10 | 0.09 | 0.54 | 0.21 | 0.06 | 0.72 | 0.05 | 29 | 0.02 | 313 | 7 | 0.92 | 35 | 13.4 |
| 088 | — | — | — | — | 0.36 | 0.25 | 0.36 | 0.82 | 0.64 | 1.05 | 0.23 | 0.10 | 52 | 0.07 | 471 | 26 | 0.30 | 72 | 2.6 |
| 089 | — | — | — | — | 0.02 | 0.05 | 0.13 | 0.35 | 0.37 | 0.02 | 0.14 | 0.04 | 4 | — | 26 | 6 | — | 16 | 0.8 |
| 090 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 091 | 5 | — | — | — | 0.02 | 0.05 | 0.14 | 0.32 | 0.35 | 0.01 | 0.14 | — | 4 | — | 30 | 6 | — | 18 | — |
| 092 | 13 | 17 | 10 | 2 | 0.05 | 0.06 | 0.26 | 0.57 | 0.65 | 0.09 | 0.03 | 0.06 | 15 | 0.07 | 75 | 16 | 0.11 | 3 | 4.1 |

**TABLE 8 Composition of Some Beef Cattle Feeds—*Continued***

| | | | | Dry Basis (100% Dry Matter) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Entry Number | Feed Name Description | International Feed Number[a] | Dry Matter (%) | DE (Mcal/kg) | ME (Mcal/kg) | $NE_m$ (Mcal/kg) | $NE_g$ (Mcal/kg) | TDN (%) | Crude Protein (%) | Ether Extract (%) | Ash (%) | Crude Fiber (%) | Cell Walls (%) |
| 093 | silage, aerial part without ears, without husks (stalklage) (stover) | 3-28-251 | 31 | 2.43 | 1.99 | 1.14 | 0.58 | 55 | 6.3 | 2.1 | 11.6 | 31.3 | 68 |
| 094 | silage, few ears | 3-28-245 | 29 | 2.73 | 2.24 | 1.38 | 0.80 | 62 | 8.4 | 3.0 | 7.2 | 32.3 | — |
| 095 | silage, well eared | 3-28-250 | 33 | 3.09 | 2.53 | 1.63 | 1.03 | 70 | 8.1 | 3.1 | 4.5 | 23.7 | 51 |
| | CORN, SWEET *Zea mays saccharata* | | | | | | | | | | | | |
| 096 | process residue, fresh (cannery residue) | 2-02-975 | 77 | 3.09 | 2.53 | 1.63 | 1.03 | 70 | 8.8 | 2.3 | 3.3 | 22.3 | — |
| 097 | process residue, silage (cannery residue) | 3-07-955 | 32 | 3.17 | 2.60 | 1.70 | 1.08 | 72 | 7.7 | 5.2 | 4.9 | 35.5 | — |
| | COTTON *Gossypium* spp | | | | | | | | | | | | |
| 098 | bolls, sun-cured | 1-01-596 | 92 | 1.94 | 1.59 | 0.75 | 0.22 | 44 | 11.0 | 2.7 | 7.7 | 32.2 | — |
| 099 | hulls | 1-01-599 | 91 | 1.85 | 1.52 | 0.68 | 0.15 | 42 | 4.1 | 1.7 | 2.8 | 47.8 | 90 |
| 100 | seeds | 5-01-614 | 92 | 4.23 | 3.47 | 2.41 | 1.69 | 96 | 23.9 | 23.1 | 4.8 | 20.8 | 39 |
| 101 | seeds, meal mechanical extracted, 41% protein | 5-01-617 | 93 | 3.44 | 2.82 | 1.88 | 1.24 | 78 | 44.3 | 5.0 | 6.6 | 12.8 | 28 |
| 102 | seeds, meal prepressed solvent extracted, 41% protein | 5-07-872 | 91 | 3.53 | 2.89 | 1.94 | 1.30 | 80 | 45.6 | 1.3 | 7.0 | 14.1 | 26 |
| 103 | seeds, meal solvent extracted, 41% protein | 5-01-621 | 91 | 3.35 | 2.75 | 1.82 | 1.19 | 76 | 45.2 | 1.6 | 7.1 | 13.3 | — |
| 104 | seeds without hulls, meal prepressed solvent extracted, 50% protein | 5-07-874 | 93 | 3.31 | 2.71 | 1.79 | 1.16 | 75 | 54.0 | 1.4 | 7.1 | 8.8 | — |
| | COWPEA, COMMON *Vigna sinensis* | | | | | | | | | | | | |
| 105 | hay, sun-cured | 1-01-645 | 90 | 2.60 | 2.13 | 1.28 | 0.71 | 59 | 19.4 | 3.1 | 11.3 | 26.7 | — |
| | DESERT MOLLY—SEE SUMMER-CYPRUS | | | | | | | | | | | | |
| | DISTILLERS GRAINS—SEE CORN, SEE SORGHUM | | | | | | | | | | | | |
| | DROPSEED, SAND *Sporobolus cryptandrus* | | | | | | | | | | | | |
| 106 | fresh, stem cured | 2-05-596 | 88 | 2.60 | 2.13 | 1.28 | 0.71 | 59 | 5.0 | 1.4 | 6.3 | — | — |
| | FATS AND OILS | | | | | | | | | | | | |
| 107 | fat, animal, hydrolyzed | 4-00-376 | 99 | 7.80 | 6.40 | 4.75 | 3.51 | 177 | — | 99.5 | — | — | — |
| 108 | fat, animal-poultry | 4-00-409 | 99 | 7.80 | 6.40 | 4.75 | 3.51 | 177 | — | 100.0 | — | — | — |
| 109 | oil, vegetable | 4-05-077 | 100 | 7.80 | 6.40 | 4.75 | 3.51 | 177 | — | 99.9 | — | — | — |
| | FESCUE *Festuca* spp | | | | | | | | | | | | |
| 110 | hay, sun-cured, early vegetative | 1-06-132 | 91 | 2.69 | 2.21 | 1.34 | 0.77 | 61 | 12.4 | 3.4 | 12.0 | 26.0 | 57 |
| 111 | hay, sun-cured, early bloom | 1-01-871 | 92 | 2.12 | 1.74 | 0.90 | 0.35 | 48 | 9.5 | 2.0 | 10.0 | 37.0 | 72 |
| | FLAX, COMMON *Linum usitatissimum* | | | | | | | | | | | | |
| 112 | seed screenings | 4-02-056 | 91 | 2.82 | 2.31 | 1.44 | 0.86 | 64 | 18.2 | 10.2 | 6.8 | 13.2 | — |
| 113 | seeds, meal mechanical extracted (linseed meal) | 5-02-045 | 91 | 3.62 | 2.97 | 2.00 | 1.35 | 82 | 37.9 | 6.0 | 6.3 | 9.6 | 25 |
| 114 | seeds, meal solvent extracted (linseed meal) | 5-02-048 | 90 | 3.44 | 2.82 | 1.88 | 1.24 | 78 | 38.3 | 1.5 | 6.5 | 10.1 | 25 |
| | GALLETA *Hilaria jamesii* | | | | | | | | | | | | |
| 115 | fresh, stem-cured | 2-05-594 | 71 | 2.12 | 1.74 | 0.90 | 0.35 | 48 | 5.5 | 1.8 | 16.2 | 33.0 | — |
| | GRAMA *Bouteloua* spp | | | | | | | | | | | | |
| 116 | fresh, early vegetative | 2-02-163 | 41 | 2.65 | 2.17 | 1.31 | 0.74 | 60 | 13.1 | 2.0 | 11.3 | 27.2 | — |
| 117 | fresh, mature | 2-02-166 | 63 | 2.43 | 1.99 | 1.14 | 0.58 | 55 | 6.5 | 1.7 | 11.4 | 32.7 | — |
| | GRAPE *Vitis* spp | | | | | | | | | | | | |
| 118 | marc, dehydrated (pomace) | 1-02-208 | 91 | 1.19 | 0.98 | 0.10 | — | 27 | 13.0 | 7.9 | 10.3 | 31.9 | 55 |
| | HEMICELLULOSE EXTRACT (MASONEX) | | | | | | | | | | | | |
| 119 | | 4-08-030 | 76 | 2.65 | 2.17 | 1.31 | 0.74 | 60 | 0.7 | 0.4 | 4.1 | 1.0 | — |
| | LESPEDEZA, COMMON-LESPEDEZA, KOREAN *Lespedeza striata-Lespedeza stipulacea* | | | | | | | | | | | | |
| 120 | fresh, late vegetative | 2-26-028 | 32 | 2.60 | 2.13 | 1.28 | 0.71 | 59 | 16.4 | — | — | 32.0 | — |
| 121 | fresh, early bloom | 2-20-885 | 28 | 2.43 | 1.99 | 1.14 | 0.58 | 55 | 16.4 | — | — | 32.0 | — |
| 122 | hay, sun-cured, early bloom | 1-26-025 | 93 | 2.43 | 1.99 | 1.14 | 0.58 | 55 | 15.5 | — | — | 28.0 | — |
| 123 | hay, sun-cured, midbloom | 1-26-026 | 93 | 2.21 | 1.81 | 0.97 | 0.42 | 50 | 14.5 | — | — | 30.0 | — |
| 124 | hay, sun-cured, full bloom | 1-26-027 | 93 | 2.07 | 1.70 | 0.86 | 0.32 | 47 | 13.4 | — | — | 32.0 | — |
| | LIGNIN SULFONATE, CALCIUM | | | | | | | | | | | | |
| 125 | dehydrated | 8-16-028 | 97 | 0.35 | 0.29 | — | — | 8 | 0.5 | 0.5 | 4.0 | 1.0 | — |
| | LINSEED—SEE FLAX | | | | | | | | | | | | |
| | MEADOW PLANTS, INTERMOUNTAIN | | | | | | | | | | | | |
| 126 | hay, sun-cured | 1-03-181 | 95 | 2.56 | 2.10 | 1.24 | 0.68 | 58 | 8.7 | 2.5 | 8.5 | 32.3 | — |
| | MILLET, FOXTAIL *Setaria italica* | | | | | | | | | | | | |
| 127 | fresh | 2-03-101 | 28 | 2.78 | 2.28 | 1.41 | 0.83 | 63 | 9.5 | 3.1 | 8.7 | 31.6 | — |
| 128 | grain | 4-03-102 | 89 | 3.75 | 3.07 | 2.09 | 1.43 | 85 | 13.5 | 4.6 | 4.0 | 9.3 | — |
| 129 | hay, sun-cured | 1-03-099 | 87 | 2.60 | 2.13 | 1.28 | 0.71 | 59 | 8.6 | 2.9 | 8.6 | 29.6 | — |
| | MILLET, PROSO *Panicum miliaceum* | | | | | | | | | | | | |
| 130 | grain | 4-03-120 | 90 | 3.70 | 3.04 | 2.06 | 1.40 | 84 | 12.9 | 3.9 | 2.9 | 6.8 | — |

| Entry Number | Acid Detergent Fiber (%) | Hemicellulose (%) | Cellulose (%) | Lignin (%) | Calcium (%) | Chlorine (%) | Magnesium (%) | Phosphorus (%) | Potassium (%) | Sodium (%) | Sulfur (%) | Cobalt (mg/kg) | Copper (mg/kg) | Iodine (mg/kg) | Iron (mg/kg) | Manganese (mg/kg) | Selenium (mg/kg) | Zinc (mg/kg) | Carotene (Provitamin A) Vitamin A Activity (1000 IU/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 093 | 55 | — | 47 | 7 | 0.38 | — | 0.31 | 0.31 | 1.54 | 0.03 | 0.11 | — | — | — | — | — | — | — | 6.0 |
| 094 | — | — | — | — | 0.34 | — | 0.23 | 0.19 | 1.41 | — | 0.08 | — | — | — | — | — | — | — | 5.0 |
| 095 | 28 | — | — | — | 0.23 | — | 0.19 | 0.22 | 0.96 | 0.01 | 0.15 | 0.06 | 10 | — | 260 | 30 | — | 21 | 18.0 |
| 096 | — | — | — | — | 0.30 | — | 0.24 | 0.72 | 1.15 | 0.03 | 0.13 | — | 7 | — | 200 | — | — | — | 5.4 |
| 097 | — | — | — | — | 0.30 | — | 0.24 | 0.90 | 1.15 | 0.03 | 0.11 | — | — | — | 200 | — | — | — | 5.4 |
| 098 | — | — | — | — | 0.90 | — | 0.28 | 0.12 | 2.73 | — | — | — | — | — | — | — | — | — | — |
| 099 | 64 | — | 40 | 24 | 0.15 | 0.02 | 0.14 | 0.09 | 0.87 | 0.02 | 0.09 | 0.02 | 13 | — | 131 | 119 | — | 22 | — |
| 100 | 29 | — | — | — | 0.16 | — | 0.35 | 0.75 | 1.21 | 0.31 | 0.26 | — | 54 | — | 151 | 10 | — | — | — |
| 101 | 20 | — | 13 | 6 | 0.21 | 0.05 | 0.58 | 1.16 | 1.45 | 0.05 | 0.43 | 0.17 | 20 | — | 197 | 24 | — | 69 | 0.1 |
| 102 | 19 | — | 12 | 6 | 0.22 | 0.04 | 0.55 | 1.21 | 1.39 | 0.04 | 0.34 | 0.82 | 20 | — | 223 | 23 | — | 69 | — |
| 103 | 17 | — | 12 | — | 0.18 | 0.05 | 0.59 | 1.21 | 1.52 | 0.05 | 0.28 | 0.17 | 22 | — | 228 | 23 | — | 68 | — |
| 104 | — | — | — | — | 0.19 | 0.05 | 0.50 | 1.24 | 1.56 | 0.06 | 0.56 | 0.05 | 16 | — | 120 | 25 | — | 79 | — |
| 105 | — | — | — | — | 1.40 | 0.17 | 0.45 | 0.35 | 2.26 | 0.27 | 0.35 | 0.07 | — | — | 300 | — | — | — | 14.0 |
| 106 | — | — | — | 6 | 0.57 | — | 0.06 | 0.06 | 0.32 | 0.01 | — | 0.57 | 15 | 0.68 | 482 | 47 | — | 42 | 0.4 |
| 107 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 108 | — | — | — | — | — | — | — | — | 0.23 | — | — | — | — | — | — | — | — | — | — |
| 109 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 110 | 32 | — | 28 | 3 | 0.51 | — | 0.22 | 0.36 | 2.30 | — | — | — | — | — | — | — | — | — | — |
| 111 | 39 | — | 33 | 5 | 0.30 | — | 0.19 | 0.26 | 1.70 | — | — | — | — | — | — | — | — | — | — |
| 112 | — | — | — | — | 0.37 | — | 0.43 | 0.47 | 0.84 | — | 0.25 | — | — | — | 100 | — | — | — | — |
| 113 | 17 | — | — | 7 | 0.45 | 0.04 | 0.64 | 0.96 | 1.34 | 0.12 | 0.41 | 0.46 | 29 | 0.07 | 194 | 42 | 0.89 | 36 | 0.1 |
| 114 | 19 | — | — | 6 | 0.43 | 0.04 | 0.66 | 0.89 | 1.53 | 0.15 | 0.43 | 0.21 | 29 | — | 354 | 42 | 0.91 | — | — |
| 115 | — | — | — | — | 1.05 | — | 0.10 | 0.07 | 1.00 | 0.01 | 0.10 | 0.69 | 19 | — | 100 | 79 | — | 23 | 0.1 |
| 116 | — | — | — | — | 0.53 | — | — | 0.19 | — | — | — | — | 6 | — | — | 44 | — | — | — |
| 117 | — | — | — | — | 0.34 | — | — | 0.12 | 0.35 | — | — | 0.18 | 13 | — | 1300 | 47 | — | — | 12.2 |
| 118 | 54 | — | — | 35, | 0.61 | 0.01 | — | 0.06 | 0.62 | 0.09 | — | — | — | — | — | 41 | — | 24 | — |
| 119 | — | — | — | — | 1.03 | — | — | 0.09 | — | — | — | — | — | — | — | — | — | — | — |
| 120 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 103.0 |
| 121 | — | — | — | — | 1.35 | — | 0.27 | 0.21 | 1.12 | — | — | — | — | — | 250 | — | — | — | — |
| 122 | — | — | — | — | 1.23 | — | 0.26 | 0.25 | 1.00 | — | — | 0.04 | 0 | — | 400 | 256 | — | — | 55.0 |
| 123 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 22.0 |
| 124 | — | — | — | — | — | — | 0.24 | — | — | — | — | — | — | — | — | — | — | — | 5.0 |
| 125 | — | — | — | 76 | 3.75 | — | — | 0.07 | — | — | 4.50 | — | — | — | — | — | — | — | — |
| 126 | — | — | — | — | 0.61 | — | 0.17 | 0.18 | 1.58 | 0.12 | — | — | — | — | — | — | — | — | 13.4 |
| 127 | — | — | — | — | 0.32 | — | — | 0.19 | 1.94 | — | — | — | — | — | — | — | — | — | — |
| 128 | — | — | — | — | — | — | — | 0.22 | 0.35 | — | — | — | — | — | — | — | — | — | — |
| 129 | — | — | — | — | 0.33 | 0.13 | 0.23 | 0.19 | 1.94 | 0.10 | 0.16 | — | — | — | — | 136 | — | — | 24.0 |
| 130 | 17 | — | — | 4 | 0.03 | — | 0.18 | 0.34 | 0.48 | — | — | — | — | — | 79 | — | — | — | — |

TABLE 8 Composition of Some Beef Cattle Feeds—*Continued*

| | | | | Dry Basis (100% Dry Matter) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Entry Number | Feed Name Description | International Feed Number[a] | Dry Matter (%) | DE (Mcal/kg) | ME (Mcal/kg) | $NE_m$ (Mcal/kg) | $NE_g$ (Mcal/kg) | TDN (%) | Crude Protein (%) | Ether Extract (%) | Ash (%) | Crude Fiber (%) | Cell Walls (%) |
| | MOLASSES AND SYRUP *Beta vulgaris altissima* | | | | | | | | | | | | |
| 131 | beet, sugar, molasses, more than 48% invert sugar, more than 79.5 degrees brix | 4-00-668 | 78 | 3.48 | 2.86 | 1.91 | 1.27 | 79 | 8.5 | 0.2 | 11.3 | — | — |
| | MOLASSES AND SYRUP *Citrus* spp | | | | | | | | | | | | |
| 132 | citrus, syrup (citrus molasses) | 4-01-241 | 68 | 3.31 | 2.71 | 1.79 | 1.16 | 75 | 8.2 | 0.3 | 7.9 | — | — |
| | MOLASSES AND SYRUP *Saccharum officinarum* | | | | | | | | | | | | |
| 133 | sugarcane, molasses, dehydrated | 4-04-695 | 94 | 3.09 | 2.53 | 1.63 | 1.03 | 70 | 10.3 | 0.9 | 13.3 | 6.7 | — |
| 134 | sugarcane, molasses, more than 46% invert sugars, more than 79.5 degrees brix (black strap) | 4-04-696 | 75 | 3.17 | 2.60 | 1.70 | 1.08 | 72 | 5.8 | 0.1 | 13.1 | 0.5 | — |
| | NAPIERGRASS *Pennisetum purpureum* | | | | | | | | | | | | |
| 135 | fresh, late vegetative | 2-03-158 | 20 | 2.43 | 1.99 | 1.14 | 0.58 | 55 | 8.7 | 3.0 | 8.6 | 33.0 | 70 |
| 136 | fresh, late bloom | 2-03-162 | 23 | 2.34 | 1.92 | 1.07 | 0.52 | 53 | 7.8 | 1.1 | 5.3 | 39.0 | 75 |
| | NEEDLEANDTHREAD *Stipa comata* | | | | | | | | | | | | |
| 137 | fresh, stem cured | 2-07-989 | 92 | 2.16 | 1.77 | 0.93 | 0.39 | 49 | 4.1 | 5.4 | 21.1 | — | 83 |
| | OATS *Avena sativa* | | | | | | | | | | | | |
| 138 | grain | 4-03-309 | 89 | 3.40 | 2.78 | 1.85 | 1.22 | 77 | 13.3 | 5.4 | 3.4 | 12.1 | 32 |
| 139 | grain, pacific coast | 4-07-999 | 91 | 3.44 | 2.82 | 1.88 | 1.24 | 78 | 10.0 | 5.5 | 4.2 | 12.3 | — |
| 140 | groats | 4-03-331 | 90 | 4.14 | 3.40 | 2.35 | 1.65 | 94 | 17.7 | 6.9 | 2.4 | 2.8 | — |
| 141 | hay, sun-cured | 1-03-280 | 91 | 2.43 | 1.99 | 1.14 | 0.58 | 55 | 9.3 | 2.6 | 7.6 | 30.4 | 66 |
| 142 | hulls | 1-03-281 | 92 | 1.54 | 1.27 | 0.41 | — | 35 | 3.9 | 1.8 | 6.6 | 33.4 | 78 |
| 143 | silage, late vegetative | 3-20-898 | 23 | 2.87 | 2.35 | 1.47 | 0.88 | 65 | 12.8 | 2.5 | 6.5 | 29.9 | 58 |
| 144 | silage, dough stage | 3-03-296 | 35 | 2.51 | 2.06 | 1.21 | 0.64 | 57 | 10.0 | 4.1 | 6.9 | 33.0 | — |
| 145 | straw | 1-03-283 | 92 | 1.98 | 1.63 | 0.79 | 0.25 | 45 | 4.4 | 2.2 | 7.8 | 40.5 | 70 |
| | ORCHARDGRASS *Dactylis glomerata* | | | | | | | | | | | | |
| 146 | fresh, early vegetative | 2-03-439 | 23 | 3.17 | 2.60 | 1.70 | 1.08 | 72 | 18.4 | 4.9 | 11.3 | 24.7 | 55 |
| 147 | fresh, midbloom | 2-03-443 | 31 | 2.51 | 2.06 | 1.21 | 0.64 | 57 | 11.0 | 3.5 | 7.5 | 33.5 | 68 |
| 148 | hay, sun-cured, early bloom | 1-03-425 | 89 | 2.87 | 2.35 | 1.47 | 0.88 | 65 | 15.0 | 2.8 | 8.7 | 31.0 | 61 |
| 149 | hay, sun-cured, late bloom | 1-03-428 | 91 | 2.38 | 1.95 | 1.11 | 0.55 | 54 | 8.4 | 3.4 | 10.1 | 37.1 | 72 |
| | PANGOLAGRASS *Digitaria decumbens* | | | | | | | | | | | | |
| 150 | fresh | 2-03-493 | 21 | 2.43 | 1.99 | 1.14 | 0.58 | 55 | 10.3 | 2.3 | 9.6 | 30.5 | — |
| 151 | hay, sun-cured, 15 to 28 days' growth | 1-10-638 | 91 | 2.25 | 1.84 | 1.00 | 0.45 | 51 | 11.5 | 2.2 | 8.5 | 34.0 | 70 |
| 152 | hay, sun-cured, 29 to 42 days' growth | 1-26-214 | 91 | 1.98 | 1.63 | 0.79 | 0.25 | 45 | 7.1 | 2.0 | 8.0 | 36.0 | 73 |
| 153 | hay, sun-cured, 43 to 56 days' growth | 1-29-573 | 91 | 1.76 | 1.45 | 0.60 | 0.08 | 40 | 5.5 | 2.0 | 7.6 | 38.0 | 77 |
| | PEA *Pisum* spp | | | | | | | | | | | | |
| 154 | seeds | 5-03-600 | 89 | 3.84 | 3.15 | 2.15 | 1.48 | 87 | 25.3 | 1.4 | 3.3 | 6.9 | — |
| 155 | straw | 1-03-577 | 87 | 2.03 | 1.66 | 0.83 | 0.29 | 46 | 8.9 | 1.8 | 6.5 | 39.5 | — |
| 156 | vines without seeds, silage | 3-03-596 | 25 | 2.51 | 2.06 | 1.21 | 0.64 | 57 | 13.1 | 3.3 | 9.0 | 29.8 | 59 |
| | PEANUT *Arachis hypogaea* | | | | | | | | | | | | |
| 157 | hay, sun-cured | 1-03-619 | 91 | 2.43 | 1.99 | 1.14 | 0.58 | 55 | 10.8 | 3.4 | 8.6 | 33.2 | — |
| 158 | hulls (pods) | 1-08-028 | 91 | 0.97 | 0.80 | — | — | 22 | 7.8 | 2.0 | 4.2 | 62.9 | 74 |
| 159 | kernels, meal mechanical extracted (peanut meal) | 5-03-649 | 93 | 3.66 | 3.00 | 2.03 | 1.37 | 83 | 52.0 | 6.3 | 5.5 | 7.5 | 14 |
| 160 | kernels, meal solvent extracted (peanut meal) | 5-03-650 | 92 | 3.40 | 2.78 | 1.85 | 1.22 | 77 | 52.3 | 1.4 | 6.3 | 10.8 | — |
| | PEARLMILLET *Pennisetum glaucum* | | | | | | | | | | | | |
| 161 | fresh | 2-03-115 | 21 | 2.69 | 2.21 | 1.34 | 0.77 | 61 | 8.5 | 2.2 | 10.0 | 31.5 | — |
| | PINEAPPLE *Ananas comosus* | | | | | | | | | | | | |
| 162 | aerial part without fruit, sun-cured (pineapple hay) | 1-13-309 | 89 | 2.69 | 2.21 | 1.34 | 0.77 | 61 | 7.8 | 2.8 | 6.1 | 29.6 | — |
| 163 | process residue, dehydrated (pineapple bran) | 4-03-722 | 87 | 3.00 | 2.46 | 1.57 | 0.97 | 68 | 4.6 | 1.5 | 3.5 | 20.9 | 73 |
| | POTATO *Solanum tuberosum* | | | | | | | | | | | | |
| 164 | process residue, dehydrated | 4-03-775 | 89 | 3.97 | 3.25 | 2.24 | 1.55 | 90 | 8.4 | 0.4 | 3.4 | 7.3 | — |
| 165 | tubers, fresh | 4-03-787 | 23 | 3.57 | 2.93 | 1.97 | 1.32 | 81 | 9.5 | 0.4 | 4.8 | 2.4 | — |
| 166 | tubers, silage | 4-03-768 | 25 | 3.62 | 2.97 | 2.00 | 1.35 | 82 | 7.6 | 0.4 | 5.5 | 4 | — |
| | POULTRY | | | | | | | | | | | | |
| 167 | feathers, hydrolyzed | 5-03-795 | 93 | 3.09 | 2.53 | 1.63 | 1.03 | 70 | 91.3 | 3.2 | 3.8 | 1.5 | — |
| 168 | manure, dehydrated | 5-14-015 | 90 | 2.29 | 1.88 | 1.04 | 0.49 | 52 | 28.2 | 2.4 | 30.1 | 13.2 | 38 |
| 169 | manure and litter, dehydrated | 5-05-587 | 89 | 2.91 | 2.39 | 1.51 | 0.91 | 66 | 24.5 | 3.0 | 22.0 | 16.1 | — |
| | PRAIRIE PLANTS, MIDWEST | | | | | | | | | | | | |
| 170 | hay, sun-cured | 1-03-191 | 92 | 2.25 | 1.84 | 1.00 | 0.45 | 51 | 5.8 | 2.4 | 7.1 | 34.0 | — |
| | RAPE *Brassica napus* | | | | | | | | | | | | |
| 171 | fresh, early bloom | 2-03-866 | 11 | 3.31 | 2.71 | 1.79 | 1.16 | 75 | 23.5 | 3.8 | 14.0 | 15.8 | — |
| 172 | seeds, meal mechanical extracted | 5-03-870 | 92 | 3.35 | 2.75 | 1.82 | 1.19 | 76 | 38.7 | 7.9 | 7.5 | 13.1 | — |
| 173 | seeds, meal solvent extracted | 5-03-871 | 91 | 3.04 | 2.50 | 1.60 | 1.00 | 69 | 40.6 | 1.8 | 7.5 | 13.2 | — |

| Entry Number | Acid Detergent Fiber (%) | Hemicellulose (%) | Cellulose (%) | Lignin (%) | Calcium (%) | Chlorine (%) | Magnesium (%) | Phosphorus (%) | Potassium (%) | Sodium (%) | Sulfur (%) | Cobalt (mg/kg) | Copper (mg/kg) | Iodine (mg/kg) | Iron (mg/kg) | Manganese (mg/kg) | Selenium (mg/kg) | Zinc (mg/kg) | Carotene (Provitamin A) Vitamin A Activity (1000 IU/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 131 | — | — | — | — | 0.17 | 1.64 | 0.29 | 0.03 | 6.07 | 1.48 | 0.60 | 0.46 | 22 | — | 87 | 6 | — | 18 | — |
| 132 | — | — | — | — | 1.72 | 0.11 | 0.21 | 0.13 | 0.14 | 0.41 | 0.23 | 0.16 | 108 | — | 508 | 38 | — | 137 | — |
| 133 | — | — | — | — | 1.10 | — | 0.47 | 0.15 | 3.60 | 0.20 | 0.46 | 1.21 | 79 | 2.10 | 250 | 57 | — | 33 | — |
| 134 | 0 | — | — | 0 | 1.00 | 3.10 | 0.43 | 0.11 | 3.84 | 0.22 | 0.47 | 1.21 | 79 | 2.10 | 250 | 56 | — | 30 | — |
| 135 | 45 | — | 33 | 10 | 0.60 | — | 0.26 | 0.41 | 1.31 | 0.01 | 0.10 | — | — | — | — | — | — | — | — |
| 136 | 47 | — | 35 | 14 | 0.35 | — | 0.26 | 0.30 | 1.31 | 0.01 | 0.10 | — | — | — | — | — | — | — | — |
| 137 | 43 | 40 | 36 | 6 | 1.08 | — | — | 0.06 | — | — | — | — | — | — | — | — | — | — | — |
| 138 | 16 | 15 | 11 | 3 | 0.07 | 0.11 | 0.14 | 0.38 | 0.44 | 0.08 | 0.23 | 0.06 | 7 | 0.11 | 85 | 42 | 0.26 | 41 | 0.0 |
| 139 | — | — | — | — | 0.11 | 0.13 | 0.19 | 0.34 | 0.42 | 0.07 | 0.22 | — | — | — | 80 | 42 | 0.08 | — | — |
| 140 | — | — | — | — | 0.08 | 0.09 | 0.13 | 0.48 | 0.39 | 0.06 | 0.22 | — | 7 | 0.12 | 82 | 31 | — | 0 | — |
| 141 | 36 | 26 | — | 6 | 0.24 | 0.52 | 0.26 | 0.22 | 1.51 | 0.18 | 0.25 | 0.07 | 15 | — | 155 | 64 | 0.17 | 39 | 11.1 |
| 142 | 42 | — | 30 | 8 | 0.15 | 0.08 | 0.09 | 0.15 | 0.62 | 0.04 | 0.15 | — | 4 | — | 111 | 20 | — | — | — |
| 143 | — | — | — | — | — | — | — | 0.10 | 2.44 | 0.37 | 0.24 | — | — | — | — | — | — | — | 65.0 |
| 144 | — | — | — | — | 0.47 | — | — | 0.33 | — | — | — | — | — | — | — | — | — | — | 24.0 |
| 145 | 54 | — | 40 | 14 | 0.24 | 0.78 | 0.18 | 0.06 | 2.57 | 0.42 | 0.23 | — | 10 | — | 175 | 37 | — | 6 | 1.5 |
| 146 | 31 | 24 | 25 | 3 | 0.58 | 0.08 | 0.31 | 0.54 | 3.58 | 0.04 | 0.21 | — | 7 | — | 169 | 96 | — | — | 192.8 |
| 147 | 41 | 27 | 33 | 6 | 0.23 | — | — | 0.23 | — | — | — | — | — | — | — | — | — | — | — |
| 148 | 34 | 27 | 29 | 5 | 0.27 | — | 0.11 | 0.34 | 2.91 | 0.01 | — | 0.43 | 19 | — | 93 | 158 | — | 40 | 15.0 |
| 149 | 45 | 27 | 39 | 9 | 0.26 | — | 0.11 | 0.30 | 2.67 | 0.01 | — | 0.30 | 20 | — | 84 | 168 | — | 38 | 8.0 |
| 150 | 38 | — | 35 | 5 | 0.43 | — | 0.14 | 0.18 | 1.43 | — | — | — | — | — | — | — | — | — | 24.8 |
| 151 | 41 | — | 33 | 6 | 0.58 | — | 0.20 | 0.21 | 1.70 | — | — | — | — | — | — | — | — | — | — |
| 152 | 43 | — | 35 | 6 | 0.46 | — | 0.15 | 0.23 | 1.40 | — | — | — | — | — | — | — | — | — | — |
| 153 | 46 | — | 37 | 7 | 0.38 | — | 0.14 | 0.18 | 1.10 | — | — | — | — | — | — | — | — | — | — |
| 154 | — | — | — | — | 0.15 | 0.06 | 0.14 | 0.44 | 1.13 | 0.05 | — | — | — | — | 57 | — | — | 33 | 0.3 |
| 155 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 156 | 49 | — | 34 | 9 | 1.31 | — | 0.39 | 0.24 | 1.40 | 0.01 | 0.25 | — | — | — | 100 | — | — | — | 75.6 |
| 157 | — | — | — | — | 1.23 | — | 0.49 | 0.15 | 1.38 | — | 0.23 | 0.08 | — | — | — | — | — | — | 13.9 |
| 158 | 65 | — | 40 | 23 | 0.26 | — | 0.17 | 0.07 | 0.95 | 0.13 | 0.10 | 0.12 | 18 | — | 312 | 69 | — | 24 | 0.4 |
| 159 | 6 | — | 5 | — | 0.20 | 0.03 | 0.31 | 0.61 | 1.25 | 0.23 | 0.29 | 0.12 | 16 | 0.07 | 169 | 28 | 0.31 | 22 | 0.1 |
| 160 | — | — | — | — | 0.29 | 0.03 | 0.17 | 0.68 | 1.23 | 0.08 | 0.33 | 0.12 | 17 | 0.07 | 154 | 29 | — | 22 | — |
| 161 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 73.0 |
| 162 | — | — | — | — | 0.39 | — | — | 0.23 | — | — | — | — | — | — | — | — | — | — | — |
| 163 | 37 | — | — | 7 | 0.23 | — | — | 0.13 | — | — | — | — | — | — | 561 | — | — | — | 21.6 |
| 164 | — | — | — | — | 0.16 | — | — | 0.25 | — | — | — | — | — | — | — | — | — | — | — |
| 165 | — | — | — | — | 0.04 | 0.28 | 0.14 | 0.24 | 2.17 | 0.09 | 0.09 | — | 28 | — | 78 | 42 | — | — | — |
| 166 | — | — | — | — | 0.04 | — | 0.14 | 0.23 | 2.13 | 0.09 | 0.23 | — | — | — | 90 | — | — | — | — |
| 167 | — | — | — | — | 0.28 | 0.30 | 0.22 | 0.72 | 0.31 | 0.76 | 1.61 | 0.05 | 7 | 0.05 | 81 | 14 | 0.90 | 74 | — |
| 168 | 15 | — | — | 2 | 9.31 | 0.95 | 0.64 | 2.52 | 2.25 | 0.74 | 0.18 | 0.00 | 89 | — | 2000 | 406 | — | 434 | — |
| 169 | — | — | — | 9 | 3.16 | — | 0.50 | 1.78 | 1.68 | 0.51 | 1.26 | — | 192 | — | 778 | 289 | 0.79 | 444 | — |
| 170 | — | — | — | — | 0.43 | 0.06 | 0.29 | 0.15 | 1.08 | 0.04 | — | 0.13 | 7 | — | 129 | 110 | — | 34 | 9.8 |
| 171 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 172 | — | — | — | — | 0.72 | — | 0.54 | 1.14 | 0.90 | 0.50 | — | — | 7 | — | 190 | 60 | 1.04 | 47 | — |
| 173 | — | — | — | — | 0.67 | 0.11 | 0.60 | 1.04 | 1.36 | 0.10 | 1.25 | — | — | — | — | — | 1.07 | — | — |

**TABLE 8 Composition of Some Beef Cattle Feeds—*Continued***

| | | | | Dry Basis (100% Dry Matter) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Entry Number | Feed Name Description | International Feed Number[a] | Dry Matter (%) | DE (Mcal/kg) | ME (Mcal/kg) | $NE_m$ (Mcal/kg) | $NE_g$ (Mcal/kg) | TDN (%) | Crude Protein (%) | Ether Extract (%) | Ash (%) | Crude Fiber (%) | Cell Walls (%) |
| | REDTOP *Agrostis alba* | | | | | | | | | | | | |
| 174 | fresh | 2-03-897 | 29 | 2.78 | 2.28 | 1.41 | 0.83 | 63 | 11.6 | 3.9 | 8.1 | 26.7 | 64 |
| 175 | hay, sun-cured, midbloom | 1-03-886 | 94 | 2.51 | 2.06 | 1.21 | 0.64 | 57 | 11.7 | 2.6 | 6.5 | 30.7 | — |
| | RICE *Oryza sativa* | | | | | | | | | | | | |
| 176 | bran with germs (rice, bran) | 4-03-928 | 91 | 3.09 | 2.53 | 1.63 | 1.03 | 70 | 14.1 | 15.1 | 12.8 | 12.8 | 33 |
| 177 | grain, ground (ground rough rice) (ground paddy rice) | 4-03-938 | 89 | 3.48 | 2.86 | 1.91 | 1.27 | 79 | 8.9 | 1.9 | 5.3 | 10.0 | — |
| 178 | hulls | 1-08-075 | 92 | 0.53 | 0.43 | — | — | 12 | 3.3 | 0.8 | 20.6 | 42.9 | 82 |
| 179 | straw | 1-03-925 | 91 | 1.81 | 1.48 | 0.64 | 0.11 | 41 | 4.3 | 1.4 | 17.0 | 35.1 | 71 |
| | RYE *Secale cereale* | | | | | | | | | | | | |
| 180 | distillers grains, dehydrated | 5-04-023 | 92 | 2.69 | 2.21 | 1.34 | 0.77 | 61 | 23.5 | 7.8 | 2.5 | 13.4 | — |
| 181 | fresh | 2-04-018 | 24 | 3.04 | 2.50 | 1.60 | 1.00 | 69 | 15.9 | 3.7 | 8.1 | 28.5 | — |
| 182 | grain | 4-04-047 | 88 | 3.70 | 3.04 | 2.06 | 1.40 | 84 | 13.8 | 1.7 | 1.9 | 2.5 | — |
| 183 | mill run, less than 9.5% fiber (rye feed) | 4-04-034 | 90 | 3.31 | 2.71 | 1.79 | 1.16 | 75 | 18.5 | 3.7 | 4.2 | 5.1 | — |
| 184 | straw | 1-04-007 | 90 | 1.37 | 1.12 | 0.26 | — | 31 | 3.0 | 1.7 | 5.0 | 43.1 | — |
| | RYEGRASS, ITALIAN *Lolium multiflorum* | | | | | | | | | | | | |
| 185 | fresh | 2-04-073 | 25 | 2.65 | 2.17 | 1.31 | 0.74 | 60 | 14.5 | 3.2 | 14.0 | 23.8 | — |
| 186 | hay, sun-cured, late vegetative | 1-04-065 | 86 | 2.73 | 2.24 | 1.38 | 0.80 | 62 | 10.3 | 2.4 | 11.0 | 23.8 | — |
| 187 | hay, sun-cured, early bloom | 1-04-066 | 83 | 2.38 | 1.95 | 1.11 | 0.55 | 54 | 5.5 | 0.9 | 8.4 | 36.3 | — |
| | RYEGRASS, PERENNIAL *Lolium perenne* | | | | | | | | | | | | |
| 188 | fresh | 2-04-086 | 27 | 3.00 | 2.46 | 1.57 | 0.97 | 68 | 10.4 | 2.7 | 8.6 | 23.2 | — |
| 189 | hay, sun-cured | 1-04-077 | 86 | 2.65 | 2.17 | 1.31 | 0.74 | 60 | 8.6 | 2.2 | 11.5 | 30.3 | 41 |
| | SAFFLOWER *Carthamus tinctorius* | | | | | | | | | | | | |
| 190 | seeds | 4-07-958 | 94 | 3.92 | 3.22 | 2.21 | 1.52 | 89 | 17.4 | 35.1 | 3.1 | 28.6 | — |
| 191 | seeds, meal mechanical extracted | 5-04-109 | 91 | 2.65 | 2.17 | 1.31 | 0.74 | 60 | 22.1 | 6.7 | 4.1 | 35.4 | 59 |
| 192 | seeds, meal solvent extracted | 5-04-110 | 92 | 2.51 | 2.06 | 1.21 | 0.64 | 57 | 25.4 | 1.5 | 5.9 | 32.5 | 58 |
| 193 | seeds without hulls, meal solvent extracted | 5-07-959 | 92 | 3.22 | 2.64 | 1.73 | 1.11 | 73 | 46.9 | 1.4 | 8.2 | 14.7 | — |
| | SAGE, BLACK *Salvia mellifera* | | | | | | | | | | | | |
| 194 | browse, fresh, stem-cured | 2-05-564 | 65 | 2.16 | 1.77 | 0.93 | 0.39 | 49 | 8.5 | 10.8 | 5.5 | — | — |
| | SAGEBRUSH, BIG *Artemisia tridentata* | | | | | | | | | | | | |
| 195 | browse, fresh, stem-cured | 2-07-992 | 65 | 2.21 | 1.81 | 0.97 | 0.42 | 50 | 9.3 | 11.0 | 6.6 | — | 42 |
| | SAGEBRUSH, BUD *Artemisia spinescens* | | | | | | | | | | | | |
| 196 | browse, fresh, early vegetative | 2-07-991 | 23 | 2.25 | 1.84 | 1.00 | 0.45 | 51 | 17.3 | 4.9 | 21.4 | — | — |
| 197 | browse, fresh, late vegetative | 2-04-124 | 32 | 2.29 | 1.88 | 1.04 | 0.49 | 52 | 17.5 | 2.5 | 21.6 | 22.7 | — |
| | SAGEBRUSH, FRINGED *Artemisia frigida* | | | | | | | | | | | | |
| 198 | browse, fresh, midbloom | 2-04-129 | 43 | 2.56 | 2.10 | 1.24 | 0.68 | 58 | 9.4 | 2.0 | 6.5 | 33.2 | — |
| 199 | browse, fresh, mature | 2-04-130 | 60 | 2.25 | 1.84 | 1.00 | 0.45 | 51 | 7.1 | 3.4 | 17.1 | 31.8 | 46 |
| | SALTBUSH, NUTTALL *Atriplex nuttallii* | | | | | | | | | | | | |
| 200 | browse, fresh, stem-cured | 2-07-993 | 55 | 1.59 | 1.30 | 0.45 | — | 36 | 7.2 | 2.2 | 21.5 | — | — |
| | SALTGRASS *Distichlis* spp | | | | | | | | | | | | |
| 201 | fresh, post ripe | 2-04-169 | 74 | 2.34 | 1.92 | 1.07 | 0.52 | 53 | 4.2 | 2.6 | 7.3 | 34.9 | — |
| 202 | hay, sun-cured | 1-04-168 | 89 | 2.25 | 1.84 | 1.00 | 0.45 | 51 | 8.9 | 2.1 | 12.7 | 31.6 | — |
| | SEAWEED, KELP *Laminariales (order)-fucales (order)* | | | | | | | | | | | | |
| 203 | whole, dehydrated | 4-08-073 | 91 | 1.41 | 1.16 | 0.30 | — | 32 | 7.1 | 0.5 | 38.6 | 7.1 | — |
| | SEDGE *Carex* spp | | | | | | | | | | | | |
| 204 | hay, sun-cured | 1-04-193 | 89 | 2.29 | 1.88 | 1.04 | 0.49 | 52 | 9.4 | 2.4 | 7.2 | 31.3 | — |
| | SESAME *Sesamum indicum* | | | | | | | | | | | | |
| 205 | seeds, meal mechanical extracted | 5-04-220 | 93 | 3.40 | 2.78 | 1.85 | 1.22 | 77 | 49.1 | 7.5 | 12.1 | 6.1 | 17 |
| | SOLKA FLOC | | | | | | | | | | | | |
| 206 | | 1-28-258 | 93 | 3.09 | 2.53 | 1.63 | 1.03 | 70 | — | — | — | — | 99 |
| | SORGHUM *Sorghum bicolor* | | | | | | | | | | | | |
| 207 | aerial part with heads, sun-cured (fodder) | 1-07-960 | 89 | 2.56 | 2.10 | 1.24 | 0.68 | 58 | 7.5 | 2.4 | 9.4 | 26.9 | — |
| 208 | aerial part without heads, sun-cured (stover) | 1-04-302 | 88 | 2.38 | 1.95 | 1.11 | 0.55 | 54 | 5.2 | 1.7 | 11.0 | 33.5 | — |
| 209 | distillers grains, dehydrated | 5-04-374 | 94 | 3.66 | 3.00 | 2.03 | 1.37 | 83 | 34.4 | 9.5 | 3.8 | 12.7 | — |
| 210 | grain, less than 8% protein | 4-20-892 | 88 | 3.75 | 3.07 | 2.09 | 1.43 | 85 | 7.7 | 3.0 | — | 2.2 | — |
| 211 | grain, 8–10% protein | 4-20-893 | 87 | 3.70 | 3.04 | 2.06 | 1.40 | 84 | 10.1 | 3.4 | 2.1 | 2.6 | — |
| 212 | grain, more than 10% protein | 4-20-894 | 88 | 3.66 | 3.00 | 2.03 | 1.37 | 83 | 12.5 | 2.4 | 2.1 | 2.6 | — |
| 213 | grain, flaked | 4-16-295 | 85 | 4.06 | 3.33 | 2.30 | 1.60 | 92 | — | — | — | — | — |
| 214 | grain, reconstituted | 4-16-296 | 70 | 4.10 | 3.36 | 2.33 | 1.62 | 93 | — | — | — | — | — |
| 215 | silage | 3-04-323 | 30 | 2.65 | 2.17 | 1.31 | 0.74 | 60 | 7.5 | 3.0 | 8.7 | 27.9 | — |

| Entry Number | Acid Detergent Fiber (%) | Hemicellulose (%) | Cellulose (%) | Lignin (%) | Calcium (%) | Chlorine (%) | Magnesium (%) | Phosphorus (%) | Potassium (%) | Sodium (%) | Sulfur (%) | Cobalt (mg/kg) | Copper (mg/kg) | Iodine (mg/kg) | Iron (mg/kg) | Manganese (mg/kg) | Selenium (mg/kg) | Zinc (mg/kg) | Carotene (Provitamin A) Vitamin A Activity (1000 IU/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 174 | — | 19 | — | 8 | 0.46 | 0.09 | 0.23 | 0.29 | 2.35 | 0.05 | 0.19 | — | 26 | — | 200 | — | — | — | 86.9 |
| 175 | — | — | — | — | 0.63 | — | — | 0.35 | 1.69 | — | — | — | — | — | — | — | — | — | 2.0 |
| 176 | 18 | 15 | 11 | 4 | 0.08 | 0.08 | 1.04 | 1.70 | 1.92 | 0.04 | 0.20 | — | 15 | — | 210 | 415 | 0.44 | 32 | — |
| 177 | — | — | — | — | 0.07 | 0.09 | 0.15 | 0.32 | 0.36 | 0.06 | 0.05 | 0.05 | 3 | 0.05 | 57 | 20 | — | 17 | — |
| 178 | 49 | — | 33 | 16 | 0.10 | 0.08 | 0.83 | 0.08 | 0.57 | 0.12 | 0.09 | — | — | — | — | 334 | — | — | — |
| 179 | 55 | — | — | 5 | 0.21 | — | 0.11 | 0.08 | 1.32 | 0.31 | — | — | — | — | — | 346 | — | — | — |
| 180 | — | — | — | — | 0.16 | 0.05 | 0.18 | 0.52 | 0.08 | 0.18 | 0.48 | — | — | — | — | 20 | — | — | — |
| 181 | — | — | — | — | 0.39 | — | 0.31 | 0.33 | 3.40 | 0.07 | — | — | — | — | — | — | — | — | 137.0 |
| 182 | — | — | — | — | 0.07 | 0.03 | 0.14 | 0.37 | 0.52 | 0.03 | 0.17 | — | 8 | — | 69 | 66 | 0.44 | 36 | 0.0 |
| 183 | — | — | — | — | 0.08 | — | 0.26 | 0.71 | 0.92 | — | 0.04 | — | — | — | — | — | — | — | — |
| 184 | — | — | — | — | 0.24 | 0.24 | 0.08 | 0.09 | 0.97 | 0.13 | 0.11 | — | 4 | — | — | 7 | — | — | — |
| 185 | — | — | — | — | 0.65 | — | 0.35 | 0.41 | 2.00 | 0.01 | 0.10 | — | — | — | 650 | — | — | — | 160.4 |
| 186 | — | — | — | — | 0.62 | — | — | 0.34 | 1.56 | — | — | — | — | — | 320 | — | — | — | 116.0 |
| 187 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 188 | — | — | — | — | 0.55 | — | — | 0.27 | 1.91 | — | 0.30 | 0.06 | 13 | — | — | — | — | — | 88.8 |
| 189 | 30 | — | — | 2 | 0.65 | — | — | 0.32 | 1.67 | — | — | — | — | — | — | — | — | — | 48.0 |
| 190 | — | — | — | — | 0.26 | — | 0.36 | 0.67 | 0.79 | 0.06 | — | — | 11 | — | 500 | 20 | — | — | — |
| 191 | 41 | — | — | — | 0.27 | — | 0.36 | 0.78 | 0.79 | 0.05 | — | — | 11 | — | 515 | 20 | — | 44 | — |
| 192 | 41 | — | — | 14 | 0.37 | — | 0.37 | 0.81 | 0.82 | 0.05 | 0.14 | — | 11 | — | 537 | 20 | — | 44 | — |
| 193 | — | — | — | — | 0.38 | 0.18 | 1.11 | 1.40 | 1.19 | 0.05 | 0.22 | 2.15 | 9 | — | 528 | 43 | — | 36 | — |
| 194 | — | — | — | — | 0.81 | — | — | 0.17 | — | — | — | — | — | — | — | — | — | — | — |
| 195 | 30 | — | — | 12 | 0.71 | — | — | 0.18 | — | — | — | — | — | — | — | — | — | — | 6.4 |
| 196 | — | — | — | — | 0.97 | — | — | 0.33 | — | — | — | — | — | — | — | — | — | — | 9.5 |
| 197 | — | — | — | — | 0.60 | — | 0.49 | 0.42 | — | — | — | — | — | — | — | — | — | — | — |
| 198 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 199 | 35 | — | — | 10 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 200 | — | — | — | — | 2.21 | — | — | 0.12 | — | — | — | — | — | — | — | — | — | — | 7.6 |
| 201 | — | — | — | — | 0.23 | — | 0.30 | 0.07 | — | — | — | — | — | — | — | — | — | — | — |
| 202 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 203 | — | — | — | — | 2.72 | — | 0.93 | 0.31 | — | — | — | — | — | — | — | — | — | — | — |
| 204 | — | — | — | — | — | — | — | — | — | — | — | — | 3 | — | — | — | — | — | — |
| 205 | 17 | — | — | 2 | 2.17 | 0.07 | 0.50 | 1.46 | 1.35 | 0.04 | 0.35 | — | — | — | 100 | 52 | — | 108 | 0.2 |
| 206 | 79 | — | — | 4 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 207 | — | — | — | — | 0.40 | — | 0.29 | 0.21 | 1.47 | 0.02 | — | — | — | — | — | — | — | — | 20.7 |
| 208 | 46 | — | 41 | 6 | 0.52 | — | 0.28 | 0.13 | 1.20 | 0.02 | — | — | — | — | — | — | — | — | 9.1 |
| 209 | — | — | — | — | 0.16 | — | 0.19 | 0.74 | 0.38 | 0.05 | 0.18 | — | — | — | 50 | — | — | — | — |
| 210 | — | — | — | — | 0.03 | — | 0.19 | 0.32 | 0.38 | 0.05 | 0.18 | — | — | — | 50 | — | — | — | — |
| 211 | — | — | — | — | 0.04 | — | 0.18 | 0.34 | 0.40 | 0.01 | 0.09 | — | — | — | — | 17 | — | — | — |
| 212 | — | — | — | — | 0.04 | — | 0.14 | 0.36 | 0.38 | 0.01 | 0.13 | — | — | — | — | — | — | — | — |
| 213 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 214 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 215 | 38 | — | — | 6 | 0.35 | 0.13 | 0.29 | 0.21 | 1.37 | 0.02 | 0.11 | 0.30 | 35 | — | 285 | 73 | 0.22 | 32 | 6.2 |

TABLE 8 Composition of Some Beef Cattle Feeds—*Continued*

| | | | | Dry Basis (100% Dry Matter) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Entry Number | Feed Name Description | International Feed Number[a] | Dry Matter (%) | DE (Mcal/kg) | ME (Mcal/kg) | $NE_m$ (Mcal/kg) | $NE_g$ (Mcal/kg) | TDN (%) | Crude Protein (%) | Ether Extract (%) | Ash (%) | Crude Fiber (%) | Cell Walls (%) |
| | SORGHUM, JOHNSONGRASS *Sorghum halepense* | | | | | | | | | | | | |
| 216 | hay, sun-cured | 1-04-407 | 89 | 2.34 | 1.92 | 1.07 | 0.52 | 53 | 9.5 | 2.4 | 8.2 | 33.5 | — |
| | SORGHUM, SORGO *Sorghum bicolor saccharatum* | | | | | | | | | | | | |
| 217 | silage | 3-04-468 | 27 | 2.56 | 2.10 | 1.24 | 0.68 | 58 | 6.2 | 2.6 | 6.4 | 28.3 | — |
| | SORGHUM, SUDANGRASS *Sorghum bicolor sudanense* | | | | | | | | | | | | |
| 218 | fresh, early vegetative | 2-04-484 | 18 | 3.09 | 2.53 | 1.63 | 1.03 | 70 | 16.8 | 3.9 | 9.0 | 23.0 | 55 |
| 219 | fresh, midbloom | 2-04-485 | 23 | 2.78 | 2.28 | 1.41 | 0.83 | 63 | 8.8 | 1.8 | 10.5 | 30.0 | 65 |
| 220 | hay, sun-cured | 1-04-480 | 91 | 2.47 | 2.03 | 1.18 | 0.61 | 56 | 8.0 | 1.8 | 9.6 | 36.0 | 68 |
| 221 | silage | 3-04-499 | 28 | 2.43 | 1.99 | 1.14 | 0.58 | 55 | 10.8 | 2.8 | 9.8 | 33.1 | — |
| | SOYBEAN *Glycine max* | | | | | | | | | | | | |
| 222 | hay, sun-cured, midbloom | 1-04-538 | 94 | 2.34 | 1.92 | 1.07 | 0.52 | 53 | 17.8 | 5.4 | 8.8 | 29.8 | — |
| 223 | hulls (seed coats) | 1-04-560 | 91 | 2.82 | 2.31 | 1.44 | 0.86 | 64 | 12.1 | 2.1 | 5.1 | 40.1 | 67 |
| 224 | seeds | 5-04-610 | 92 | 4.01 | 3.29 | 2.27 | 1.57 | 91 | 42.8 | 18.8 | 5.5 | 5.8 | — |
| 225 | seeds, meal mechanical extracted | 5-04-600 | 90 | 3.75 | 3.07 | 2.09 | 1.43 | 85 | 47.7 | 5.3 | 6.7 | 6.6 | — |
| 226 | seeds, meal solvent extracted, 44% protein | 5-20-637 | 89 | 3.70 | 3.04 | 2.06 | 1.40 | 84 | 49.9 | 1.5 | 7.3 | 7.0 | — |
| 227 | seeds without hulls, meal solvent extracted | 5-04-612 | 90 | 3.84 | 3.15 | 2.15 | 1.48 | 87 | 55.1 | 1.0 | 6.5 | 3.7 | 8 |
| 228 | silage | 3-04-581 | 27 | 2.43 | 1.99 | 1.14 | 0.58 | 55 | 17.3 | 2.7 | 9.7 | 28.4 | — |
| 229 | straw | 1-04-567 | 88 | 1.85 | 1.52 | 0.68 | 0.15 | 42 | 5.2 | 1.5 | 6.4 | 44.3 | 70 |
| | SPELT *Triticum spelta* | | | | | | | | | | | | |
| 230 | grain | 4-04-651 | 90 | 3.31 | 2.71 | 1.79 | 1.16 | 75 | 13.3 | 2.1 | 3.9 | 10.2 | — |
| | SQUIRRELTAIL *Sitanion* spp | | | | | | | | | | | | |
| 231 | fresh, stem-cured | 2-05-566 | 50 | 2.21 | 1.81 | 0.97 | 0.42 | 50 | 3.1 | 2.2 | 17.0 | — | — |
| | SUGARCANE *Saccharum officinarum* | | | | | | | | | | | | |
| 232 | bagasse, dehydrated | 1-04-686 | 91 | 2.12 | 1.74 | 0.90 | 0.35 | 48 | 1.6 | 0.7 | 3.2 | 48.1 | 87 |
| | MOLASSES—SEE MOLASSES AND SYRUP | | | | | | | | | | | | |
| 233 | stems, fresh | 2-13-248 | 15 | 2.69 | 2.21 | 1.34 | 0.77 | 61 | 7.6 | 0.7 | 6.0 | 27.5 | 74 |
| 234 | sugar | 4-04-701 | 100 | 4.32 | 3.54 | 2.47 | 1.74 | 98 | — | — | 0.1 | — | — |
| | SUMMERCYPRESS, GRAY *Kochia vestita* | | | | | | | | | | | | |
| 235 | fresh, stem-cured | 2-08-843 | 85 | 2.21 | 1.81 | 0.97 | 0.42 | 50 | 9.0 | 3.7 | 24.8 | 22.0 | — |
| | SUNFLOWER, COMMON *Helianthus annuus* | | | | | | | | | | | | |
| 236 | seeds, meal solvent extracted | 5-09-340 | 90 | 1.94 | 1.59 | 0.75 | 0.22 | 44 | 25.9 | 1.2 | 6.3 | 35.1 | 40 |
| 237 | seeds without hulls, meal mechanical extracted | 5-04-738 | 93 | 3.26 | 2.68 | 1.76 | 1.14 | 74 | 44.6 | 8.7 | 7.1 | 13.1 | — |
| 238 | seeds without hulls, meal solvent extracted | 5-04-739 | 93 | 2.87 | 2.35 | 1.47 | 0.88 | 65 | 49.8 | 3.1 | 8.1 | 12.2 | — |
| | SWEETCLOVER, YELLOW *Melilotus officinalis* | | | | | | | | | | | | |
| 239 | hay, sun-cured | 1-04-754 | 87 | 2.38 | 1.95 | 1.11 | 0.55 | 54 | 15.7 | 2.0 | 8.8 | 33.4 | — |
| | TIMOTHY *Phleum pratense* | | | | | | | | | | | | |
| 240 | fresh, late vegetative | 2-04-903 | 26 | 3.17 | 2.60 | 1.70 | 1.08 | 72 | 18.0 | 3.8 | 6.6 | 32.1 | — |
| 241 | fresh, midbloom | 2-04-905 | 29 | 2.78 | 2.28 | 1.41 | 0.83 | 63 | 9.1 | 3.0 | 6.6 | 33.5 | 64 |
| 242 | hay, sun-cured, late vegetative | 1-04-881 | 89 | 2.73 | 2.24 | 1.38 | 0.80 | 62 | 17.0 | 2.8 | 7.1 | 27.0 | 55 |
| 243 | hay, sun-cured, early bloom | 1-04-882 | 90 | 2.60 | 2.13 | 1.28 | 0.71 | 59 | 15.0 | 2.9 | 5.7 | 28.0 | 61 |
| 244 | hay, sun-cured, midbloom | 1-04-883 | 89 | 2.51 | 2.06 | 1.21 | 0.64 | 57 | 9.1 | 2.6 | 6.3 | 31.0 | 67 |
| 245 | hay, sun-cured, full bloom | 1-04-884 | 89 | 2.47 | 2.03 | 1.18 | 0.61 | 56 | 8.1 | 3.1 | 5.2 | 32.0 | 68 |
| 246 | silage, full bloom | 3-04-920 | 36 | 2.47 | 2.03 | 1.18 | 0.61 | 56 | 9.7 | 3.2 | 6.9 | 36.3 | — |
| | TOMATO *Lycopersicon esculentum* | | | | | | | | | | | | |
| 247 | pomace, dehydrated | 5-05-041 | 92 | 2.56 | 2.10 | 1.24 | 0.68 | 58 | 23.5 | 10.3 | 7.5 | 26.4 | 55 |
| | TREFOIL, BIRDSFOOT *Lotus corniculatus* | | | | | | | | | | | | |
| 248 | fresh | 2-20-786 | 24 | 2.91 | 2.39 | 1.51 | 0.91 | 66 | 21.0 | 2.7 | 9.0 | 24.7 | — |
| 249 | hay, sun-cured | 1-05-044 | 92 | 2.60 | 2.13 | 1.28 | 0.71 | 59 | 16.3 | 2.5 | 7.0 | 30.7 | 47 |
| | TRITICALE *Triticale hexaploide* | | | | | | | | | | | | |
| 250 | grain | 4-20-362 | 90 | 3.70 | 3.04 | 2.06 | 1.40 | 84 | 17.6 | 1.7 | 2.0 | 4.4 | — |
| | TURNIP *Brassica rapa rapa* | | | | | | | | | | | | |
| 251 | roots, fresh | 4-05-067 | 9 | 3.75 | 3.07 | 2.09 | 1.43 | 85 | 11.8 | 1.9 | 8.9 | 11.5 | 44 |
| | UREA | | | | | | | | | | | | |
| 252 | 45% nitrogen, 281% protein equivalent | 5-05-070 | 99 | — | — | — | — | — | 287.0 | — | — | — | — |
| | VETCH *Vicia* spp | | | | | | | | | | | | |
| 253 | hay, sun-cured | 1-05-106 | 89 | 2.51 | 2.06 | 1.21 | 0.64 | 57 | 20.8 | 3.0 | 9.1 | 30.6 | 48 |

| Entry Number | Acid Detergent Fiber (%) | Hemicellulose (%) | Cellulose (%) | Lignin (%) | Calcium (%) | Chlorine (%) | Magnesium (%) | Phosphorus (%) | Potassium (%) | Sodium (%) | Sulfur (%) | Cobalt (mg/kg) | Copper (mg/kg) | Iodine (mg/kg) | Iron (mg/kg) | Manganese (mg/kg) | Selenium (mg/kg) | Zinc (mg/kg) | Carotene (Provitamin A) Vitamin A Activity (1000 IU/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 216 | — | — | — | — | 0.84 | — | 0.35 | 0.28 | 1.35 | 0.01 | 0.10 | — | — | — | 590 | — | — | — | 15.6 |
| 217 | — | — | — | — | 0.34 | 0.06 | 0.27 | 0.17 | 1.12 | 0.15 | 0.10 | — | 31 | — | 198 | 61 | — | — | 14.5 |
| 218 | 29 | 24 | 26 | 3 | 0.43 | — | 0.35 | 0.41 | 2.14 | 0.01 | 0.11 | — | — | — | 200 | — | — | — | 79.0 |
| 219 | 40 | 25 | 34 | 5 | 0.43 | — | 0.35 | 0.36 | 2.14 | 0.01 | 0.11 | — | — | — | 200 | — | — | — | 73.0 |
| 220 | 42 | 26 | 35 | 6 | 0.55 | — | 0.51 | 0.30 | 1.87 | 0.02 | 0.06 | 0.13 | 37 | — | 193 | 91 | — | 38 | 23.5 |
| 221 | 42 | — | 38 | 5 | 0.46 | — | 0.44 | 0.21 | 2.25 | 0.02 | 0.06 | 0.31 | 37 | — | 127 | 99 | — | — | 42.1 |
| 222 | — | — | — | — | 1.26 | — | 0.79 | 0.27 | 0.97 | 0.12 | 0.26 | — | — | — | 300 | — | — | — | 13.3 |
| 223 | 50 | 18 | 46 | 2 | 0.49 | — | — | 0.21 | 1.27 | 0.01 | 0.09 | 0.12 | 18 | — | 324 | 11 | — | 24 | — |
| 224 | 10 | — | — | — | 0.27 | 0.03 | 0.29 | 0.65 | 1.82 | 0.02 | 0.24 | — | 20 | — | 91 | 39 | 0.12 | 62 | 0.4 |
| 225 | — | — | — | — | 0.29 | 0.08 | 0.28 | 0.68 | 1.98 | 0.03 | 0.37 | 0.20 | 24 | — | 175 | 35 | 0.11 | 66 | 0.1 |
| 226 | — | — | — | — | 0.33 | — | 0.30 | 0.71 | 2.14 | 0.03 | 0.47 | 0.10 | 30 | — | 142 | 32 | 0.14 | 61 | — |
| 227 | 6 | — | 5 | — | 0.29 | 0.05 | 0.32 | 0.70 | 2.30 | 0.03 | 0.48 | 0.07 | 22 | 0.12 | 148 | 41 | 0.11 | 61 | — |
| 228 | — | — | — | — | 1.36 | — | 0.38 | 0.47 | 0.93 | 0.09 | 0.30 | — | 9 | — | 400 | 114 | — | 34 | 41.5 |
| 229 | 54 | — | 38 | 16 | 1.59 | — | 0.92 | 0.06 | 0.56 | 0.12 | 0.26 | — | — | — | 300 | 51 | — | — | — |
| 230 | — | — | — | — | 0.13 | — | — | 0.42 | — | — | — | — | — | — | — | — | — | — | — |
| 231 | — | — | — | — | 0.37 | — | — | 0.06 | — | — | — | — | — | — | — | — | — | — | — |
| 232 | 60 | — | — | 14 | 0.90 | — | 0.10 | 0.29 | 0.50 | 0.20 | 0.10 | — | — | — | 100 | — | — | — | — |
| 233 | — | 30 | 34 | 11 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 234 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 235 | — | — | — | — | 2.36 | — | — | 0.12 | — | — | — | — | — | — | — | — | — | — | 7.2 |
| 236 | 33 | — | — | 12 | 0.23 | — | 0.75 | 1.03 | 1.06 | — | 0.33 | — | — | — | — | — | — | — | — |
| 237 | — | — | — | — | 0.42 | 0.20 | 0.78 | 1.14 | 1.14 | 0.24 | — | — | 4 | — | 33 | 22 | — | — | — |
| 238 | — | — | — | — | 0.44 | 0.11 | 0.77 | 0.98 | 1.14 | 0.24 | — | — | 4 | — | 33 | 20 | — | — | — |
| 239 | — | — | — | — | 1.27 | 0.37 | 0.49 | 0.25 | 1.60 | 0.09 | 0.47 | — | 10 | — | 152 | 108 | — | — | 39.5 |
| 240 | — | — | — | — | 0.39 | — | 0.15 | 0.32 | 2.40 | 0.19 | 0.13 | — | — | — | 200 | — | — | — | 94.0 |
| 241 | 37 | — | 31 | 4 | 0.38 | 0.64 | 0.14 | 0.30 | 2.06 | 0.19 | 0.13 | — | 11 | — | 179 | 192 | — | — | 78.0 |
| 242 | 29 | 26 | 28 | 3 | 0.66 | — | 0.14 | 0.34 | 1.68 | 0.18 | — | — | 26 | — | 200 | 89 | — | 67 | 50.0 |
| 243 | 32 | 29 | 31 | 4 | 0.53 | — | 0.14 | 0.25 | — | 0.18 | — | — | 64 | — | 200 | 103 | — | 62 | 21.0 |
| 244 | 36 | 31 | 33 | 5 | 0.48 | — | 0.16 | 0.22 | 1.59 | 0.18 | — | — | 5 | — | 170 | — | — | 43 | 21.3 |
| 245 | 38 | 30 | 34 | 6 | 0.43 | 0.62 | 0.14 | 0.20 | 1.64 | 0.18 | — | — | 5 | — | 157 | — | — | 54 | — |
| 246 | — | — | — | — | 0.54 | — | — | 0.29 | — | — | — | — | — | — | — | — | — | — | — |
| 247 | 50 | — | — | 11 | 0.43 | — | 0.20 | 0.60 | 3.63 | — | — | — | 33 | — | 4600 | 51 | — | — | — |
| 248 | — | — | — | — | 1.91 | — | 0.28 | 0.22 | 1.99 | 0.07 | 0.25 | 0.21 | — | — | 400 | — | — | — | — |
| 249 | 36 | — | 24 | 9 | 1.70 | — | 0.51 | 0.27 | 1.92 | 0.07 | 0.25 | 0.11 | 9 | — | 228 | 29 | — | — | 75.2 |
| 250 | — | — | — | — | 0.06 | — | — | 0.33 | 0.40 | — | 0.17 | — | 7 | — | 44 | 45 | — | 25 | — |
| 251 | 34 | — | — | 10 | 0.59 | 0.65 | 0.22 | 0.26 | 2.99 | 1.05 | 0.43 | — | 21 | — | 118 | 43 | — | 29 | — |
| 252 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 253 | 33 | — | — | 8 | 1.18 | — | 0.25 | 0.32 | 2.32 | 0.52 | 0.15 | 0.36 | 10 | 0.49 | 420 | 73 | — | — | 184.2 |

TABLE 8 Composition of Some Beef Cattle Feeds—*Continued*

| | | | | Dry Basis (100% Dry Matter) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Entry Number | Feed Name Description | International Feed Number[a] | Dry Matter (%) | DE (Mcal/kg) | ME (Mcal/kg) | $NE_m$ (Mcal/kg) | $NE_g$ (Mcal/kg) | TDN (%) | Crude Protein (%) | Ether Extract (%) | Ash (%) | Crude Fiber (%) | Cell Walls (%) |
| | WHEAT *Triticum aestivum* | | | | | | | | | | | | |
| 254 | bran | 4-05-190 | 89 | 3.09 | 2.53 | 1.63 | 1.03 | 70 | 17.1 | 4.4 | 6.9 | 11.3 | 51 |
| 255 | bread, dehydrated | 4-07-944 | 95 | 3.79 | 3.11 | 2.12 | 1.45 | 86 | 13.0 | 2.4 | 2.4 | 0.3 | — |
| 256 | flour by-product, less than 7% fiber (wheat shorts) | 4-05-201 | 88 | 3.22 | 2.64 | 1.73 | 1.11 | 73 | 18.6 | 5.2 | 4.9 | 7.7 | — |
| 257 | flour by-product, less than 9.5% fiber (wheat middlings) | 4-05-205 | 89 | 3.04 | 2.50 | 1.60 | 1.00 | 69 | 18.4 | 4.9 | 5.2 | 8.2 | — |
| 258 | fresh, early vegetative | 2-05-176 | 22 | 3.22 | 2.64 | 1.73 | 1.11 | 73 | 28.6 | 4.4 | 13.3 | 17.4 | 52 |
| 259 | grain | 4-05-211 | 89 | 3.88 | 3.18 | 2.18 | 1.50 | 88 | 16.0 | 2.0 | 1.9 | 2.9 | — |
| 260 | grain, hard red spring | 4-05-258 | 88 | 3.92 | 3.22 | 2.21 | 1.52 | 89 | 17.2 | 2.0 | 1.8 | 2.9 | — |
| 261 | grain, hard winter | 4-05-268 | 88 | 3.88 | 3.18 | 2.18 | 1.50 | 88 | 14.4 | 1.8 | 1.9 | 2.8 | — |
| 262 | grain, soft red winter | 4-05-294 | 88 | 3.92 | 3.22 | 2.21 | 1.52 | 89 | 13.0 | 1.8 | 2.1 | 2.4 | — |
| 263 | grain, soft white winter | 4-05-337 | 89 | 3.92 | 3.22 | 2.21 | 1.52 | 89 | 11.3 | 1.9 | 1.8 | 2.6 | 14 |
| 264 | grain, soft white winter, pacific coast | 4-08-555 | 89 | 3.88 | 3.18 | 2.18 | 1.50 | 88 | 11.2 | 2.2 | 2.1 | 2.8 | — |
| 265 | grain screenings | 4-05-216 | 89 | 3.13 | 2.57 | 1.67 | 1.06 | 71 | 15.8 | 3.9 | 6.1 | 7.7 | — |
| 266 | hay, sun-cured | 1-05-172 | 88 | 2.56 | 2.10 | 1.24 | 0.68 | 58 | 8.5 | 2.2 | 7.1 | 28.1 | 68 |
| 267 | mill run, less than 9.5% fiber | 4-05-206 | 90 | 3.48 | 2.86 | 1.91 | 1.27 | 79 | 17.2 | 4.6 | 5.9 | 9.2 | — |
| 268 | silage, full bloom | 3-05-185 | 25 | 2.60 | 2.13 | 1.28 | 0.71 | 59 | 8.1 | 3.0 | 8.4 | 30.9 | — |
| 269 | straw | 1-05-175 | 89 | 1.81 | 1.48 | 0.64 | 0.11 | 41 | 3.6 | 1.8 | 7.8 | 41.6 | 70 |
| | WHEAT, DURUM *Triticum durum* | | | | | | | | | | | | |
| 270 | grain | 4-05-224 | 88 | 3.75 | 3.07 | 2.09 | 1.43 | 85 | 15.9 | 2.0 | 1.8 | 2.5 | — |
| | WHEATGRASS, CRESTED *Agropyron desertorum* | | | | | | | | | | | | |
| 271 | fresh, early vegetative | 2-05-420 | 28 | 3.31 | 2.71 | 1.79 | 1.16 | 75 | 21.5 | 2.2 | 10.0 | 22.2 | — |
| 272 | fresh, full bloom | 2-05-424 | 45 | 2.69 | 2.21 | 1.34 | 0.77 | 61 | 9.8 | 3.6 | 9.3 | 30.3 | — |
| 273 | fresh, post ripe | 2-05-428 | 80 | 2.16 | 1.77 | 0.93 | 0.39 | 49 | 3.1 | 1.2 | 4.1 | 40.3 | — |
| 274 | hay, sun-cured | 1-05-418 | 93 | 2.34 | 1.92 | 1.07 | 0.52 | 53 | 12.4 | 2.3 | 7.2 | 32.9 | — |
| | WHEY *Bos taurus* | | | | | | | | | | | | |
| 275 | dehydrated (cattle) | 4-01-182 | 93 | 3.57 | 2.93 | 1.97 | 1.32 | 81 | 14.2 | 0.7 | 9.8 | 0.2 | 0 |
| 276 | fresh (cattle) | 4-08-134 | 7 | 4.14 | 3.40 | 2.35 | 1.65 | 94 | 13.0 | 4.3 | 8.7 | — | — |
| 277 | low lactose, dehydrated (dried whey product) (cattle) | 4-01-186 | 93 | 3.48 | 2.86 | 1.91 | 1.27 | 79 | 17.9 | 1.1 | 16.5 | 0.2 | — |
| | WINTERFAT, COMMON *Eurotia lanata* | | | | | | | | | | | | |
| 278 | fresh, stem-cured | 2-26-142 | 80 | 1.54 | 1.27 | 0.41 | — | 35 | 10.8 | 2.8 | 15.8 | — | 72 |
| | YEAST, BREWERS *Saccharomyces cerevisiae* | | | | | | | | | | | | |
| 279 | dehydrated | 7-05-527 | 93 | 3.48 | 2.86 | 1.91 | 1.27 | 79 | 46.9 | 0.9 | 7.1 | 3.1 | — |
| | YEAST, IRRADIATED *Saccharomyces cerevisiae* | | | | | | | | | | | | |
| 280 | dehydrated | 7-05-529 | 94 | 3.35 | 2.75 | 1.82 | 1.19 | 76 | 51.2 | 1.2 | 6.6 | 6.6 | — |
| | YEAST, PRIMARY *Saccharomyces cerevisiae* | | | | | | | | | | | | |
| 281 | dehydrated | 7-05-533 | 93 | 3.40 | 2.78 | 1.85 | 1.22 | 77 | 51.8 | 1.1 | 8.6 | 3.3 | — |
| | YEAST, TORULA *Torulopsis utilis* | | | | | | | | | | | | |
| 282 | dehydrated | 7-05-534 | 93 | 3.44 | 2.82 | 1.88 | 1.24 | 78 | 52.7 | 1.7 | 8.3 | 2.4 | — |

| Entry Number | Acid Detergent Fiber (%) | Hemicellulose (%) | Cellulose (%) | Lignin (%) | Calcium (%) | Chlorine (%) | Magnesium (%) | Phosphorus (%) | Potassium (%) | Sodium (%) | Sulfur (%) | Cobalt (mg/kg) | Copper (mg/kg) | Iodine (mg/kg) | Iron (mg/kg) | Manganese (mg/kg) | Selenium (mg/kg) | Zinc (mg/kg) | Carotene (Provitamin A) Vitamin A Activity (1000 IU/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 254 | 15 | 34 | 11 | 3 | 0.13 | 0.05 | 0.60 | 1.38 | 1.56 | 0.04 | 0.25 | 0.11 | 14 | 0.07 | 128 | 125 | 0.43 | 128 | 1.2 |
| 255 | — | — | — | — | 0.07 | — | — | 0.11 | — | — | — | — | — | — | — | — | — | — | — |
| 256 | — | — | — | — | 0.10 | 0.08 | 0.28 | 0.91 | 1.06 | 0.03 | 0.22 | 0.12 | 13 | — | 82 | 132 | 0.49 | 124 | — |
| 257 | — | — | — | — | 0.13 | 0.04 | 0.40 | 0.99 | 1.13 | 0.19 | 0.20 | 0.10 | 22 | 0.12 | 93 | 126 | 0.83 | 116 | 1.4 |
| 258 | 30 | 18 | 24 | 4 | 0.42 | — | 0.21 | 0.40 | 3.50 | 0.18 | 0.22 | — | — | — | 100 | — | — | — | 208.0 |
| 259 | 8 | — | 8 | — | 0.04 | 0.08 | 0.16 | 0.42 | 0.42 | 0.05 | 0.18 | 0.14 | 7 | 0.10 | 61 | 42 | 0.30 | 50 | 0.0 |
| 260 | 13 | — | 8 | — | 0.04 | 0.09 | 0.17 | 0.43 | 0.41 | 0.03 | 0.17 | 0.13 | 7 | — | 64 | 42 | 0.29 | 52 | 0.0 |
| 261 | 4 | — | — | — | 0.05 | 0.06 | 0.13 | 0.43 | 0.49 | 0.02 | 0.15 | 0.16 | 5 | — | 35 | 33 | 0.45 | 43 | — |
| 262 | — | — | — | — | 0.05 | 0.08 | 0.11 | 0.43 | 0.46 | 0.01 | 0.12 | 0.12 | 7 | — | 30 | 36 | 0.05 | 48 | — |
| 263 | 4 | — | — | — | 0.07 | 0.09 | 0.13 | 0.36 | 0.46 | 0.04 | 0.16 | 0.15 | 8 | — | 41 | 43 | 0.06 | 29 | — |
| 264 | — | — | — | — | 0.10 | — | 0.15 | 0.34 | 0.51 | 0.10 | 0.18 | — | — | — | 60 | — | — | — | — |
| 265 | — | — | 6 | 8 | 0.15 | — | 0.18 | 0.39 | 0.58 | 0.10 | 0.22 | — | — | — | 60 | 33 | 0.68 | — | — |
| 266 | 41 | — | — | 7 | 0.15 | — | 0.12 | 0.20 | 1.00 | 0.21 | 0.22 | — | — | — | 200 | — | — | — | 34.2 |
| 267 | — | — | — | — | 0.11 | — | 0.52 | 1.13 | 1.33 | 0.24 | 0.34 | 0.23 | 21 | — | 105 | 116 | — | — | — |
| 268 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 269 | 54 | — | 39 | 14 | 0.18 | 0.32 | 0.12 | 0.05 | 1.42 | 0.14 | 0.19 | 0.05 | 4 | — | 157 | 41 | — | 6 | 0.9 |
| 270 | — | — | — | — | 0.10 | — | 0.17 | 0.41 | 0.51 | — | — | 0.09 | 8 | — | 48 | 32 | 1.02 | 37 | — |
| 271 | — | — | — | — | 0.46 | — | 0.28 | 0.34 | — | — | — | — | — | — | — | — | — | — | 180.4 |
| 272 | — | — | — | — | 0.39 | — | 0.09 | 0.28 | 1.04 | 0.01 | 0.47 | — | 7 | — | — | 43 | — | 13 | 61.6 |
| 273 | — | — | — | — | 0.27 | — | — | 0.07 | — | — | — | 0.25 | 8 | — | — | 53 | — | — | 0.1 |
| 274 | 36 | — | — | 6 | 0.33 | — | 0.16 | 0.21 | 2.00 | — | — | 0.24 | 16 | — | 178 | 36 | 0.40 | 32 | 8.9 |
| 275 | 0 | 0 | — | — | 0.92 | 0.08 | 0.14 | 0.82 | 1.23 | 0.70 | 1.12 | 0.12 | 50 | — | 181 | 6 | — | 3 | — |
| 276 | — | — | — | — | 0.73 | — | — | 0.65 | 2.75 | — | — | — | — | — | 290 | 3 | — | — | — |
| 277 | — | — | — | — | 1.71 | 1.10 | 0.23 | 1.12 | 3.16 | 1.54 | 1.15 | — | 8 | 10.55 | 262 | 9 | 0.06 | 8 | — |
| 278 | 44 | — | — | 10 | 1.98 | — | — | 0.12 | — | — | — | — | — | — | — | — | — | — | 7.2 |
| 279 | — | — | — | — | 0.13 | 0.08 | 0.27 | 1.49 | 1.79 | 0.08 | 0.45 | 0.20 | 35 | 0.38 | 117 | 6 | 0.98 | 41 | — |
| 280 | — | — | — | — | 0.83 | — | — | 1.51 | 2.28 | — | — | — | — | — | — | — | — | — | — |
| 281 | — | — | — | — | 0.39 | 0.02 | 0.39 | 1.86 | — | — | 0.62 | — | — | — | 324 | 4 | — | — | — |
| 282 | — | — | — | — | 0.54 | 0.02 | 0.18 | 1.71 | 2.04 | 0.04 | 0.59 | 0.03 | 14 | 2.69 | 126 | 9 | 1.08 | 100 | — |

TABLE 9 Composition of Mineral Supplements for Beef Cattle[a]

| Entry Number | Feed Name Description | International Feed Number | Dry Matter (%) | Dry Basis (100% Dry Matter): Protein Equivalent N×6.25 (%) | Calcium (Ca) (%) | Chlorine (Cl) (%) | Magnesium (Mg) (%) | Phosphorus (P) (%) | Potassium (K) (%) | Sodium (Na) (%) | Sulfur (S) (%) | Cobalt (Co) (mg/kg) | Copper (Cu) (mg/kg) | Fluorine (F) (mg/kg) | Iodine (I) (mg/kg) | Iron (Fe) (mg/kg) | Manganese (Mn) (mg/kg) | Selenium (Se) (mg/kg) | Zinc (Zn) (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AMMONIUM | | | | | | | | | | | | | | | | | | |
| 01 | phosphate, monobasic, $(NH_4)H_2PO_4$ | 6-09-338 | 97 | 70.9 | 0.28 | — | 0.46 | 24.74 | 0.01 | 0.06 | 1.46 | 10 | 10 | 2500 | — | 17400 | 400 | — | 100 |
| 02 | phosphate, dibasic, $(NH_4)_2HPO_4$ | 6-00-370 | 97 | 115.9 | 0.52 | — | 0.46 | 20.60 | 0.01 | 0.05 | 2.16 | — | 10 | 2100 | — | 12400 | 400 | — | 100 |
| 03 | sulfate | 6-09-339 | 100 | 134.1 | — | — | — | — | — | — | 24.10 | — | 1 | — | — | 10 | 1 | — | — |
| | BONE | | | | | | | | | | | | | | | | | | |
| 04 | charcoal (Bone black) (Bone char) | 6-00-402 | 90 | 9.4 | 30.11 | — | 0.59 | 14.14 | 0.16 | — | — | — | — | — | — | — | — | — | — |
| 05 | meal, steamed | 6-00-400 | 97 | 8.4 | 31.53 | 0.01 | 0.64 | 14.22 | 0.19 | 0.40 | 0.21 | — | 14 | — | 31 | 780 | 34 | — | 342 |
| | CALCIUM | | | | | | | | | | | | | | | | | | |
| 06 | carbonate, $CaCO_3$ | 6-01-069 | 100 | — | 39.39 | — | 0.05 | 0.04 | 0.06 | 0.06 | — | — | — | — | — | 300 | 300 | — | — |
| 07 | phosphate, monobasic, from defluorinated phosphoric acid | 6-01-082 | 97 | — | 16.40 | — | 0.61 | 21.60 | 0.08 | 0.06 | 1.22 | 10 | 10 | 2100 | — | 15800 | 360 | — | 90 |
| 08 | phosphate, dibasic, from defluorinated phosphoric acid (Dicalcium phosphate) | 6-01-080 | 97 | — | 22.00 | — | 0.59 | 19.30 | 0.07 | 0.05 | 1.14 | 10 | 10 | 1800 | — | 14400 | 300 | — | 100 |
| 09 | sulfate, dihydrate (Gypsum), $CaSO_4 \cdot 2H_2O$ | 6-01-090 | 85 | — | 25.90 | — | 2.61 | 0.01 | — | — | 23.54 | — | — | — | — | 2010 | — | — | — |
| | COBALT | | | | | | | | | | | | | | | | | | |
| 10 | carbonate, $CoCO_3$ | 6-01-566 | 99[b] | — | — | — | — | — | — | — | 0.20 | 460000 | — | — | — | 500 | — | — | — |
| | COLLOIDAL | | | | | | | | | | | | | | | | | | |
| 11 | clay (soft rock phosphate) | 6-03-947 | 99[b] | — | 17.17 | — | 0.38 | 9.09 | — | 0.10 | — | — | — | 15000 | — | 19200 | — | — | — |
| | COPPER (CUPRIC) | | | | | | | | | | | | | | | | | | |
| 12 | sulfate, pentahydrate, $CuSO_4 \cdot 5H_2O$, cp[c] | 6-01-720 | 100 | — | — | — | — | — | — | — | 12.84 | — | 254500 | — | — | — | — | — | — |
| | CURACAO | | | | | | | | | | | | | | | | | | |
| 13 | phosphate | 6-05-586 | 99[b] | — | 34.34 | — | 0.81 | 14.14 | — | 0.20 | — | — | — | 5500 | — | 3500 | — | — | — |
| | ETHYLENEDIAMINE | | | | | | | | | | | | | | | | | | |
| 14 | dihydroiodide | 6-01-842 | 100[b] | — | — | — | — | — | — | — | — | — | — | — | 803385 | — | — | — | — |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | IRON (FERROUS) | | | | | | | | | | | | | | | | | | |
| 15 | sulfate, heptahydrate | 6-20-734 | 98[b] | — | — | — | — | — | — | — | 12.35 | — | — | — | — | 218400 | — | — | — |
| | LIMESTONE | | | | | | | | | | | | | | | | | | |
| 16 | limestone | 6-02-632 | 100 | — | 34.00 | 0.03 | 2.06 | 0.02 | 0.12 | 0.06 | 0.04 | — | — | — | — | 3500 | — | — | — |
| 17 | magnesium (dolomitic) | 6-02-633 | 99[b] | — | 22.30 | 0.12 | 9.99 | 0.04 | 0.36 | — | — | — | — | — | — | 770 | — | — | — |
| | MAGNESIUM | | | | | | | | | | | | | | | | | | |
| 18 | carbonate, $MgCO_3Mg(OH)_2$ | 6-02-754 | 98[b] | — | 0.02 | 0.00 | 30.81 | — | — | — | — | — | — | — | — | 220 | — | — | — |
| 19 | oxide MgO | 6-02-756 | 98[b] | — | 3.07 | — | 56.20 | — | — | — | — | — | — | — | — | — | 100 | — | — |
| | MANGANESE (MANGANOUS) | | | | | | | | | | | | | | | | | | |
| 20 | oxide, MnO, cp[c] | 6-03-056 | 99[b] | — | — | — | — | — | — | — | — | — | — | — | — | — | 774500 | — | — |
| | OYSTERSHELL | | | | | | | | | | | | | | | | | | |
| 21 | ground (flour) | 6-03-481 | 99 | — | 38.00 | 0.01 | 0.30 | 0.07 | 0.10 | 0.21 | — | — | — | — | — | 2870 | 100 | — | — |
| | PHOSPHATE | | | | | | | | | | | | | | | | | | |
| 22 | defluorinated | 6-01-780 | 100 | — | 32.00 | — | 0.42 | 18.00 | 0.08 | 4.90 | — | 10 | 20 | 1800 | — | 6700 | 200 | — | 60 |
| | POTASSIUM | | | | | | | | | | | | | | | | | | |
| 23 | bicarbonate, $KHCO_3$, CP[c] | 6-29-493 | 99[b] | — | — | — | — | — | 39.05 | — | — | — | — | — | — | — | — | — | — |
| 24 | chloride, KCl | 6-03-755 | 100 | — | 0.05 | 47.26 | 0.11 | — | 50.54 | 1.00 | 0.19 | — | 7 | — | — | 600 | 7 | — | — |
| 25 | iodide, KI | 6-03-759 | 100[b] | — | — | — | — | — | 21.00 | — | — | — | — | — | 681700 | — | — | — | — |
| | SODIUM | | | | | | | | | | | | | | | | | | |
| 26 | bicarbonate, $NaHCO_3$ | 6-04-272 | 100 | — | — | — | — | — | — | 27.00 | — | — | — | — | — | — | — | — | — |
| 27 | chloride, NaCl | 6-04-152 | 100 | — | — | 60.66 | — | — | — | 39.34 | — | — | — | — | — | — | — | — | — |
| 28 | phosphate, monobasic, monohydrate, $NaH_2PO_4 \cdot H_2O$ | 6-04-288 | 97 | — | — | — | — | 22.50 | — | 16.68 | — | — | — | — | — | — | — | — | — |
| 29 | selenite, $Na_2SeO_3$ | 6-26-013 | 98[b] | — | — | — | — | — | — | 26.60 | — | — | — | — | — | — | — | 456000 | — |
| 30 | sulfate, decahydrate, $Na_2SO_4 \cdot 10H_2O$, cp[c] | 6-04-292 | 97[b] | — | — | — | — | — | — | 14.27 | 9.95 | — | — | — | — | — | — | — | — |
| 31 | tripolyphosphate, $Na_5P_3O_{10}$ | 6-08-076 | 96 | — | — | — | — | 25.00 | — | 31.00 | — | — | — | — | — | 40 | — | — | — |
| | ZINC | | | | | | | | | | | | | | | | | | |
| 32 | oxide, ZnO | 6-05-553 | 100 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 780000 |
| 33 | sulfate, monohydrate, $ZnSO_4 \cdot H_2O$ | 6-05-555 | 99[b] | — | 0.02 | 0.015 | — | — | — | — | 17.68 | — | 100 | — | — | 1000 | 100 | — | 363600 |

[a]The composition of mineral ingredients that are hydrated (e.g., $CaSO_4 \cdot 2H_2O$) is shown, including the waters of hydration. Mineral compositions of feed grade mineral supplements vary by source, mining site, and manufacturer. Use manufacturer's analysis when available.

[b]Dry matter values have been estimated for these minerals.

[c]cp = chemically pure.

# References

## ENERGY


Agricultural Research Council. 1965. The Nutrient Requirements of Farm Livestock. No. 2. Ruminants. Agricultural Research Council, London.

Agricultural Research Council. 1980. The Nutrient Requirements of Ruminant Livestock. Commonwealth Agricultural Bureaux. Surrey: The Gresham Press.

Berg, R. T., and R. M. Butterfield. 1976. New Concepts of Cattle Growth. Sydney: Sydney University Press.

Byers, F. M., and R. E. Rompala. 1980. Level of energy effects on patterns and energetic efficiency of tissue deposition in small or large mature size beef cattle. P. 141 *in* Energy Metabolism, L. E. Mount, ed. EAAP Publ. No. 26. London: Butterworths.

Eley, R. M., W. W. Thatcher, F. W. Bazer, C. J. Wilcox, R. B. Becker, H. H. Head, and R. W. Adkinson. 1978. Development of the conceptus in the bovine. J. Dairy Sci. 61:467.

Ferrell, C. L., W. N. Garrett, and N. Hinman. 1976a. Growth, development and composition of the udder and gravid uterus of beef heifers during pregnancy. J. Anim. Sci. 42:1477.

Ferrell, C. L., W. N. Garrett, N. Hinman, and G. Grichting. 1976b. Energy utilization by pregnant and non-pregnant heifers. J. Anim. Sci. 42:937.

Flipse, R. J., and J. O. Almquist. 1961. Effect of total digestible nutrient intake from birth to four years of age on growth and reproductive development and performance of dairy bulls. J. Dairy Sci. 44:905.

Fox, D. G., and J. R. Black. 1984. A system for predicting body composition and performance of growing cattle. J. Anim. Sci.

Frisch, J. E., and J. E. Vercoe. 1977. Food intake, eating rate, weight gains, metabolic rate and efficiency of feed utilization in Bos taurus and Bos indicus crossbred cattle. Anim. Prod. 25:343–358.

Garrett, W. N. 1971. Energetic efficiency of beef and dairy steers. J. Anim. Sci. 32:451–456.

Garrett, W. N. 1974a. Influence of roughage quality on the performance of feedlot cattle. Calif. Feeders' Day Rep. 13:51.

Garrett, W. N. 1974b. Energy gain in mature, nonpregnant beef cows. J. Anim. Sci. 34:238 (Abstr.).

Garrett, W. N. 1976. Least cost gain and profit projection. 1. Estimating nutrient requirements. Calif. Feeders' Day Rep. 15:68.

Garrett, W. N. 1980a. Energy utilization of growing cattle as determined in seventy-two comparative slaughter experiments. P. 3 *in* Energy Metabolism, L. E. Mount, ed. EAAP Publ. No. 26. London: Butterworths.

Garrett, W. N. 1980b. Factors influencing energetic efficiency of beef production. J. Anim. Sci. 51:1434.

Garrett, W. N., and N. Hinman. 1969. Re-evaluation of the relationship between carcass density and body composition of beef steers. J. Anim. Sci. 28:1.

Geay, Y. 1982. Energy and protein utilization in growing cattle. J. Anim. Sci.

Jesse, G. W., G. B. Thompson, J. L. Clark, H. B. Hedrick, and K. G. Weimer. 1976. Effects of ration energy and slaughter weight on composition of empty body and carcass gain of beef cattle. J. Anim. Sci. 43:418.

Kay, M., A. Macdearmid, and N. A. MacLeod. 1970. Intensive beef production. 10. Replacement of cereals with chopped straw. Anim. Prod. 12:261.

Lofgreen, G. P., and W. N. Garrett. 1968. A system for expressing net energy requirements and feed values for growing and finishing beef cattle. J. Anim. Sci. 27:793.

Loveday, H. D., and M. E. Dikeman. 1980. Diet energy and steer type effects of adipose composition lipogenesis and carcass composition. J. Anim. Sci. 51:78.

Maynard, L. A. 1953. Total digestible nutrients as a measure of feed energy. J. Nutr. 51:15.

Moore, T. 1977. The calorie as the unit of nutritional energy. World Rev. Nutr. Diet. 26:1–25.

National Research Council. 1976. Nutrient Requirements of Beef Cattle. Washington, D.C.: National Academy of Sciences.

National Research Council. 1978. Nutrient Requirements of Dairy Cattle. Washington, D.C.: National Academy of Sciences.

National Research Council. 1981a. Nutritional Energetics of Domestic Animals and Glossary of Energy Terms. Washington, D.C.: National Academy Press.

National Research Council. 1981b. Effect of Environment on Nutrient Requirements of Domestic Animals. Washington, D.C.: National Academy Press.

Nehring, K., and G. F. W. Haenlein. 1973. Feed evaluation and ration calculation based on net energy (fat). J. Anim. Sci. 36:949.

Prior, R. L., and D. B. Laster. 1979. Development of the bovine fetus. J. Anim. Sci. 48:1546.

Rattray, P. V., W. N. Garrett, N. E. East, and N. Hinman. 1974. Efficiency of utilization of metabolizable energy and the energy requirements for pregnancy in sheep. J. Anim. Sci. 38:383.

Reid, J. T., G. H. Wellington, and H. O. Dunn. 1955. Some relationships among the major chemical components of the bovine body

and their application to nutritional investigations. J. Dairy Sci. 38:1344.
Schneider, B. H., and W. P. Flatt. 1975. The Evaluation of Feeds Through Digestibility Experiments. Athens, Ga.: University of Georgia Press.
Silvey, M. W., and K. P. Haydock. 1978. A note on live-weight adjustment for pregnancy in cows. Anim. Prod. 27:113.
Swingle, R. S., C. B. Rowbicek, R. A. Wooten, J. A. Marchello, and F. D. Dryden. 1979. Realimentation of cull range cows. 1. Effect of final body condition and dietary energy level on rate, efficiency and composition of gains. J. Anim. Sci. 48:913.
Van Demark, N. L., and R. E. Manger. 1964. Effect of energy intake on reproductive performance of dairy bulls. II. Semen production and replenishment. J. Dairy Sci. 47:898.
Webster, A. J. F. 1978. Prediction of energy requirements for growth in beef cattle. World Rev. Nutr. Diet. 30:189–226.

## PROTEIN

Agricultural Research Council. 1980. The Nutrient Requirements of Ruminant Livestock. Commonwealth Agricultural Bureaux. Surrey: The Gresham Press.
Armstrong, D. G., and K. Hutton. 1975. Fate of nitrogenous compounds entering the small intestine. P. 432 *in* Digestion and Metabolism in the Ruminant, I. W. McDonald and A. C. I. Warner, eds. Armidale, NSW, Australia: The University of New England Publishing Unit.
Bartley, E. E., A. Davidovich, G. W. Barr, G. W. Griffel, A. D. Dayton, D. W. Deyoe, and R. M. Bechtle. 1976. Ammonia toxicity in cattle. I. Rumen and blood changes associated with toxicity and treatment methods. J. Anim. Sci. 43:835.
Bryant, M. P. 1973. Nutritional requirements of the predominant rumen cellulolytic bacteria. Fed. Proc. 32:1809.
Bryant, M. P., and I. M. Robinson. 1963. Apparent incorporation of ammonia and amino acid carbon during growth of selected species of ruminal bacteria. J. Dairy Sci. 46:150.
Burroughs, W., D. K. Nelson, and D. R. Mertens. 1975. Protein physiology and its application in the lactating cow: The metabolizable protein feeding standard. J. Anim. Sci. 41:933.
Byers, F. M., and R. E. Rompala. 1979. Rate of protein deposition in beef cattle as a function of mature size, weight and rate of empty body growth. Ohio Beef Cattle Research Progress Report, Animal Science Series 79-1.
Chalupa, W. 1975. Rumen bypass and protection of proteins and amino acids. J. Dairy Sci. 58:1198.
Edwards, J. J., and E. E. Bartley. 1979. Soybean meal or starea for microbial protein synthesis or milk production with rations above thirteen percent natural protein. J. Dairy Sci. 62:732.
Fenderson, C. L., and W. G. Bergen. 1976. Effect of excess dietary protein on feed intake and nitrogen metabolism in steers. J. Anim. Sci. 42:1323.
Foldager, J., J. T. Huber, and W. G. Bergen. 1977. Methionine and sulfur amino acid requirement in the preruminant calf. J. Dairy Sci. 60:1095.
Fox, D. G., C. J. Sniffen, and P. J. Van Soest. 1982. A net protein system for cattle: Meeting protein requirements of cattle *in* Protein Requirements for Cattle: Symposium, F. N. Owens, ed. Okla. State Univ. MP-109:280.
Henderickx, H., and J. Martin. 1963. In vitro study of the nitrogen metabolism in the rumen. Comptes Rendes de Recherches. Sci. Ind. Agr. Bruxelles 31:1.
Hespell, R. B. 1979. Efficiency of growth by ruminal bacteria. Fed. Proc. 38:2707.
Lamond, D. R., J. H. G. Holmes, and K. P. Haydock. 1969. Estimation of yield and composition of milk produced by grazing beef cows. J. Anim. Sci. 29:606.
Macgregor, C. A., C. J. Sniffen, and W. H. Hoover. 1978. Amino acid profiles of total and soluble protein in feedstuffs commonly fed to ruminants. J. Dairy Sci. 61:566.
Maeng, W. J., and R. L. Baldwin. 1976. Factors influencing rumen microbial growth rates and yields: Effect of amino acid additions to a purified diet with nitrogen from urea. J. Dairy Sci. 59:648.
Mehrez, A. Z., E. R. Ørskov, and I. McDonald. 1977. Rates of rumen fermentation in relation to ammonia concentration. Br. J. Nutr. 38:447.
Minish, G. L., and D. Fox. 1982. Beef Production and Management. Reston, Va.: Reston Publishing Co.
Morrill, J. L., and A. D. Dayton. 1978. Factors affecting requirements and use of crude protein in calf starters. J. Dairy Sci. 61:940.
National Research Council. 1978. Nutrient Requirements of Dairy Cattle. Washington, D.C.: National Academy of Sciences.
National Research Council. 1981b. Effect of Environment on Nutrient Requirements of Domestic Animals. Washington, D.C.: National Academy Press.
Owens, F. N. (ed.) 1982. Protein Requirements for Cattle: Symposium. Okla. State Univ. MP-109.
Owens, F. N., and W. G. Bergen. 1983. Nitrogen metabolism of ruminant animals: Historical perspective, current understanding and future implications. J. Anim. Sci. 57 (Suppl. 2):498.
Prior, R. L., and D. B. Laster. 1979. Development of the bovine fetus. J. Anim. Sci. 48:1546.
Roy, J. H. B., and I. J. F. Stobo. 1975. Nutrition of the pre-ruminant calf. P. 32 *in* Digestion and Metabolism in the Ruminant, I. W. McDonald and A. C. I. Warner, eds. Armidale, NSW, Australia: The University of New England Publishing Unit.
Satter, L. D., and L. L. Slyter. 1974. Effect of ammonia concentration on rumen microbial protein production in vitro. Br. J. Nutr. 32:199.
Satter, L. D., and R. E. Roffler. 1975. Nitrogen requirements and utilization in dairy cattle. J. Dairy Sci. 58:1219.
Satter, L. D., L. W. Whitlow, and G. L. Beardsley. 1977. Resistance of protein to rumen degradation and its significance to the dairy cow. Distillers Feed Res. Counc. Proc. 32:63. Des Moines, Ia.
Slyter, L. L., L. D. Satter, and D. A. Dinius. 1979. Effect of ruminal ammonia concentration on nitrogen utilization by steers. J. Anim. Sci. 48:906.
Smith, R. H. 1975. Nitrogen metabolism in the rumen and the composition and nutritive value of nitrogen compounds entering the duodenum. P. 399 *in* Digestion and Metabolism in the Ruminant, I. W. McDonald and A. C. I. Warner, eds. Armidale, NSW, Australia: The University of New England Publishing Unit.
Thomas, P. C. 1973. Microbial protein synthesis. Proc. Nutr. Soc. 32:85.
Williams, J. H., D. C. Anderson, and D. D. Kress. 1979. Milk production in Hereford cattle. I. Effects of separation interval on weigh-suckle-weigh milk production estimates. J. Dairy Sci. 49:1438.
Zinn, R. A., and F. N. Owens. 1983. Influence of feed intake level on site of digestion in steers fed a high concentrate diet. J. Anim. Sci. 56:471.

## MINERALS

### *Calcium*

Baker, G. N. 1964. The influence of calcium level in the ration on beef cattle performance. Nebr. Exp. Stn. Rep. 91.

Beeson, W. M., D. W. Bolin, C. W. Hickman, and R. F. Johnson. 1941. The phosphorus requirement for growing and fattening beef steers. Idaho Exp. Stn. Bull. 240.

Butcher, J. E., J. W. Call, J. T. Blake, and J. L. Shupe. 1979. Dietary phosphorus levels can cause problems in beef cows. Proc. West. Sect., Am. Soc. Anim. Sci. 30:312.

Call, J. W., J. E. Butcher, J. T. Blake, R. A. Smart, and J. L. Shupe. 1978. Phosphorus influence on growth and reproduction of beef cattle. J. Anim. Sci. 47:216.

Colovos, N. F., H. A. Keener, and H. A. Davis. 1957. Effect of pulverized limestone and dicalcium phosphate on the nutritive value of dairy cattle feed. J. Dairy Sci. 41:676.

Comar, C. L., R. H. Wasserman, and A. R. Twardock. 1961. Secretion of calcium and strontium into milk. Health Phys. 7:69.

DeLuca, H. F. 1974. Vitamin D: the vitamin and the hormone. Fed. Proc. 33:2211.

Dowe, T. W., J. Matsushima, and V. H. Arthaud. 1957. The effects of adequate and excessive calcium when fed with adequate phosphorus in growing rations for beef calves. J. Anim. Sci. 16:811.

Ellenberger, H. G., J. A. Newlander, and C. H. Jones. 1950. Composition of the bodies of dairy cattle. Vt. Agric. Exp. Stn. Bull. 558.

Hansard, S. L., C. L. Comar, and M. P. Plumlee. 1954. The effect of age upon calcium utilization and maintenance requirements in the bovine. J. Anim. Sci. 13:25.

Hansard, S. L., H. M. Crowder, and W. A. Lyke. 1957. The biological availability of calcium in feeds for cattle. J. Anim. Sci. 16:437.

Jacobson, N. L., K. D. Wiggers, and G. N. Jacobson. 1975. Calcium in beef and dairy nutrition. Natl. Feed Ingred. Assoc., Des Moines, Iowa.

Kleiber, M., A. H. Smith, N. P. Ralston, and A. L. Black. 1951. Radiophosphorus ($P^{32}$) as tracer for measuring endogenous phosphorus in cow's feces. J. Nutr. 45:253.

Lofgreen, G. P., and M. Kleiber. 1953. The availability of the phosphorus in alfalfa hay. J. Anim. Sci. 12:366.

Lofgreen, G. P., and M. Kleiber. 1954. Further studies on the availability of phosphorus in alfalfa hay. J. Anim. Sci. 13:258.

Lofgreen, G. P., M. Kleiber, and V. R. Luick. 1952. The metabolic fecal phosphorus excretion of the young calf. J. Nutr. 47:571.

Mitchell, H. H. 1947. Mineral requirements of farm animals. J. Anim. Sci. 6:365.

National Research Council. 1978. Nutrient Requirements of Dairy Cattle. Washington, D.C.: National Academy of Sciences.

National Research Council. 1980. Mineral Tolerance of Domestic Animals. Washington, D.C.: National Academy of Sciences.

Ramberg, C. F., Jr., and S. E. Olson. 1970. Fluoride effects on bone morphology and calcium kinetics. Fluoride 3:175.

Ricketts, R. E., J. R. Campbell, D. E. Weinman, and M. E. Tumbleson. 1970. Effect of three calcium:phosphorus rations on performance of growing Holstein steers. J. Dairy Sci. 53:898.

Smith, A. M., G. L. Holck, and H. B. Spafford. 1966. Symposium: Re-evaluation of nutrient allowances for high-producing cows. Calcium, phosphorus and vitamin D. J. Dairy Sci. 49:239.

Suttle, N. F., and A. C. Field. 1970. Effects of dietary calcium and phosphorus concentrations on the fecal excretion of copper, manganese and zinc in sheep. Proc. Nutr. Soc. 29:33A.

Tillman, A. D., and J. R. Brethour. 1958. Dicalcium phosphate and phosphoric acid as phosphorus sources for beef cattle. J. Anim. Sci. 17:100.

Varner, L., and W. Woods. 1968. High grain rations and calcium. Nebr. Cattle Feeders Rep. p. 21.

Varner, L., and W. Woods. 1972. Calcium levels in high grain beef cattle rations. J. Anim. Sci. 35:415.

Wentworth, R. A., and S. F. Smith. 1961. The calcium requirement of dairy calves. Proc. Cornell Nutr. Conf. p. 53.

Wise, M. B., S. E. Smith, and L. L. Barnes. 1958. The phosphorus requirement of calves. J. Anim. Sci. 17:89.

Wise, M. B., A. L. Ordoveza, and E. R. Barrick. 1963. Influence of variations in dietary calcium:phosphorus ratio on performance and blood constituents of calves. J. Nutr. 79:79.

### *Cobalt*

Ammerman, C. B. 1970. Recent developments in cobalt and copper in ruminant nutrition: A review. J. Dairy Sci. 53:1097.

Andrews, E. D., L. T. Hart, and B. J. Stephenson. 1959. A comparison of the vitamin $B_{12}$ and cobalt contents from normal lambs, cobalt-dosed lambs, and others with a recent history of mild cobalt deficiency disease. N. Z. J. Agric. Res. 2:274.

Dunn, K. M., R. E. Ely, and C. F. Huffman. 1952. Alleviation of cobalt toxicity by methionine administration. J. Anim. Sci. 11:326.

Gawthorne, J. M., and R. M. Smith. 1974. Folic acid metabolism in vitamin $B_{12}$-deficient sheep. Biochem. J. 142:119.

Keener, H. A., G. P. Percival, K. S. Morrow, and G. H. Ellis. 1949. Cobalt tolerance in young dairy cattle. J. Dairy Sci. 32:527.

Marston, H. R., S. H. Allen, and R. M. Smith. 1961. Primary metabolic defect supervening on vitamin $B_{12}$ deficiency in the sheep. Nature 190:1085.

National Research Council. 1978. Nutrient Requirements of Dairy Cattle. Washington, D.C.: National Academy of Sciences.

Smith, E. L. 1965. Vitamin $B_{12}$. London, England: Methuen and Company, Ltd.

Smith, R. M., and H. R. Marston. 1970. Production, absorption, distribution and excretion of vitamin $B_{12}$ in sheep. Br. J. Nutr. 24:857.

Smith, S. E., and J. K. Loosli. 1957. Cobalt and vitamin $B_{12}$ in ruminant nutrition: A review. J. Dairy Sci. 40:1215.

Underwood, E. J. 1966. The Mineral Nutrition of Livestock. London: Commonwealth Agricultural Bureaux by arrangement with the Food and Agriculture Organization of the United Nations.

Underwood, E. J. 1977. Trace Elements in Human and Animal Nutrition, 4th ed. New York: Academic Press.

### *Copper*

Beck, A. B. 1956. The copper content of the liver and blood of some vertebrates. Aust. J. Zool. 4:1.

Carnes, W. H. 1971. Role of copper in connective tissue metabolism. Fed. Proc. 30:995.

Chapman, H. L., and M. C. Bell. 1963. Relative absorption and excretion by beef cattle of copper from various sources. J. Anim. Sci. 22:82.

Cunninghan, I. J. 1931. Some biochemical and physiological aspects of copper in animal nutrition. Biochem. J. 25:1267.

Forth, W., G. Nell, and W. Rummel. 1973. Chelating agents and the transfer of heavy metals across the mucosal epithelium. Seventh Annual Conference on Trace Substances in Environmental Health. University of Missouri. p. 339.

Goodrich, R. D., and A. D. Tillman. 1966. Copper, sulfate and molybdenum interrelationships in sheep. J. Nutr. 90:76.

Goodrich, R. D., J. C. Meiske, and A. D. Tillman. 1972. Some aspects of copper as an essential nutrient. Proceedings, Minnesota Nutrition Conference. p. 169.

Hill, C. H., and G. Matrone. 1970. Chemical parameters in the study of *in vivo* and *in vitro* interactions of transition elements. Fed. Proc. 29:1474.

Kim, C. S., and C. H. Hill. 1966. Interrelation of dietary copper and amine oxidase in the formation of elastin. Biochem. Biophys. Res. Comm. 24:395.

Marston, H. R., H. J. Lee, and I. W. McDonald. 1948. Cobalt and copper in the nutrition of sheep. J. Agric. Sci. 38:216.
Mills, C. F. 1956. Studies of the copper compounds in aqueous extract of herbage. Biochem. J. 63:187.
Mills, C. F. 1958. Comparative metabolic studies of inorganic and herbage-complex forms of copper in rats and sheep. Soil Sci. 85:100.
National Research Council. 1980. Mineral Tolerance of Domestic Animals. Washington, D.C.: National Academy of Sciences.
Shacklette, H. T. 1970. A U.S. Geological Survey study of elements in soils and other surficial materials in the United States. Fourth Annual Conference on Trace Substances in Environmental Health. University of Missouri. p. 35.
Starcher, B., C. H. Hill, and G. Matrone. 1964. Importance of dietary copper in the formation of aortic elastin. J. Nutr. 82:318.
Underwood, E. J. 1977. Trace Elements in Human and Animal Nutrition, 4th ed. New York: Academic Press.

### *Iodine*

Ammerman, C. B., and S. M. Miller. 1972. Biological availability of minor mineral ions: A review. J. Anim. Sci. 35:681.
Barua, J., R. G. Gragle, and J. K. Miller. 1964. Sites of gastrointestinal blood passage of iodine and thyroxine in young cattle. J. Dairy Sci. 47:529.
Conrad, L. M., and R. W. Hemken. 1975. Milk iodine as influenced by iodophar teat dip. J. Dairy Sci. 58:752.
Convey, E. M., L. T. Chapin, J. S. Kesner, D. Hillman, and A. R. Curtis. 1977. Serum thyrotropin and thyroxine after thyrotropin releasing hormone in dairy cows fed varying amounts of iodine. J. Dairy Sci. 60:975.
Fish, R. E., and E. W. Swanson. 1977. Iodine tolerance of calves, yearlings, dry cows, and lactating cows. J. Dairy Sci. (Suppl. 1) 60:151.
Gross, J. 1962. Iodine and bromine. *In* Mineral Metabolism, C. L. Comar and F. Bonner, eds. New York: Academic Press.
Harper, H. A., V. W. Rodwell, and P. A. Mayes. 1979. Review of Physiological Chemistry. Los Altos, Calif.: Lange Pub.
Hemken, R. W. 1978. Factors that influence the iodine content of milk and meat: A review. J. Anim. Sci. 48:981.
Hemken, R. W., J. N. Vandersall, M. A. Oskarsson, and L. R. Fryman. 1972. Iodine intake related to milk iodine and performance in dairy cattle. J. Dairy Sci. 55:931.
Miller, J. K., W. A. Lyke, and W. F. Byrne. 1972. Iodine metabolism by calves fed soybean or cottonseed meal. J. Dairy Sci. 55:400 (Abstr.).
Miller, J. K., E. W. Swanson, and G. E. Spalding. 1975. Iodine absorption, excretion, recycling and tissue distribution in the dairy cow. J. Dairy Sci. 58:1578.
Newton, G. L., E. R. Barrick, R. W. Harvey, and M. B. Wise. 1974. Iodine toxicity: Physiological effects of elevated dietary iodine on calves. J. Anim. Sci. 38:449.
Underwood, E. J. 1977. Trace Elements in Human and Animal Nutrition. 4th ed. New York: Academic Press.

### *Iron*

Ammerman, C. B., J. M. Wing, B. G. Dunavant, W. K. Robertson, J. P. Feaster, and L. R. Arrington. 1967. Utilization of inorganic iron by ruminants as influenced by form of iron and iron status of the animal. J. Anim. Sci. 26:404.
Blaxter, K. L., G. A. M. Sarman, and A. M. MacDonald. 1957. Iron-deficiency anaemia in calves. Br. J. Nutr. 11:234.
Bremner, I., and A. C. Dalgarno. 1973. Iron metabolism in the veal calf. 2. Iron requirements and the effect of copper supplementation. Br. J. Nutr. 30:76.
Dubach, R., C. V. Moore, and S. Callender. 1955. Studies in iron transportation and metabolism. IX. The excretion of iron as measured by the isotope technique. J. Lab. Clin. Med. 45:599.
Hartley, W. J., J. Mullins, and B. M. Lawson. 1959. Nutritional siderosis in the bovine. N. Z. Vet. J. 7:99.
Koong, L. J., M. B. Wise, and E. A. Barrick. 1970. Effect of elevated dietary levels of iron on the performance and blood constituents of calves. J. Anim. Sci. 31:422.
Matrone, G., C. Conley, G. H. Wise, and R. K. Waugh. 1957. A study of iron and copper requirements of dairy calves. J. Dairy Sci. 40:1437.
National Research Council. 1978. Nutrient Requirements of Dairy Cattle. Washington, D.C.: National Academy of Sciences.
National Research Council. 1980. Mineral Tolerance of Domestic Animals. Washington, D.C.: National Academy of Sciences.
Raven, A. M., and A. Thompson. 1959. The availability of iron in certain grasses, clover and herb spices. I. Perennial ryegrass, cocksfoot and timothy. J. Agric. Sci. 52:177.
Standish, J. F., and C. B. Ammerman. 1971. Effect of excess dietary iron as ferrous sulfate and ferric citrate on tissue mineral composition of sheep. J. Anim. Sci. 33:481.
Standish, J. F., C. B. Ammerman, C. F. Simpson, F. C. Neal, and A. Z. Palmer. 1969. Influence of graded levels of dietary iron, as ferrous sulfate, on performance and tissue mineral composition of steers. J. Anim. Sci. 29:496.
Standish, J. F., C. B. Ammerman, A. Z. Palmer, and C. F. Simpson. 1971. Influence of dietary iron and phosphorus on performance, tissue mineral composition and mineral absorption in steers. J. Anim. Sci. 33:171.
Thomas, J. W. 1970. Metabolism of iron and manganese. J. Dairy Sci. 53:1107.
Thompson, A., and A. M. Raven. 1959. The availability of iron in certain grasses, clover and herb species. II. Alsike, Broad red clover, Kent wild white clover, trefoil and lucerne. J. Agric. Sci. 53:224.

### *Magnesium*

Ammerman, C. B., and C. F. Chicco. 1968. Availability of inorganic magnesium salts to sheep. J. Anim. Sci. 27:288 (Abstr.).
Blaxter, M. L., and R. F. McGill. 1956. Magnesium metabolism in cattle. Vet. Rev. Ann. 2:35.
Blaxter, M. L., and J. A. F. Rook. 1954. Experimental magnesium deficiency in calves. The metabolism of calcium, magnesium and nitrogen and magnesium requirements. J. Comp. Pathol. Therap. 64:176.
Blaxter, M. L., J. A. F. Rook, and A. M. MacDonald. 1954. Experimental magnesium deficiency in calves. Clinical and pathological observations. J. Comp. Pathol. Therap. 64:157.
Care, A. D. 1960. The effect on cattle of high level magnesium supplementation of their diet. Vet. Rec. 72:517.
Care, A. D., and A. Th. Van't Klooster. 1965. In vivo transport of magnesium and other cations across the wall of the gastro-intestinal tract of sheep. J. Physiol. (London) 177:174.
Elin, R. L., W. D. Armstrong, and L. Singer. 1971. Body fluid electrolyte composition of chronically magnesium deficient and control rats. Am. J. Physiol. 220:543.
Field, A. C. 1961. Studies on magnesium in ruminant nutrition. Distribution of $^{28}Mg$ in the gastrointestinal tract and tissues of sheep. Br. J. Nutr. 15:349.
Gerken, H. J., Jr., and J. P. Fontenot. 1967. Availability and utiliza-

tion of magnesium from dolomitic limestone and magnesium oxide in steers. J. Anim. Sci. 24:1404.
Grace, N. D., M. J. Wyatt, and J. C. Macrae. 1974. Quantitative digestion of fresh herbage by sheep. III. The movement of Mg, Ca, P, K and Na in the digestive tract. J. Agric. Sci. 82:321.
Greene, L. W., K. E. Webb, Jr., and J. P. Fontenot. 1983. Effect of potassium level on site of absorption of magnesium and other macroelements in sheep. J. Anim. Sci. 56:1214.
Huffman, C. F., C. L. Conley, C. C. Lightfoot, and C. W. Duncan. 1941. Magnesium studies in calves. II. The effect of magnesium salts and various natural feeds upon the magnesium content of the blood plasma. J. Nutr. 22:609.
Martin, J. E., L. R. Arrington, J. E. Moore, C. B. Ammerman, G. K. Davis, and R. L. Shirley. 1964. Effect of magnesium and sulfur upon cellulose digestion of purified rations by cattle and sheep. J. Nutr. 83:60.
Moore, L. A., E. T. Hallmon, and L. B. Shell. 1938. Cardiovascular and other lesions in calves fed diets low in magnesium. Arch. Pathol. 26:820.
National Research Council. 1980. Mineral Tolerance of Domestic Animals. Washington, D.C.: National Academy of Sciences.
Newton, G. L., J. P. Fontenot, R. E. Tucker, and C. E. Polan. 1972. Effects of high dietary potassium intake on the metabolism of magnesium by sheep. J. Anim. Sci. 35:440.
O'Kelley, R. E., and J. P. Fontenot. 1968. Dietary magnesium levels for gestating beef cows. J. Anim. Sci. 27:1173.
O'Kelley, R. E., and J. P. Fontenot. 1969. Effects of feeding different magnesium levels to drylot-fed lactating beef cows. J. Anim. Sci. 29:959.
Pierce, A. W. 1959. Studies on salt tolerance of sheep. II. The tolerance of sheep for mixtures of sodium chloride and magnesium chloride in the drinking water. Nutr. J. Agric. Res. 10:725.
Rook, J. A. F., C. C. Balch, and C. Line. 1958. Magnesium metabolism in the dairy cow. I. Metabolism on stall rations. J. Agric. Sci. 51:189.
Smith, R. H. 1962. Net exchange of certain inorganic ions and water in the alimentary tract of the milk-fed calf. Biochem. J. 83:151.
Thomas, J. W. 1965. Mechanisms responsible for grass tetany. Proc. Ga. Nutr. Conf. p. 14.
Tufts, E. V., and D. M. Greenberg. 1938. The biochemistry of magnesium deficiency. I. Chemical changes resulting from magnesium deprivation. J. Biol. Chem. 122:693.
Underwood, E. J. 1966. The Mineral Nutrition of Livestock. London: Commonwealth Agricultural Bureaux by arrangement with the Food and Agriculture Organization of the United Nations.
Wacker, W. E. C., and B. L. Vallee. 1964. *In* Mineral Metabolism. Vol. I. Part A. C. L. Comar, ed. New York: Academic Press.
Wise, M. B., A. L. Ordoveza, and E. R. Barrick. 1963. Influence of variation in dietary calcium:phosphorus ratios on performance and blood constituents of calves. J. Nutr. 79:79.

## *Manganese*

Bentley, O. G., and P. H. Phillips. 1951. The effect of low manganese rations upon dairy cattle. J. Dairy Sci. 34:396.
Bertinchamps, A. L., S. T. Miller, and G. C. Cotzias. 1966. Interdependence of routes excreting manganese. Am. J. Physiol. 211:217.
Cunningham, G. N., M. B. Wise, and E. R. Barrick. 1966. Effect of high dietary levels of manganese on the performance and blood constituents of calves. J. Anim. Sci. 25:532.
Dyer, I. A., W. A. Cassatt, and R. R. Rao. 1964. Manganese deficiency in the etiology of deformed calves. Bioscience 14:31.
Hawkins, G. E., Jr., G. H. Wise, G. Matrone, R. K. Waugh, and W. L. Lott. 1955. Manganese in the nutrition of young dairy cattle fed different levels of calcium and phosphorus. J. Dairy Sci. 38:536.
Hidiroglou, M. 1979. Manganese in ruminant nutrition. Can. J. Anim. Sci. 59:217.
Hidiroglou, M., and D. A. Shearer. 1976. Concentration of manganese in the tissues of cycling and anestrous ewes. Can. J. Comp. Med. 40:306.
Hidiroglou, M., S. K. Ho, and J. F. Standish. 1978. Effects of dietary manganese levels on reproductive performance of ewes and on tissue mineral composition of ewes and day-old lambs. Can. J. Anim. Sci. 58:35.
Lassiter, J. W., W. J. Miller, F. M. Pate, and R. P. Gentry. 1972. Effect of dietary calcium and phosphorus on 54 Mn metabolism following a single tracer intraperitoneal and oral doses in rats. Proc. Soc. Exp. Biol. Med. 139:345.
Leach, R. M., Jr. 1971. Role of manganese in mucopolysaccharide metabolism. Fed. Proc. 30:991.
Matrone, G., R. H. Hartman, and A. J. Clawson. 1959. Studies of a manganese-iron antagonism in the nutrition of rabbits and baby pigs. J. Nutr. 67:309.
National Research Council. 1978. Nutrient Requirements of Dairy Cattle. Washington, D.C.: National Academy of Sciences.
National Research Council. 1980. Mineral Tolerance of Domestic Animals. Washington, D.C.: National Academy of Sciences.
Redshaw, E. S., P. J. Martin, and D. H. Laverty. 1978. Iron, manganese, copper, zinc and selenium concentrations in Alberta grains and roughages. Can. J. Anim. Sci. 58:553.
Rojas, M. A., I. A. Dyer, and W. A. Cassatt. 1965. Manganese deficiency in the bovine. J. Anim. Sci. 24:664.
Underwood, E. J. 1977. Trace Elements in Human and Animal Nutrition, 4th ed. New York: Academic Press.
Utter, M. 1976. The biochemistry of manganese. Med. Clin. North Amer. 60:713.

## *Molybdenum*

De Renzo, E. C., E. Kaleita, P. G. Heytler, J. J. Oleson, B. L. Hutchings, and J. H. Williams. 1953. Identification of the xanthine oxidase factor as molybdenum. Arch. Biochem. Biophy. 45:247.
Dick, A. T. 1956. Inorganic nitrogen metabolism. Molybdenum and copper relationships in animal nutrition. W. D. McElroy and B. Glass, eds. Baltimore, Md.: Johns Hopkins University Press.
Dick, A. T., D. W. Dewey, and J. M. Gawthorne. 1975. Thiomolybdates and the copper-molybdenum-sulphur interaction in ruminant nutrition. J. Agric. Sci. 85:567.
Dowdy, R. P., and G. Matrone. 1968a. Copper-molybdenum interaction in sheep and chicks. J. Nutr. 95:191.
Dowdy, R. P., and G. Matrone. 1968b. A copper-molybdenum complex: its effects and movements in the piglet and sheep. J. Nutr. 95:197.
Ellis, W. C., W. H. Pfander, M. E. Muhrer, and E. E. Pickett. 1958. Molybdenum as a dietary essential for lambs. J. Anim. Sci. 17:180.
Ferguson, W. S., A. L. Lewis, and S. J. Watson. 1943. The teart pastures of Somerset. I. The cause and cure of teartness. J. Agric. Sci. 33:44.
Huisingh, J., G. G. Gomez, and G. Matrone. 1973. Interactions of copper, molybdenum and sulfate in ruminant nutrition. Fed. Proc. 32:1921.
Mahler, H. R., B. Mackler, D. E. Green, and R. M. Bock. 1954. Studies on metalloflavoproteins. III. Aldehyde oxidase: a molybdoflavoprotein. J. Biol. Chem. 210:465.
Miller, R. F., and R. W. Engel. 1960. Interrelationships of copper, molybdenum and sulfate sulfur in nutrition. Fed. Proc. 19:666.
Mills, C. F. 1960. Comparative studies of copper, molybdenum and

sulphur metabolism in the ruminant and the rat. Proc. Nutr. Soc. 19:162.
National Research Council. 1980. Mineral Tolerance of Domestic Animals. Washington, D.C.: National Academy of Sciences.
Seelig, M. S. 1972. Review: relationships of copper and molybdenum to iron metabolism. Am. J. Clin. Nutr. 25:1022.
Suttle, N. F. 1975. The role of organic sulphur in the copper-molybdenum-S interrelationship in ruminant nutrition. Br. J. Nutr. 34:411.
Ward, G. 1978. Molybdenum toxicity and hypocuprosis in ruminants: A review. J. Anim. Sci. 46:1078.

## *Phosphorus*

Black, W. H., L. H. Tash, J. M. Jones, and R. J. Kleberg, Jr. 1943. Effects of phosphorus supplements on cattle grazing on range deficient in this mineral. U.S. Dept. Agric. Tech. Bull. 856.
Chen, T. C., L. Castillo, M. Korycka-Dahl, and H. DeLuca. 1974. Role of vitamin D metabolites in phosphate transport of rat intestine. J. Nutr. 104:1056.
Emerick, R. J., and L. B. Embry. 1963. Calcium and phosphorus levels related to the development of phosphate urinary calculi in sheep. J. Anim. Sci. 22:510.
Emerick, R. J., and L. B. Embry. 1964. Effects of calcium and phosphorus levels and diethylstilbestrol on urinary calculi incidence and feedlot performance of lambs. J. Anim. Sci. 23:1079.
Irving, J. T. 1964. Dynamics and functions of phosphorus. P. 249 *in* Mineral Metabolism, Vol. 2. C. L. Comar and F. Bonner, eds. New York: Academic Press.
Maynard, E. J., J. E. Greaves, and H. H. Smith. 1935. Phosphorus supplements improve by-product rations for cattle. Utah Agric. Exp. Stn. Bull. 265.
McGillivray, J. J. 1974. Biological availability of phosphorus in feed ingredients. Minn. Nutr. Conf. p. 15.
Peeler, H. T. 1972. Biological availability of nutrients in feeds: Availability of major mineral ions. J. Anim. Sci. 35:695.
Preston, R. L., N. L. Jacobson, K. D. Wiggers, M. H. Wiggers, and G. N. Jacobson. 1977. Phosphorus in Ruminant Nutrition. Natl. Feed Ingred. Assoc., Des Moines, Iowa.
Taylor, A. N. 1974. *In vitro* phosphate transport in chick ileum: Effect of cholecalciferol, calcium, sodium and metabolic inhibitors. J. Nutr. 104:489.
Teleni, E., B. D. Siebert, R. M. Murray, and D. C. Nancarrow. 1977. Effects of supplements of phosphorus or phosphorus and protein on the ovarian activity of cows fed native pasture hay. Aust. J. Exp. Agric. Anim. Husb. 17:207.
Underwood, E. J. 1977. Trace Elements in Human and Animal Nutrition, 4th ed. New York: Academic Press.

## *Potassium*

Blaxter, K. L., B. Cowlishaw, and J. A. Rook. 1960. Potassium and hypomagnesaemic tetany in calves. Anim. Prod. 2:1.
Clanton, D. C. 1980. Applied potassium nutrition in beef cattle. Proceedings, Third International Minerals Conference, Jan. 17 and 18, Miami, Fla.
Devlin, T. J., W. K. Roberts, and V. V. E. St. Omer. 1969. Effects of dietary potassium upon growth, serum electrolytes and intrarumen environment of finishing beef steers. J. Anim. Sci. 28:557.
Fontenot, J. P., M. B. Wise, and K. E. Webb, Jr. 1973. Interrelationship of potassium, nitrogen and magnesium. Fed. Proc. 32:1925.
Jackson, H. M., R. P. Kromann, and E. E. Ray. 1971. Energy retention in lambs as influenced by various levels of sodium and potassium in the ration. J. Anim. Sci. 33:872.
Newton, G. L., J. P. Fontenot, R. E. Tucker, and C. E. Polan. 1972. Effects of high dietary potassium intake on metabolism of magnesium by sheep. J. Anim. Sci. 35:440.
Roberts, W. K., and V. V. E. St. Omer. 1965. Dietary potassium requirements of fattening steers. J. Anim. Sci. 24:902 (Abstr.).
Telle, P. P., R. L. Preston, C. D. Kinter, and W. H. Pfander. 1964. Definition of the ovine potassium requirement. J. Anim. Sci. 23:59.
Welt, L. G., W. Hollander, and W. B. Blythe. 1960. The consequences of potassium depletion. J. Chron. Dis. 11:213.
Wilde, S. W. 1962. Potassium. Chap. 26 *in* Mineral Metabolism, Vol. 2, part B. New York: Academic Press.
Wright, F. S., N. Strieder, N. B. Fowler, and G. Giebisch. 1971. Potassium secretion by distal tubule after potassium adaptation. Am. J. Physiol. 221:437.

## *Selenium*

Briggs, G. M., and D. H. Calloway. 1979. Pages 298–301 *in* Nutrition and Physical Fitness. Philadelphia: W. B. Saunders Company.
Burk, R. F. 1976. Selenium. Pp. 310–316 *in* Present Knowledge in Nutrition. New York: The Nutrition Foundation, Inc.
Burk, R. F., D. G. Brown, R. J. Seely, and C. C. Scaief. 1972. III: Influence of dietary and injected selenium on whole-body retention, route of excretion, and tissue retention of $^{75}SeO_3^{2-}$ in the rat. J. Nutr. 102:1049.
Franke, K. W. 1934. A new toxicant occurring naturally in certain samples of foodstuffs. I. Results obtained in preliminary feeding trials. J. Nutr. 8:597.
Ganther, H. E., O. A. Levander, and C. A. Baumann. 1966. Dietary control of selenium volatilization in the rat. J. Nutr. 88:55.
Hartley, W. J., and A. B. Grant. 1961. A review of selenium responsive diseases of New Zealand livestock. Fed. Proc. 20:679.
Herrman, J. L., and K. P. McConnell. 1973. The binding of selenium to serum albumin. *In* Trace Element Metabolism in Animals—2. W. G. Hoekstra, J. W. Suttie, H. E. Ganther, and W. Mertz, eds. Baltimore, Md.: University Park Press.
Hoekstra, W. G. 1973. Biochemical role of selenium. *In* Trace Element Metabolism in Animals—2. W. G. Hoekstra, J. W. Suttie, H. E. Ganther, and W. Mertz, eds. Baltimore, Md.: University Park Press.
Levander, O. A., and C. A. Baumann. 1966. Selenium metabolism. VI. Effect of arsenic on the excretion of selenium in the bile. Toxicol. Appl. Pharmacol. 9:106.
McConnell, K. P. 1941. Distribution and excretion studies in the rat after a single subtoxic subcutaneous injection of sodium selenate containing radioselenium. J. Biol. Chem. 141:427.
McConnell, K. P. 1942. Respiratory excretion of selenium studied with the radio-active isotope. J. Biol. Chem. 145:55.
McConnell, K. P., and O. W. Portman. 1952. Excretion of dimethyl selenide by the rat. J. Biol. Chem. 195:277.
Moxon, A. L., and M. Rhian. 1943. Selenium poisoning. Physiol. Rev. 23:305.
Muth, O. H., J. E. Oldfield, L. F. Remmert, and J. R. Schubert. 1958. Effects of selenium and vitamin E on white muscle disease. Science 128:1090.
National Research Council. 1980. Mineral Tolerance of Domestic Animals. Washington, D.C.: National Academy of Sciences.
Olson, O. E., E. J. Novacek, E. I. Whitehead, and I. S. Palmer. 1970. Investigations on selenium in wheat. Phytochemistry 9:1181.
Parizek, J., J. Kalouskova, A. Babicky, J. Benes, and L. Pavlik. 1973. Interaction of selenium with mercury, cadmium and other toxic metals. *In* Trace Element Metabolism in Animals—2. W. G. Hoekstra, J. W. Suttie, H. E. Ganther, and W. Mertz, eds. Baltimore, Md.: University Park Press.

Rosenfeld, I., and O. A. Beath. 1964. Selenium. New York: Academic Press.
Rotruck, J. T., A. L. Pope, H. E. Ganther, A. B. Swanson, D. G. Hafeman, and W. G. Hoekstra. 1973. Selenium: Biochemical role as a component of glutathione peroxidase. Science 179:588.
Ullrey, D. E. 1973. The selenium deficiency problem in animal agriculture. *In* Trace Element Metabolism in Animals—2. W. G. Hoekstra, J. W. Suttie, H. E. Ganther, and W. Mertz, eds. Baltimore, Md.: University Park Press.
Underwood, E. J. 1971. Trace Elements in Human and Animal Nutrition. New York: Academic Press.
Whanger, P. D., N. D. Pedersen, and P. H. Weswig. 1973. Selenium-binding of protein of ovine tissues. *In* Trace Element Metabolism in Animals—2. W. G. Hoekstra, J. W. Suttie, H. E. Ganther, and W. Mertz, eds. Baltimore, Md.: University Park Press.

### *Sodium and Chlorine*

Burkhaltor, D. L., M. W. Neathery, W. J. Miller, R. H. Whitlock, and J. C. Allen. 1979. Effects of low chloride intake on performance, clinical characteristics, and chloride, sodium, potassium, and nitrogen metabolism in dairy calves. J. Dairy Sci. 62:1895.
Hafez, E. S., and I. A. Dyer. 1969. Animal Nutrition and Growth. Philadelphia, Pa.: Lea and Febiger.
Jensen, R., and D. R. Mackey. 1979. Diseases of Feedlot Cattle. Philadelphia, Pa.: Lea and Febiger.
Meyer, J. H., R. R. Grunert, R. H. Grummer, P. H. Phillips, and G. Bohstedt. 1950. Sodium, potassium, and chlorine content of feeding stuffs. J. Anim. Sci. 9:153.
Morris, J. G. 1980. Assessment of sodium requirements of grazing beef cattle. A review. J. Anim. Sci. 50:145.
Morris, J. G., and R. J. W. Gartner. 1971. The sodium requirements of beef calves for growth. J. Agric. Sci. Camb. 78:105.
Morris, J. G., and G. W. Murphy. 1972. The sodium requirements of beef calves for growth. J. Agric. Sci. Camb. 78:105.
National Research Council. 1980. Mineral Tolerance of Domestic Animals. Washington, D.C.: National Academy of Sciences.
Underwood, E. J. 1970. The Mineral Nutrition of Livestock. Food and Agriculture Organization of the United Nations.
Weeth, J. J., and L. H. Haverland. 1961. Tolerance of growing cattle for drinking water containing sodium chloride. J. Anim. Sci. 20:518.
Weeth, H. J., L. H. Haverland, and D. W. Cassard. 1960. Consumption of sodium chloride water by heifers. J. Anim. Sci. 19:845.

### *Sulfur*

Baker, D. H. 1977. Sulfur in Nonruminant Nutrition. Natl. Feed Ingred. Assoc., Des Moines, Iowa.
Block, R. J., J. A. Stekol, and J. K. Loosli. 1951. Synthesis of sulfur amino acids from inorganic sulfate by ruminants. II. Synthesis of cysteine and methionine from sodium sulfate by the goat and by the microorganisms of the rumen of the ewe. Arch. Biochem. Biophys. 33:353.
Bouchard, R., and H. R. Conrad. 1976. Do cows in milk get enough sulfur? Hoard's Dairyman 121:260.
Bray, A. C. 1969. Sulphur metabolism in sheep. II. The absorption of inorganic sulphate and inorganic sulphide from the sheep's rumen. Aust. J. Agric. Res. 20:739.
Coghlin, C. L. 1944. Hydrogen sulfide poisoning in cattle. Can. J. Comp. Med. 8:11.
Dick, A. T., D. W. Dewey, and J. M. Gawthorne. 1974. Thiomolybdates and the copper-molybdenum-sulphur interaction in ruminant nutrition. J. Agric. Sci. 85:567.
Diplock, A. T. 1976. Metabolic aspects of selenium action and toxicity. CRC Crit. Rev. Tox. 4:271.
Dowdy, R. P., and G. Matrone. 1968a. Copper-molybdenum interaction in sheep and chicks. J. Nutr. 95:191.
Dowdy, R. P., and G. Matrone. 1968b. A copper-molybdenum complex. Its effects and movements in the piglet and sheep. J. Nutr. 95:197.
Goodrich, R. D., T. S. Kahlon, D. E. Pamp, and D. P. Cooper. 1978. Sulfur in Ruminant Nutrition. Natl. Feed Ingred. Assoc., Des Moines, Iowa.
Huisingh, J., G. G. Gomez, and G. Matrone. 1973. Interactions of copper, molybdenum, and sulfate in ruminant nutrition. Fed. Proc. 32:1921.
Kahlon, T. S., J. C. Meiske, and R. D. Goodrich. 1974. Sulfur metabolism in ruminants. 1. *In vitro* availability of various chemical forms of sulfur. J. Anim. Sci. 41:1147.
Leibholz, J. 1972. The effect of nitrogen intake, sulphur intake and dietary nitrogen source on the performance of the early weaned calf. Aust. J. Exp. Agric. Anim. Husb. 12:561.
Masters, M., and R. A. McCance. 1939. The sulfur content of foods. Biochem. J. 33:1304.
Meiske, J. C., R. D. Goodrich, A. L. Harvey, and O. E. Kolari. 1966. The value of added sulfur to linseed meal or corn-urea supplements for finishing steers. Minn. Beef Cattle Feeders Day Rep., p. 9.
National Research Council. 1980. Mineral Tolerance of Domestic Animals. Washington, D.C.: National Academy of Sciences.
Rees, M. C., D. J. Minson, and F. W. Smith. 1974. The effect of supplementary and fertilizer sulphur on voluntary intake, digestibility, retention time in the rumen, and site of digestion of pangola grass in sheep. J. Agric. Sci. 82:419.
Saville, D. G., P. J. Nicholls, and W. R. McManus. 1975. Whole wheat grain feeding of pregnant and lactating ewes and their lambs. I. The influence of energy, sodium chloride and elemental sulphur on ewe productivity. Aust. J. Exp. Agric. Anim. Husb. 15:601.
Starks, P. B., W. H. Hale, U. S. Garrigus, and R. M. Forbes. 1953. The utilization of feed nitrogen by lambs as affected by elemental sulfur. J. Anim. Sci. 12:480.
Thomas, W. E., J. K. Loosli, H. H. Williams, and L. A. Maynard. 1951. The utilization of inorganic sulfates and urea nitrogen by lambs. J. Nutr. 43:515.
Weir, W. C., and V. V. Rendig. 1952. Studies on the nutritive value for lambs of alfalfa hay grown on a low sulfur soil. J. Anim. Sci. 11:780 (Abstr.).
Whanger, P. D. 1968. Sulfur in ruminant nutrition. Metabolism and importance. Sulphur Inst. J. 4:9.
Whanger, P. D. 1970. Sulphur-selenium relationships in animal nutrition. Sulphur Inst. J. 6:6
Whanger, P. D., and G. Matrone. 1966. Effect of dietary sulfur upon the production and absorption of lactate in sheep. Biochem. Biophys. Acta 124:273.
Whanger, P. D., and G. Matrone. 1967. Metabolism of lactic, succinic and acrylic acids by rumen microorganisms from sheep fed sulfur-adequate and sulfur-deficient diets. Biochem. Biophys. Acta 126:27.

### *Zinc*

Bertrand, G., and R. C. Bhattacherjee. 1935. Recherez sur l'action combinee du zinc et des vitamines dam l'alimentation des animaux. Ann. Pasteur Inst. 55:265.
Feaster, J. P., S. L. Hansard, J. T. McCall, F. H. Skipper, and G. K. Davis. 1954. Absorption and tissue distribution of radiozinc in steers fed high-zinc rations. J. Anim. Sci. 13:78.

Holod, V. M., G. E. Spak, and J. L. Gutkovic. 1969. Role of Zn and Mo in the nutrition of sheep. Nutr. Abstr. Rev. 39:976.

Hsu, J. M., and J. K. Anilare. 1966. Effect of Zn deficiency on zinc metalloenzymes in rats. Proc. Seventh Int. Cong. Nutr. 5:753.

Ivan, M., and C. M. Grieve. 1975. Effects of zinc, copper and manganese supplementation of high-concentrate ration digestibility, growth and tissue content of Holstein calves. J. Dairy Sci. 58:410.

Mayland, H. F. 1975. Zinc increases range cattle weight gains. J. Anim. Sci. 41:337 (Abstr.).

Miller, J. K., and W. J. Miller. 1962. Experimental zinc deficiency and recovery in calves. J. Nutr. 76:467.

Miller, J. K., and R. G. Cragle. 1965. Gastrointestinal sites of absorption and endogenous secretion of zinc in dairy cattle. J. Dairy Sci. 48:370.

Miller, J. K., W. J. Miller, and C. M. Clifton. 1962. Calf response to starters of varying zinc contents. J. Dairy Sci. 45:1536.

Miller, W. J., C. M. Clifton, and N. W. Cameron. 1963. Zinc requirement of Holstein bull calves to nine months of age. J. Dairy Sci. 46:715.

Miller, W. J., G. W. Powell, C. M. Clifton, and J. D. Morton. 1965. Effects of zinc deficiency per se on feed efficiency, serum alkaline phosphatase, zinc in skin, behavior, greying and other measurements in the Holstein calf. J. Dairy Sci. 48:1329.

Mills, C. F., A. C. Dalgarno, R. B. Williams, and J. Quarterman. 1967. Zinc deficiency and the zinc requirement of calves and lambs. Br. J. Nutr. 21:751.

Mills, C. F., J. Quarterman, J. K. Chesters, R. B. Williams, and A. C. Dalgarno. 1969. Metabolic role of zinc. Am. J. Clin. Nutr. 22:1240.

National Research Council. 1980. Mineral Tolerance of Domestic Animals. Washington, D.C.: National Academy of Sciences.

Ott, E. A., W. H. Smith, M. Stob, H. E. Parker, and W. M. Beeson. 1965. Zinc deficiency syndrome in the young calf. J. Anim. Sci. 24:735.

Perry, T. W., W. M. Beeson, W. H. Smith, and M. T. Mohler. 1968. Value of zinc supplementation of natural rations for fattening beef cattle. J. Anim. Sci. 27:1674.

Pierson, R. E. 1966. Zinc deficiency in young lambs. J. Am. Vet. Med. Assoc. 149:1279.

Pitts, W. J., W. J. Miller, O. T. Fosgate, J. D. Morton, and C. M. Clifton. 1966. Effect of zinc deficiency and restricted feeding from two to five months of age on reproduction in Holstein bulls. J. Dairy Sci. 49:995.

Stake, P. E., W. J. Miller, and R. P. Gentry. 1973. Zinc metabolism and homeostasis in ruminants as affected by dietary energy intake and growth rate. Proc. Soc. Exp. Biol. Med. 142:494.

Suttle, N. F., and A. C. Field. 1970. Effects of dietary calcium and phosphorus concentration on the fecal excretion of copper, manganese and zinc in sheep. Proc. Nutr. Soc. 29:33A.

Underwood, E. J. 1956. Trace Elements in Human and Animal Nutrition. New York: Academic Press.

Van Campen, D. R. 1969. Copper interference with the intestinal absorption of zinc-65 by rats. J. Nutr. 97:104.

Van Campen, D. E., and A. Mitchell. 1965. Absorption of $Cu^{64}$, $Zn^{65}$, $Mo^{99}$ and $Fe^{59}$ from ligated segments of the rat gastrointestinal tract. J. Nutr. 86:120.

Vallee, B. L. 1959. Biochemistry, physiology and pathology of zinc. Physiol. Rev. 39:443.

Vallee, B. L. 1962. Zinc. Pp. 443–482 *in* Mineral Metabolism, Vol. 2, Part B. New York: Academic Press.

## VITAMINS

Ammerman, C. B. 1970. Recent developments in cobalt and copper in ruminant nutrition: A review. J. Dairy Sci. 53:1097.

Chapman, H. L., Jr., R. L. Shirley, A. Z. Palmer, C. E. Haines, J. W. Carpenter, and T. J. Cunha. 1964. Vitamins A and E in steer fattening rations on pasture. J. Anim. Sci. 23:669.

Church, D. C., L. S. Pope, and R. MacVicar. 1956. Effect of plane of nutrition of beef cows on depletion of liver vitamin A during gestation and on carotene requirements during lactation. J. Anim. Sci. 15:1078.

Clifford, A. J., R. D. Goodrich, and A. D. Tillman. 1967. Effects of supplementing ruminant all-concentrate and purified diets with vitamins of the B complex. J. Anim. Sci. 26:400.

Conrad, H. R., and J. W. Hibbs. 1954. A high roughage system for raising calves based on early rumen development. IV. Synthesis of thiamine and riboflavin in the rumen as influenced by ratio of hay to grain fed and initiation of dry feed consumption. J. Dairy Sci. 37:512.

Cullison, A. E., and C. S. Ward. 1965. Coastal Bermuda grass hay as a source of vitamin A for beef cattle. J. Anim. Sci. 24:969.

DeLuca, H. F. 1974. Vitamin D: The vitamin and the hormone. Fed. Proc. 33:2211.

Draper, H. H., J. T. Sime, and B. C. Johnson. 1952. A study of vitamin $B_{12}$ deficiency in the calf. J. Anim. Sci. 11:332.

Eaton, H. D., J. E. Rousseau, Jr., R. C. Hall, Jr., H. I. Frier, and J. J. Lucas. 1972. Reevaluation of the mininum vitamin A requirement of Holstein male calves based upon elevated cerebrospinal fluid pressure. J. Dairy Sci. 55:232.

Frey, R. R., and R. Jensen. 1947. Depletion of vitamin A reserves in the livers of cattle. Science 105:313.

Grigat, G. A., and G. W. Mathison. 1982. Thiamin supplementation of an all-concentrate diet for feedlot steers. Can. J. Anim. Sci. 62:807.

Grigat, G. A., and G. W. Mathison. 1983. Thiamin and magnesium supplementation diets for feedlot steers. Can. J. Anim. Sci. 63:117.

Guilbert, H. R., and G. H. Hart. 1935. Minimum vitamin A with particular reference to cattle. J. Nutr. 10:409.

Guilbert, H. R., and L. H. Rochford. 1940. Beef production in California. Calif. Agric. Exp. Stn. Circ. 11.

Guilbert, H. R., C. E. Howell, and G. H. Hart. 1940. Minimum vitamin A and carotene requirements of mammalian species. J. Nutr. 19:91.

Gullickson, T. W., and C. W. Calverley. 1946. Cardiac failure in cattle on the vitamin E-free rations as revealed by electrocardiograms. Science 104:312.

Hart, G. H. 1940. Vitamin A deficiency and requirements of farm mammals. Nutr. Abstr. Rev. 10:261.

Hayes, B. W., G. E. Mitchell, Jr., C. O. Little, and N. W. Bradley. 1966. Concentrations of B-vitamins in ruminal fluid of steers fed different levels and physical forms of hay and grain. J. Anim. Sci. 25:539.

Hayes, B. W., G. E. Mitchell, Jr., C. O. Little, and H. B. Sewell. 1967. Turnover of liver vitamin A in steers. J. Anim. Sci. 26:855.

Hoekstra, W. G. 1975. Biochemical function of selenium and its relation to vitamin E. Fed. Proc. 34:2083.

Hemken, R. W., and D. H. Bremel. 1982. Possible role of beta-carotene in improving fertility in dairy cattle. J. Dairy Sci. 65:1069.

Hopper, J. H., and B. C. Johnson. 1955. The production and study of an acute nicotinic acid deficiency in the calf. J. Nutr. 56:303.

Horst, R. L., and T. A. Reinhardt. 1983. Vitamin D metabolism in ruminants and its relevance to the periparturient cow. J. Dairy Sci. 66:661.

Hunt, C. H., E. W. Burroughs, R. M. Bethke, A. F. Schalk, and P. Gerlaugh. 1943. Further studies on riboflavin and thiamine in the rumen content of cattle. II. J. Nutr. 25:207.

Johnson, B. C., T. S. Hamilton, W. B. Nevens, and L. E. Boley. 1948. Thiamine deficiency in the calf. J. Nutr. 35:137.

Johnson, B. C., J. A. Pinkos, and K. A. Burke. 1950. Pyridoxine deficiency in the calf. J. Nutr. 40:309.
Johnson, B. C., H. H. Mitchell, and J. A. Pinkos. 1951. Choline deficiency in the calf. J. Nutr. 43:37.
Jones, J. H., J. K. Riggs, G. S. Fraps, J. M. Jones, H. Schmidt, R. E. Dickson, P. E. Howe, and W. H. Black. 1938. Carotene requirements for fattening beef cattle. Proc. Am. Soc. Anim. Prod. 94:102.
Jordan, H. A., G. S. Smith, A. L. Neumann, J. E. Zimmerman, and G. W. Breniman. 1963. Vitamin A nutrition of beef cattle fed corn silage. J. Anim. Sci. 22:738.
Keating, E. K., W. H. Hale, and F. Hubbert, Jr. 1964. In vitro degradation of vitamin A and carotene by rumen liquor. J. Anim. Sci. 23:111.
Kirk, W. G., R. L. Shirley, J. F. Easley, and F. M. Peacock. 1971. Effect of carotene deficient rations and supplemental vitamin A on gain, feed utilization and liver vitamin A of calves. J. Anim. Sci. 33:476.
Klatte, F. J., G. E. Mitchell, Jr., and C. O. Little. 1964. In vitro destruction of vitamin A by abomasal and ruminal contents. J. Agric. Food Chem. 12:420.
Kohlmeier, R. H., and W. Burroughs. 1970. Estimation of critical plasma and liver vitamin A levels in feedlot cattle with observations upon influences of body stores and daily dietary requirements. J. Anim. Sci. 30:1012.
Lassiter, C. A., G. M. Ward, C. F. Huffman, C. W. Duncan, and H. D. Webster. 1953. Crystalline vitamin $B_{12}$ requirement of the young dairy calf. J. Dairy Sci. 36:997.
Link, K. P. 1959. The discovery of dicumarol and its sequels. Circulation 19:97.
Loew, F. M., and R. H. Dunlop. 1972. Induction of thiamine inadequacy and polioencephalomalacia in adult sheep with Amprolium. Am. J. Vet. Res. 33:2195.
Madsen, L. L., and I. P. Earle. 1947. Some observations on beef cattle affected with generalized edema or anasarca due to vitamin A deficiency. J. Nutr. 34:603.
Madsen, L. L., O. N. Eaton, L. Memmstra, R. E. Davis, C. A. Cabell, and B. Knapp, Jr. 1948. Effectiveness of carotene and failure of ascorbic acid to increase sexual activity and semen quality of vitamin A deficient beef bulls. J. Anim. Sci. 7:60.
Marston, H. R., S. H. Allen, and R. M. Smith. 1961. Primary metabolic defect supervening on vitamin $B_{12}$ deficiency in sheep. Nature 190:1085.
McElroy, L. W., and H. Goss. 1940a. A quantitative study of vitamins in the rumen contents of sheep and goats fed vitamin-low diets. I. Riboflavin and vitamin K. J. Nutr. 20:527.
McElroy, L. W., and H. Goss. 1940b. A quantitative study of vitamins in the rumen contents of sheep and goats fed vitamin-low diets. II. Vitamin $B_6$ (Pyridoxine). J. Nutr. 20:541.
McElroy, L. W., and H. Goss. 1941a. A quantitative study of vitamins in the rumen content of sheep and cows fed vitamin-low diets. III. Thiamine. J. Nutr. 21:163.
McElroy, L. W., and H. Goss. 1941b. A quantitative study of vitamins in the rumen content of sheep and cows fed vitamin-low diets. IV. Pantothenic acid. J. Nutr. 21:405.
Meacham, T. N., K. P. Bovard, B. M. Priode, and J. P. Fontenot. 1970. Effect of supplemental vitamin A on the performance of beef cows and their calves. J. Anim. Sci. 31:428.
Miller, R. W., R. W. Hemken, D. R. Waldo, and L. H. Moore. 1967. Vitamin A metabolism in steers fed corn silage or alfalfa hay pellets. J. Dairy Sci. 50:997.
Mitchell, G. E., Jr. 1967. Vitamin A nutrition of ruminants. J. Am. Vet. Med. Assoc. 151:430.
Mitchell, G. E., Jr., C. O. Little, and B. W. Hayes. 1967. Pre-intestinal destruction of vitamin A by ruminants fed nitrates. J. Anim. Sci. 26:827.
Moore, L. A. 1939. Carotene intake, level of blood plasma carotene, and the development of papillary edema and nyctalopia in calves. J. Dairy Sci. 22:803.
Moore, L. A. 1941. Some ocular changes and deficiency manifestations in mature cows fed a ration deficient in vitamin A. J. Dairy Sci. 24:893.
Moore, T. 1957. Vitamin A. Amsterdam: Elsevier.
Muth, O. H., J. E. Oldfield, L. F. Remmert, and J. P. Schubert. 1958. Effect of selenium and vitamin E on white muscle disease. Science 128:1090.
Parakkasi, A., G. E. Mitchell, Jr., R. E. Tucker, C. O. Little, and A. W. Young. 1970. Pre-intestinal disappearance of vitamin $D_2$2 in ruminants. J. Anim. Sci. 35:273 (Abstr.).
National Research Council. 1976. Nutrient Requirements of Beef Cattle. Washington, D.C.: National Academy of Sciences.
Perry, T. W., W. H. Smith, W. M. Beeson, and M. T. Mohler. 1965. Value of supplemental vitamin A for fattening beef cattle on pasture. J. Anim. Sci. 25:814.
Perry, T. W., W. M. Beeson, W. H. Smith, and M. T. Mohler. 1967. Injectible vs. oral vitamin A for fattening steer calves. J. Anim. Sci. 26:115.
Perry, T. W., W. M. Beeson, W. H. Smith, R. B. Harrington, and M. T. Mohler. 1968. Interrelationships among vitamins A, E, and K when added to the rations of fattening beef cattle. J. Anim. Sci. 27:190.
Riddell, D. O., E. E. Bartley, and A. D. Dayton. 1980. Effect of nicotinic acid on rumen fermentation in vitro and in vivo. J. Dairy Sci. 63:1429.
Riddell, D. O., E. E. Bartley, and A. D. Dayton. 1981. Effect of nicotinic acid on microbial protein synthesis in vitro and on dairy cattle growth and milk production. J. Dairy Sci. 64:782.
Rupel, I. W., G. Bohstedt, and E. B. Hart. 1933. Vitamin D in the nutrition of the dairy calf. Wisc. Agric. Exp. Stn. Res. Bull. 115.
Sapienza, D. A., and B. E. Brent. 1974. Ruminal thiaminase vs. concentrate adaptation. J. Anim. Sci. 31:251.
Schelling, G. T., L. W. Chittenden, T. C. Jackson, Jr., S. A. Koch, R. L. Stuart, R. E. Tucker, and G. E. Mitchell, Jr. 1975. Liver storage of oral and intramuscular vitamin A. J. Anim. Sci. 40:199 (Abstr.).
Sheppard, J. J., and B. C. Johnson. 1957. Pantothenic acid deficiency in the growing calf. J. Nutr. 61:195.
Smith, G. W., W. M. Durdle, J. E. Zimmerman, and A. L. Neumann. 1964. Relationships of carotene intake, thyro-active substances and soil fertility to vitamin A depletion of feeder cattle fed corn silages. J. Anim. Sci. 23:625.
Sommerfeldt, J. L., R. L. Horst, E. T. Littledike, and D. C. Beitz. 1979. In vitro degradation of cholecalciferol in rumen fluid. J. Dairy Sci. 62 (Suppl. 1):192 (Abstr.).
Somogyi, J. C. 1973. Antivitamins. Pp. 254-275 *in* Toxicants Occurring Naturally in Foods. Washington, D.C.: National Academy of Sciences.
Stafford, J. W., K. F. Swingle, and H. Marsh. 1954. Experimental tocopherol deficiency in young calves. Am. J. Vet. Res. 15:373.
Stallings, B. R., J. W. Bratzler, L. F. Marriott, and R. C. Miller. 1964. Utilization of magnesium and other minerals by ruminants consuming low and high nitrogen-containing forages and vitamin D. J. Anim. Sci. 23:1148.
Swanson, E. W., G. G. Martin, F. E. Pardue, and G. M. Gorman. 1968. Milk production of cows fed diets deficient in vitamin A. J. Anim. Sci. 27:541.
Ullrey, D. E. 1972. Symposium—Biological Availability of Nutrients in Feeds. Biological availability of fat-soluble vitamins: Vitamin A and carotene. J. Anim. Sci. 35:648.

Wallis, G. C. 1944. Vitamin D deficiency in dairy cows: symptoms, causes, and treatment. S. Dak. Agric. Exp. Stn. Bull. 372.

Warner, R. G., and T. S. Sutton. 1948. The nutrition of the newborn dairy calf. III. The response to a photolyzed milk diet. J. Dairy Sci. 31:976.

Wegner, M. I., A. N. Booth, C. A. Elvehjem, and E. B. Hart. 1940. Rumen synthesis of the vitamin B complex. Proc. Soc. Exp. Biol. Med. 45:769.

Wegner, M. I., A. N. Booth, C. A. Elvehjem, and E. B. Hart. 1941. Rumen synthesis of the vitamin B complex on natural rations. Proc. Soc. Exp. Biol. Med. 47:9.

Wiese, A. C., B. C. Johnson, and W. B. Nevens. 1946. Biotin deficiency in the dairy calf. Proc. Soc. Exp. Biol. Med. 63:521.

Wiese, A. C., B. C. Johnson, H. H. Mitchell, and W. B. Nevens. 1947. Riboflavin deficiency in the dairy calf. J. Nutr. 33:263.

## WATER

National Research Council. 1974. Nutrients and Toxic Substances in Water for Livestock and Poultry. Washington, D.C.: National Academy of Sciences.

Utley, P. R., N. W. Bradley, and J. A. Boling. 1970. Effect of restricting water intake on feed intake, nutrient digestibility and nitrogen metabolism in steers. J. Anim. Sci. 31:130.

Winchester, C. F., and M. J. Morris. 1956. Water intake rates of cattle. J. Anim. Sci. 15:722.

## BREEDING FEMALES

Anderson, V. L., L. Jost, C. A. Dinkel, and M. A. Brown. 1983. Prediction of daily total digestible nutrient requirement of beef cows in northern climates. J. Anim. Sci. 56:271.

Bellows, R. W., and R. E. Short. 1978. Effect of precalving feed level on birth weight, calving difficulty and subsequent fertility. J. Anim. Sci. 46:1522.

Blaxter, K. L., and R. S. Wilson. 1963. An assessment of a crop husbandry technique in terms of animal production. Anim. Prod. 5:27.

Campling, R. C. 1966. A preliminary study of the effect of pregnancy and lactation on the voluntary intake of food by cows. Br. J. Nutr. 20:25.

Campling, R. C., and C. C. Balch. 1961. Factors affecting the voluntary intake of food by cows. 1. Preliminary observations on the effect, on the voluntary intake of hay, of changes in the amount of the reticulo-ruminal contents. Br. J. Nutr. 15:523.

Campling, R. C., M. Freer, and C. C. Balch. 1961. Factors affecting the voluntary intake of food by cows. 2. The relationship between the voluntary intake of roughages, the amount of digestion in the reticulo-rumen and the rate of disappearance of digesta from the alimentary tract. Br. J. Nutr. 15:531.

Campling, R. C., M. Freer, and C. C. Balch. 1962. Factors affecting the voluntary intake of food by cows. 3. Effect of urea on the voluntary intake of oat straw. Br. J. Nutr. 16:115.

Clanton, D. C., and D. R. Zimmerman. 1970. Symposium on pasture methods for maximum production in beef cattle: Protein and energy requirements for female beef cattle. J. Anim. Sci. 30:122.

Clanton, D. C., J. T. Nichols, and B. R. Somerhalder. 1971. Young cows on irrigated pasture. Nebr. Beef Cattle Rep. EC 71-218:16.

Conrad, H. R., A. D. Pratt, and J. W. Hibbs. 1964. Regulation of feed intake in dairy cows. 1. Change in importance of physical and physiological factors with increasing digestibility. J. Dairy Sci. 47:54.

Forbes, T. J., A. M. Raven, J. H. Irwin, and K. L. Robinson. 1967. The utilization of grass fed indoors to young beef cattle, with or without supplementary barley. J. Br. Grassl. Soc. 22:158.

Hennessy, D. W., and G. G. Robinson. 1979. The herbage intake, eating behavior and calf production of beef cows grazing improved pastures on the Northern Tablelands of New South Wales. Aust. J. Exp. Agric. Anim. Husb. 19:261.

Holloway, J. W., W. T. Butts, Jr., J. D. Beaty, J. T. Hopper, and N. S. Hall. 1979. Forage intake and performance of lactating beef cows grazing high or low quality pastures. J. Anim. Sci. 48:692.

Horn, F. P., J. P. Telford, J. E. McCroskey, D. F. Stephens, J. V. Whiteman, and R. Totusek. 1979. Relationship of animal performance and dry matter intake to chemical constituents of grazed forage. J. Anim. Sci. 49:1051.

Johnstone-Wallace, D. B., and K. Kennedy. 1944. Grazing management practices and their relationship to the behavior and grazing habits of cattle. J. Agric. Sci. 34:190.

Jordan, W. A., E. E. Lister, J. M. Wauthy, and J. E. Comeau. 1973. Voluntary roughage intake by nonpregnant and pregnant or lactating beef cows. Can. J. Anim. Sci. 53:733.

Kartchner, R. J., L. R. Rittenhouse, and R. J. Raleigh. 1979. Forage and animal management implications of spring and fall calving. J. Anim. Sci. 48:425.

Klosterman, E. W., L. G. Stanford, and C. F. Parker. 1968. Effect of cow size and condition and ration protein content upon maintenance requirements of mature beef cows. J. Anim. Sci. 27:242.

Lemenager, R. P., F. N. Owens, K. S. Lusby, and R. Totusek. 1978. Monensin, forage intake and lactation of range beef cows. J. Anim. Sci. 43:543.

Lemenager, R. P., L. A. Nelson, and K. S. Hendrix. 1980. Influence of cow size and breed type on energy requirements. J. Anim. Sci. 51:566.

Lusby, K. S., D. F. Stephens, and R. Totusek. 1976. Influence of breed and levels of winter supplement on forage intake of range cows. J. Anim. Sci. 43:543.

National Research Council. 1978. Nutrient Requirements of Dairy Cattle. Washington, D. C.: National Academy of Sciences.

National Research Council. 1981b. Effect of Environment on Nutrient Requirements of Domestic Animals. Washington, D.C.: National Academy Press.

Phillips, R. L., and M. Vavra. 1981. The effect of pre-calving energy levels on cow performance. Proc. West. Sec., Am. Soc. Anim. Sci. 32:117.

Powell, D. J., D. C. Clanton, and J. T. Nichols. 1982. Effect of range condition on the diet and performance of steers grazing native sandhills range in Nebraska. J. Range Manage. 35:96.

Pruitt, R. J. 1980. Forage intake and performance of range beef cows as affected by delayed winter supplemental feeding and mineral supplementation. M.S. thesis. Kansas State University, Manhattan.

Rittenhouse, L. R., D. C. Clanton, and C. L. Streeter. 1970. Intake and digestibility of winter-range forage by cattle with and without supplements. J. Anim. Sci. 31:1215.

Scales, G. H., A. H. Denham, C. L. Streeter, and G. M. Ward. 1974. Winter supplementation of beef calves on sandhill range. J. Anim. Sci. 38:442.

Streeter, C. L., D. C. Clanton, and O. E. Hoehne. 1968. Influence of advance in season on nutritive value of forage consumed by cattle grazing western Nebraska native range. Nebr. Agric. Exp. Stn. Res. Bull. 227.

Streeter, C. L., C. B. Rumberg, T. H. Hall, and E. G. Siemer. 1974. Meadow forage quality, intake and milk production of cows. J. Range Manage. 27:133.

Thompson, W. R., J. C. Meiske, R. D. Goodrich, J. R. Rust, and F. M. Byers. 1983. Influence of body composition on energy requirements of beef cows during winter. J. Anim. Sci. 56:1241.

Umoh, J. E., and W. Holmes. 1974. The influence of type and level of supplementary feed on intake and performance of beef cattle on pasture. J. Br. Grassl. Soc. 29:31.

Wiltbank, J. N., W. W. Rowden, J. E. Ingalls, K. E. Gregory, and R. M. Koch. 1962. Effect of energy level on reproductive phenomena of mature Hereford cows. J. Anim. Sci. 21:219.

Wiltbank, J. N., W. W. Rowden, J. E. Ingalls, and D. R. Zimmerman. 1964. Influence of post-partum energy level on reproductive performance of Hereford cows restricted in energy intake prior to calving. J. Anim. Sci. 23:1049.

Yates, D. A., D. C. Clanton, and J. T. Nichols. 1982. Effect of continuous grazing on the diet of steers. J. Range Manage. 35:339.

## PROCESSING FEEDSTUFFS

Berger, L. L., T. Klopfenstein, and R. Britton. 1979. Effects of sodium hydroxide on efficiency of rumen digestion. J. Anim. Sci. 49:1317.

Brethour, J. R. 1970. The use and value of wheat in beef cattle feeding. Pp. 177–190 *in* Wheat in Livestock and Poultry Feeds. Proceedings of an International Symposium at Oklahoma State University, June 18–19.

Brethour, J. R. 1980. Nutritional value of milo for cattle. Report of Progress 384, Roundup 67, Fort Hays Branch, Kansas State University: 5–8.

Buchanan-Smith, J. G., R. Totusek, and A. D. Tillman. 1968. Effect of methods of processing on digestibility and utilization grain sorghum by cattle and sheep. J. Anim. Sci. 27:525.

Campling, R. C., and J. A. Milne. 1972. The nutritive value of processed roughage for milking cattle. Proc. Br. Soc. Anim. Prod. 53–60.

Clark, J. H. 1975. Utilization of high-moisture grains by dairy and beef cattle. Second International Silage Research Conference. Tech. Pap. 205–238.

Coombe, J. B., D. A. Dinius, and W. E. Wheeler. 1979. Effect of alkali treatment on intake and digestion of barley straw by beef steers. J. Anim. Sci. 49:169.

Croka, D. C., and D. G. Wagner. 1975. Micronized sorghum grain. III. Energetic efficiency for feedlot cattle. J. Anim. Sci. 40:936.

Franks, L. G., J. R. Newsom, R. E. Renbarger, and R. Totusek. 1972. Relationship of rumen volatile fatty acids to type of grains, sorghum grain processing method and feedlot performance. J. Anim. Sci. 35:404.

Galyean, M., D. G. Wagner, and R. R. Johnson. 1976. Site and extent of starch digestion in steers fed processed corn rations. J. Anim. Sci. 43:1088.

Galyean, M. L., D. G. Wagner, and F. N. Owens. 1979. Corn particles size and site and extent of digestion by steers. J. Anim. Sci. 49:204.

Garrett, W. N. 1965. Comparative feeding value of steam-rolled or ground barley and milo for cattle. J. Anim. Sci. 24:726.

Garrett, W. N. 1968. Influence of method of processing on the feeding value of milo and wheat. Eighth Annu. Calif. Feeders Day Rep.

Garrett, W. N., G. P. Lofgreen, and J. L. Hull. 1966. Steam processing of wheat, corn, barley and milo for feedlot cattle. Sixth Annu. Calif. Feeders Day Rep.

Garrett, W. N., H. G. Walker, G. D. Kohler, and M. R. Hart. 1979. Response of ruminants to diets containing sodium hydroxide or ammonia treated rice straw. J. Anim. Sci. 48:92.

Goering, H. K. 1976. A laboratory assessment of the frequency of overheating in commercial dehydrated alfalfa samples. J. Anim. Sci. 43:869.

Goodrich, R. D., and J. C. Meiske. 1966. Whole corn grain vs. ground corn grain, long hay vs. ground hay and 10 lb. vs. 15 lb. of corn silage for finishing cattle. Minn. Beef Cattle Feeders Day Res. Rep. B-76:61–67.

Greenhalgh, J. F. D., and F. W. Wainman. 1972. The nutritive value of processed roughages for fattening cattle and sheep. Proc. Br. Soc. Anim. Prod. 61–72.

Hale, W. H., and C. B. Theurer. 1972. Feed preparation and processing. Pp. 49–76 *in* Digestive Physiology and Nutrition of Ruminants. Vol. 3. Practical Nutrition, D. C. Church, ed. Corvallis, Oreg.: Oregon State University.

Hale, W. H., C. B. Theurer, J. A. Marchello, B. R. Taylor, and H. Essig. 1970. Bird resistant milo and wheat in high concentrate steer fattening rations. Ariz. Cattle Feeders Day Ser. P-12.

Hinman, D. D., and R. R. Johnson. 1974. Influence of processing methods on digestion of sorghum starch in high concentrate beef cattle rations. J. Anim. Sci. 39:417.

Hironaka, R., N. Kimura, and G. C. Kozub. 1979. Influence of feed particle size on rate and efficiency of gain characteristics of rumen fluid and rumen epithelium, and numbers of rumen protozoa. Can. J. Anim. Sci. 59:395.

Homb, T., F. Sundstol, and J. Arnason. 1977. Chemical treatment of straw at commercial and farm levels. Pp. 25–38 *in* F.A.O. (U.N.) Animal Production and Health Paper No. 4—New Feed Resources. F.A.O., Rome.

Horrisberger, G., F. M. Byers, and G. R. Wilson. 1979. The efficacy of sodium hydroxide treatment through cubing on feedlot performance and forage energy utilization of cattle. Ohio Beef Cattle Res. Rep. Animal Sci. Series 79. Pp. 26–31.

Horton, G. M. J. 1978. The intake and digestibility of ammoniated cereal straws by cattle. Can. J. Anim. Sci. 58:471.

Horton, G. M. J., and G. M. Steacy. 1979. Effect of anhydrous ammonia treatment on the intake and digestibility of cereal straws by steers. J. Anim. Sci. 48:1239.

Husted, W. T., S. Mehen, W. H. Hale, M. Little, and B. Theurer. 1968. Digestibility of milo processed by different methods. J. Anim. Sci. 27:531.

Jackson, M. G. 1978. Treating Straw for Animal Feeding. F.A.O., Production and Health Paper 10. F.A.O., Rome.

Johnson, D. E., J. K. Matsushima, and K. L. Knox. 1968. Utilization of flaked vs. cracked corn by steers with observations on starch modification. J. Anim. Sci. 27:1431.

Keating, E. R., W. J. Saba, W. H. Hale, and B. Taylor. 1965. Further observations on the digestion of milo and barley by steers and lambs. J. Anim. Sci. 24:1080.

Kernan, J., E. Coxworth, H. Nicholson, and R. Chaplin. 1977. Ammoniation of straw to improve its nutritional value as a feed for ruminant animals. Univ. Saskatchewan Coll. Agric. Ext. Pub. 329:1–13.

Kiesling, H. E., J. E. McCroskey, and D. G. Wagner. 1973. A comparison of energetic efficiency of dry rolled and reconstituted rolled sorghum grain by steers using indirect calorimetry and the comparative slaughter technique. J. Anim. Sci. 37:790.

Klopfenstein, T., L. Berger, and J. Paterson. 1979. Performance of animals fed crop residues. Fed. Proc. 38:1939.

Macleod, G. K., D. N. Mowat, and R. A. Curtis. 1976. Feeding value for finishing steers and Holstein male calves of whole dried corn and of whole and rolled high moisture acid-treated corn. Can. J. Anim. Sci. 56:43.

Maxson, W. E., R. L. Shirley, J. E. Bertrand, and A. Z. Palmer. 1973. Energy values of corn, bird-resistant and non bird-resistant sorghum grain in rations fed to steers. J. Anim. Sci. 37:1451.

McCaffree, J. D., and W. G. Merrill. 1968. High moisture corn for dairy cows in early lactation. J. Dairy Sci. 51:553.

McDonald, P., and R. A. Edwards. 1976. Influence of conservation methods on digestion and utilization of forages by ruminants. Proc. Nutr. Soc. 35:201.

McKnight, D. R., G. K. Macleod, J. G. Buchanan-Smith, and D. N. Mowat. 1973. Utilization of ensiled or acid-treated high-moisture shelled corn by cattle. Can. J. Anim. Sci. 53:491.

McNeill, J. W., G. D. Potter, and J. K. Riggs. 1971. Ruminal and postruminal carbohydrate utilization in steers fed processed sorghum grain. J. Anim. Sci. 33:1371.

Minson, D. J. 1963. The effect of pelleting and wafering on the feeding value of roughage—a review. J. Br. Grassl. Soc. 18:39.

Moe, P. W., and H. F. Tyrrell. 1977. Effects of feed intake and physical form on energy value of corn in timothy hay diets for lactating cows. J. Dairy Sci. 60:752–758.

Moe, P. W., and H. F. Tyrrell. 1979. Effect of endosperm type on incremental energy value of corn grain for dairy cows. J. Dairy Sci. 62:447.

Moe, P. W., H. F. Tyrrell, and N. W. Hoover, Jr. 1973. Physical form and energy value of corn in timothy hay diets for lactating cows. J. Dairy Sci. 60:752.

Morgan, C. A., and R. C. Campling. 1978. Digestibility of whole barley and oats grains by cattle of different ages. Anim. Prod. 27:323.

Morris, P. J., and D. N. Mowat. 1980. Nutritive value of ground and/or ammoniated corn stover. Can. J. Anim. Sci. 60:327.

Murdoch, J. C. 1965. The effect of length of silage on voluntary intake by cattle. J. Br. Grassl. Soc. 20:54.

National Research Council. 1981b. Effect of Environment on Nutrient Requirements of Domestic Animals. Washington, D.C.: National Academy Press.

Newsom, J., R. Totusek, R. Renbarger, E. C. Nelson, L. Franks, V. Newhouse, and W. Basler. 1968. Methods of processing milo for fattening cattle. Animal Science Research, Okla. Agric. Exp. Stn. Misc. Publ. 80.

Oji, U., J. G. Buchanan-Smith, W. L. Grovum, and D. N. Mowat. 1980. Nutritive value of thermo-ammoniated and steam-treated corn stover. II. Rumen metabolites and rate of passage. Anim. Feed Sci. Tech. 4:187.

Ørskov, E. R. 1976. The effect of processing on digestion and utilization of cereals by ruminants. Proc. Nutr. Soc. 35:245.

Ørskov, E. R. 1979. Recent information on processing of grain for ruminants. Livestock Prod. Sci. 6:335.

Parrot, J. C., III., S. Mehen, W. H. Hale, M. Little, and B. Theurer. 1969. Digestibility of dry rolled and steam processed flaked barley. J. Anim. Sci. 28:425.

Preston, R. L. 1975. Net energy evaluation of cattle finishing rations containing varying proportions of corn grain and corn silage. J. Anim. Sci. 41:622.

Riggs, J. K., J. W. Sorenson, Jr., J. L. Adame, and L. M. Schake. 1970. Popped sorghum grain for finishing beef cattle. J. Anim. Sci. 30:634.

Saenger, P. F., R. P. Lemenager, and K. S. Hendrix. 1982. Anhydrous ammonia treatment of corn stover and its effects on digestibility intake and performance of beef cattle. J. Anim. Sci. 54:419.

Sherrod, L. B., R. C. Albin, and R. D. Furr. 1969. Net energy of regular and waxy sorghum grains for finishing steers. J. Anim. Sci. 29:997.

Sudweeks, E. M., L. O. Ely, and L. R. Sisk. 1979. Effect of particle size of corn silage on digestibility and rumen fermentation. J. Dairy Sci. 62:292.

Suleiman, A., and G. W. Mathison. 1979. Net energy evaluation of barley diets for cattle in cold environments. J. Anim. Sci. 48:1447.

Sundstøl, F., E. Coxworth, and D. N. Mowat. 1978. Improving the nutritive quality of straw and other low-quality roughages by treatment with ammonia. World Anim. Rev. 26:13.

Thomas, J. W., Yu Yu, D. Hillman, J. T. Huber, and R. Litchtenwalner. 1972. Unavailable nitrogen in haylage and hays. J. Anim. Sci. 35:1115 (Abstr.).

Tonroy, B. R., T. W. Perry, and W. M. Beeson. 1974. Dry, ensiled high-moisture, ensiled reconstituted high moisture and volatile fatty acid treated high moisture corn for growing-finishing beef cattle. J. Anim. Sci. 39:931.

Trowbridge, E. A., and H. C. Moffett. 1933. Wheat as a cattle feed. Mo. Agric. Exp. Stn. Bull. 325.

Vance, R. D., R. R. Johnson, E. W. Klosterman, B. A. Dehority, and R. L. Preston. 1970. All-concentrate rations for growing-finishing cattle. Ohio Agricultural Research and Development Center Research Summary 43:49.

Vance, R. D., R. L. Preston, E. W. Klosterman, and V. R. Cahill. 1972. Utilization of whole shelled and crimped corn grain with varying proportions of corn silage by growing-finishing steers. J. Anim. Sci. 35:598.

Young, L. G., A. Lun, J. Pos, R. P. Forshaw, and D. Edmeades. 1975. Vitamin E stability in corn and mixed feed. J. Anim. Sci. 40:495.

## IMPLANTS AND NONNUTRITIVE ADDITIVES

Buffers, Electrolytes and Neutralytes Symposium. 1983. National Feed Ingredients Association. West Des Moines, Iowa 50265.

Garrett, W. N. 1982. The influence of monensin on the efficiency of energy utilization by cattle. P. 104 *in* Energy Metabolism of Farm Animals, A. Ekern and F. Sundstøl, eds. EAAP Publ. No. 29. Aas, Norway: Agricultural University of Norway.

Kirk, D. J., L. W. Greene, G. T. Schelling, W. C. Ellis, and F. M. Byers. 1983. Effects of monensin on mineral metabolism in lambs. J. Anim. Sci. 57 (Suppl. 1):446.

Poos, M. I., T. L. Hanson, and T. J. Klopfenstein. 1979. Monensin effects on diet digestibility, ruminal protein bypass and microbial protein synthesis. J. Anim. Sci. 48:1516.

## COMPOSITION OF FEEDS

National Research Council. 1982. United States-Canadian Tables of Feed Composition, 3d ed. Washington, D.C.: National Academy Press.

Cooperative Extension Service. University of California. 1980. By-products and Unusual Feedstuffs in Livestock Rations. Berkeley, California.

# Appendix Tables 10 and 11

TABLE 10 Nutrient Requirements for Growing and Finishing Cattle (Nutrient Concentration in Diet Dry Matter, avoirdupois system)[a,b,c]

| Weight (lb) | Daily Gain (lb) | Dry Matter Intake (lb) | Protein Intake (lb) | Protein (%) | ME (Mcal/lb) | $NE_m$ (Mcal/lb) | $NE_g$ (Mcal/lb) | TDN (%) | Ca (%) | P (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| *Medium-frame steer calves* | | | | | | | | | | |
| 300 | 0.5 | 7.8 | 0.75 | 9.6 | 0.89 | 0.50 | 0.25 | 54.0 | 0.31 | 0.20 |
| | 1.0 | 8.4 | 0.95 | 11.4 | 0.96 | 0.57 | 0.31 | 58.5 | 0.45 | 0.24 |
| | 1.5 | 8.7 | 1.14 | 13.2 | 1.04 | 0.64 | 0.38 | 63.0 | 0.58 | 0.28 |
| | 2.0 | 8.9 | 1.32 | 14.8 | 1.11 | 0.70 | 0.44 | 67.5 | 0.72 | 0.32 |
| | 2.5 | 8.9 | 1.48 | 16.7 | 1.21 | 0.79 | 0.51 | 73.5 | 0.87 | 0.37 |
| | 3.0 | 8.0 | 1.60 | 19.9 | 1.39 | 0.95 | 0.64 | 85.0 | 1.13 | 0.47 |
| 400 | 0.5 | 9.7 | 0.87 | 8.9 | 0.89 | 0.50 | 0.25 | 54.0 | 0.27 | 0.18 |
| | 1.0 | 10.4 | 1.06 | 10.3 | 0.96 | 0.57 | 0.31 | 58.5 | 0.38 | 0.21 |
| | 1.5 | 10.8 | 1.24 | 11.5 | 1.04 | 0.64 | 0.38 | 63.0 | 0.47 | 0.25 |
| | 2.0 | 11.0 | 1.41 | 12.7 | 1.11 | 0.70 | 0.44 | 67.5 | 0.56 | 0.26 |
| | 2.5 | 11.0 | 1.56 | 14.2 | 1.21 | 0.79 | 0.51 | 73.5 | 0.68 | 0.30 |
| | 3.0 | 10.0 | 1.65 | 16.6 | 1.39 | 0.95 | 0.64 | 85.0 | 0.86 | 0.37 |
| 500 | 0.5 | 11.5 | 0.98 | 8.5 | 0.89 | 0.50 | 0.25 | 54.0 | 0.25 | 0.17 |
| | 1.0 | 12.3 | 1.16 | 9.5 | 0.96 | 0.57 | 0.31 | 58.5 | 0.32 | 0.20 |
| | 1.5 | 12.8 | 1.33 | 10.5 | 1.04 | 0.64 | 0.38 | 63.0 | 0.40 | 0.22 |
| | 2.0 | 13.1 | 1.49 | 11.4 | 1.11 | 0.70 | 0.44 | 67.5 | 0.47 | 0.24 |
| | 2.5 | 13.0 | 1.63 | 12.5 | 1.21 | 0.79 | 0.51 | 73.5 | 0.56 | 0.27 |
| | 3.0 | 11.8 | 1.69 | 14.4 | 1.39 | 0.95 | 0.64 | 85.0 | 0.69 | 0.32 |
| 600 | 0.5 | 13.2 | 1.08 | 8.2 | 0.89 | 0.50 | 0.25 | 54.0 | 0.23 | 0.18 |
| | 1.0 | 14.1 | 1.26 | 9.0 | 0.96 | 0.57 | 0.31 | 58.5 | 0.28 | 0.19 |
| | 1.5 | 14.7 | 1.42 | 9.8 | 1.04 | 0.64 | 0.38 | 63.0 | 0.35 | 0.21 |
| | 2.0 | 15.0 | 1.57 | 10.5 | 1.11 | 0.70 | 0.44 | 67.5 | 0.40 | 0.22 |
| | 2.5 | 14.9 | 1.69 | 11.4 | 1.21 | 0.79 | 0.51 | 73.5 | 0.46 | 0.24 |
| | 3.0 | 13.5 | 1.73 | 12.9 | 1.39 | 0.95 | 0.64 | 85.0 | 0.57 | 0.29 |
| 700 | 0.5 | 14.8 | 1.18 | 7.9 | 0.89 | 0.50 | 0.25 | 54.0 | 0.22 | 0.18 |
| | 1.0 | 15.8 | 1.35 | 8.6 | 0.96 | 0.57 | 0.31 | 58.5 | 0.27 | 0.18 |
| | 1.5 | 16.5 | 1.50 | 9.2 | 1.04 | 0.64 | 0.38 | 63.0 | 0.31 | 0.20 |
| | 2.0 | 16.8 | 1.65 | 9.8 | 1.11 | 0.70 | 0.44 | 67.5 | 0.34 | 0.21 |
| | 2.5 | 16.7 | 1.75 | 10.5 | 1.21 | 0.79 | 0.51 | 73.5 | 0.40 | 0.22 |
| | 3.0 | 15.2 | 1.77 | 11.7 | 1.39 | 0.95 | 0.64 | 85.0 | 0.49 | 0.26 |

TABLE 10 Nutrient Requirements for Growing and Finishing Cattle (Nutrient Concentration in Diet Dry Matter, avoirdupois system)[a,b,c]—*Continued*

| Weight (lb) | Daily Gain (lb) | Dry Matter Intake (lb) | Protein Intake (lb) | Protein (%) | ME (Mcal/lb) | $NE_m$ (Mcal/lb) | $NE_g$ (Mcal/lb) | TDN (%) | Ca (%) | P (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| 800 | 0.5 | 16.4 | 1.27 | 7.7 | 0.89 | 0.50 | 0.25 | 54.0 | 0.22 | 0.17 |
| | 1.0 | 17.5 | 1.44 | 8.3 | 0.96 | 0.57 | 0.31 | 58.5 | 0.24 | 0.19 |
| | 1.5 | 18.2 | 1.58 | 8.8 | 1.04 | 0.64 | 0.38 | 63.0 | 0.28 | 0.19 |
| | 2.0 | 18.6 | 1.72 | 9.2 | 1.11 | 0.70 | 0.44 | 67.5 | 0.31 | 0.20 |
| | 2.5 | 18.5 | 1.81 | 9.8 | 1.21 | 0.79 | 0.51 | 73.5 | 0.35 | 0.21 |
| | 3.0 | 16.8 | 1.81 | 10.8 | 1.39 | 0.95 | 0.64 | 85.0 | 0.42 | 0.25 |
| 900 | 0.5 | 17.9 | 1.36 | 7.6 | 0.89 | 0.50 | 0.25 | 54.0 | 0.21 | 0.18 |
| | 1.0 | 19.1 | 1.52 | 8.0 | 0.96 | 0.57 | 0.31 | 58.5 | 0.23 | 0.18 |
| | 1.5 | 19.9 | 1.66 | 8.4 | 1.04 | 0.64 | 0.38 | 63.0 | 0.25 | 0.19 |
| | 2.0 | 20.3 | 1.79 | 8.8 | 1.11 | 0.70 | 0.44 | 67.5 | 0.28 | 0.20 |
| | 2.5 | 20.2 | 1.87 | 9.3 | 1.21 | 0.79 | 0.51 | 73.5 | 0.31 | 0.20 |
| | 3.0 | 18.3 | 1.85 | 10.1 | 1.39 | 0.95 | 0.64 | 85.0 | 0.37 | 0.23 |
| 1000 | 0.5 | 19.3 | 1.45 | 7.5 | 0.89 | 0.50 | 0.25 | 54.0 | 0.21 | 0.18 |
| | 1.0 | 20.7 | 1.60 | 7.8 | 0.96 | 0.57 | 0.31 | 58.5 | 0.21 | 0.18 |
| | 1.5 | 21.5 | 1.74 | 8.1 | 1.04 | 0.64 | 0.38 | 63.0 | 0.24 | 0.18 |
| | 2.0 | 22.0 | 1.85 | 8.4 | 1.11 | 0.70 | 0.44 | 67.5 | 0.25 | 0.19 |
| | 2.5 | 21.9 | 1.92 | 8.8 | 1.21 | 0.79 | 0.51 | 73.5 | 0.27 | 0.19 |
| | 3.0 | 19.8 | 1.88 | 9.5 | 1.39 | 0.95 | 0.64 | 85.0 | 0.32 | 0.22 |
| *Large-frame steer calves and compensating medium-frame yearling steers* | | | | | | | | | | |
| 300 | 0.5 | 8.2 | 0.77 | 9.5 | 0.86 | 0.48 | 0.23 | 52.5 | 0.30 | 0.19 |
| | 1.0 | 8.7 | 0.99 | 11.3 | 0.92 | 0.54 | 0.28 | 56.0 | 0.46 | 0.23 |
| | 1.5 | 9.1 | 1.19 | 12.9 | 0.98 | 0.59 | 0.33 | 59.5 | 0.58 | 0.27 |
| | 2.0 | 9.4 | 1.37 | 14.6 | 1.04 | 0.64 | 0.38 | 63.5 | 0.70 | 0.30 |
| | 2.5 | 9.6 | 1.55 | 16.3 | 1.11 | 0.70 | 0.44 | 67.5 | 0.85 | 0.34 |
| | 3.0 | 9.6 | 1.73 | 18.0 | 1.18 | 0.77 | 0.49 | 72.0 | 0.99 | 0.39 |
| | 3.5 | 9.3 | 1.88 | 20.3 | 1.29 | 0.86 | 0.57 | 78.5 | 1.16 | 0.45 |
| 400 | 0.5 | 10.1 | 0.89 | 8.9 | 0.86 | 0.48 | 0.23 | 52.5 | 0.26 | 0.17 |
| | 1.0 | 10.8 | 1.10 | 10.2 | 0.92 | 0.54 | 0.28 | 56.0 | 0.37 | 0.20 |
| | 1.5 | 11.3 | 1.30 | 11.4 | 0.98 | 0.59 | 0.33 | 59.5 | 0.47 | 0.23 |
| | 2.0 | 11.7 | 1.47 | 12.7 | 1.04 | 0.64 | 0.38 | 63.5 | 0.57 | 0.26 |
| | 2.5 | 11.9 | 1.64 | 13.9 | 1.11 | 0.70 | 0.44 | 67.5 | 0.65 | 0.30 |
| | 3.0 | 11.9 | 1.81 | 15.2 | 1.18 | 0.77 | 0.49 | 72.0 | 0.76 | 0.33 |
| | 3.5 | 11.5 | 1.94 | 16.9 | 1.29 | 0.86 | 0.57 | 78.5 | 0.90 | 0.36 |
| 500 | 0.5 | 12.0 | 1.0 | 8.5 | 0.86 | 0.48 | 0.23 | 52.5 | 0.24 | 0.17 |
| | 1.0 | 12.8 | 1.21 | 9.5 | 0.92 | 0.54 | 0.28 | 56.0 | 0.33 | 0.19 |
| | 1.5 | 13.4 | 1.40 | 10.4 | 0.98 | 0.59 | 0.33 | 59.5 | 0.39 | 0.21 |
| | 2.0 | 13.8 | 1.57 | 11.4 | 1.04 | 0.64 | 0.38 | 63.5 | 0.46 | 0.24 |
| | 2.5 | 14.0 | 1.73 | 12.4 | 1.11 | 0.70 | 0.44 | 67.5 | 0.55 | 0.25 |
| | 3.0 | 14.0 | 1.88 | 13.4 | 1.18 | 0.77 | 0.49 | 72.0 | 0.63 | 0.28 |
| | 3.5 | 13.6 | 2.00 | 14.7 | 1.29 | 0.86 | 0.57 | 78.5 | 0.73 | 0.32 |
| 600 | 0.5 | 13.8 | 1.11 | 8.2 | 0.86 | 0.48 | 0.23 | 52.5 | 0.22 | 0.18 |
| | 1.0 | 14.6 | 1.31 | 9.0 | 0.92 | 0.54 | 0.28 | 56.0 | 0.29 | 0.18 |
| | 1.5 | 15.3 | 1.50 | 9.7 | 0.98 | 0.59 | 0.33 | 59.5 | 0.35 | 0.20 |
| | 2.0 | 15.8 | 1.66 | 10.5 | 1.04 | 0.64 | 0.38 | 63.5 | 0.40 | 0.22 |
| | 2.5 | 16.1 | 1.81 | 11.3 | 1.11 | 0.70 | 0.44 | 67.5 | 0.47 | 0.23 |
| | 3.0 | 16.1 | 1.95 | 12.1 | 1.18 | 0.77 | 0.49 | 72.0 | 0.52 | 0.26 |
| | 3.5 | 15.6 | 2.05 | 13.2 | 1.29 | 0.86 | 0.57 | 78.5 | 0.61 | 0.28 |
| 700 | 0.5 | 15.4 | 1.21 | 7.9 | 0.86 | 0.48 | 0.23 | 52.5 | 0.21 | 0.17 |
| | 1.0 | 16.4 | 1.41 | 8.6 | 0.92 | 0.54 | 0.28 | 56.0 | 0.27 | 0.19 |
| | 1.5 | 17.2 | 1.59 | 9.2 | 0.98 | 0.59 | 0.33 | 59.5 | 0.31 | 0.19 |
| | 2.0 | 17.8 | 1.74 | 9.8 | 1.04 | 0.64 | 0.38 | 63.5 | 0.36 | 0.21 |
| | 2.5 | 18.0 | 1.88 | 10.5 | 1.11 | 0.70 | 0.44 | 67.5 | 0.40 | 0.22 |
| | 3.0 | 18.0 | 2.01 | 11.1 | 1.18 | 0.77 | 0.49 | 72.0 | 0.45 | 0.23 |
| | 3.5 | 17.5 | 2.10 | 12.0 | 1.29 | 0.86 | 0.57 | 78.5 | 0.52 | 0.26 |

TABLE 10 Nutrient Requirements for Growing and Finishing Cattle (Nutrient Concentration in Diet Dry Matter, avoirdupois system)[a,b,c]—*Continued*

| Weight (lb) | Daily Gain (lb) | Dry Matter Intake (lb) | Protein Intake (lb) | Protein (%) | ME (Mcal/lb) | $NE_m$ (Mcal/lb) | $NE_g$ (Mcal/lb) | TDN (%) | Ca (%) | P (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| 800 | 0.5 | 17.1 | 1.31 | 7.7 | 0.86 | 0.48 | 0.23 | 52.5 | 0.21 | 0.18 |
| | 1.0 | 18.2 | 1.51 | 8.3 | 0.92 | 0.54 | 0.28 | 56.0 | 0.24 | 0.18 |
| | 1.5 | 19.0 | 1.68 | 8.8 | 0.98 | 0.59 | 0.33 | 59.5 | 0.28 | 0.19 |
| | 2.0 | 19.6 | 1.82 | 9.3 | 1.04 | 0.64 | 0.38 | 63.5 | 0.32 | 0.20 |
| | 2.5 | 19.9 | 1.96 | 9.8 | 1.11 | 0.70 | 0.44 | 67.5 | 0.35 | 0.21 |
| | 3.0 | 19.9 | 2.07 | 10.4 | 1.18 | 0.77 | 0.49 | 72.0 | 0.40 | 0.22 |
| | 3.5 | 19.3 | 2.15 | 11.1 | 1.29 | 0.86 | 0.57 | 78.5 | 0.45 | 0.24 |
| 900 | 0.5 | 18.6 | 1.40 | 7.6 | 0.86 | 0.48 | 0.23 | 52.5 | 0.20 | 0.18 |
| | 1.0 | 19.8 | 1.60 | 8.0 | 0.92 | 0.54 | 0.28 | 56.0 | 0.23 | 0.18 |
| | 1.5 | 20.8 | 1.77 | 8.5 | 0.98 | 0.59 | 0.33 | 59.5 | 0.27 | 0.18 |
| | 2.0 | 21.4 | 1.90 | 8.9 | 1.04 | 0.64 | 0.38 | 63.5 | 0.29 | 0.20 |
| | 2.5 | 21.8 | 2.03 | 9.3 | 1.11 | 0.70 | 0.44 | 67.5 | 0.31 | 0.20 |
| | 3.0 | 21.7 | 2.13 | 9.8 | 1.18 | 0.77 | 0.49 | 72.0 | 0.36 | 0.21 |
| | 3.5 | 21.1 | 2.19 | 10.4 | 1.29 | 0.86 | 0.57 | 78.5 | 0.40 | 0.23 |
| 1000 | 0.5 | 20.2 | 1.49 | 7.5 | 0.86 | 0.48 | 0.23 | 52.5 | 0.20 | 0.17 |
| | 1.0 | 21.5 | 1.69 | 7.8 | 0.92 | 0.54 | 0.28 | 56.0 | 0.23 | 0.17 |
| | 1.5 | 22.5 | 1.85 | 8.2 | 0.98 | 0.59 | 0.33 | 59.5 | 0.25 | 0.18 |
| | 2.0 | 23.2 | 1.98 | 8.6 | 1.04 | 0.64 | 0.38 | 63.5 | 0.27 | 0.18 |
| | 2.5 | 23.6 | 2.09 | 8.9 | 1.11 | 0.70 | 0.44 | 67.5 | 0.29 | 0.19 |
| | 3.0 | 23.6 | 2.19 | 9.3 | 1.18 | 0.77 | 0.49 | 72.0 | 0.32 | 0.20 |
| | 3.5 | 22.8 | 2.24 | 9.8 | 1.29 | 0.86 | 0.57 | 78.5 | 0.35 | 0.21 |
| 1100 | 0.5 | 21.7 | 1.58 | 7.4 | 0.86 | 0.48 | 0.23 | 52.5 | 0.19 | 0.18 |
| | 1.0 | 23.1 | 1.77 | 7.7 | 0.92 | 0.54 | 0.28 | 56.0 | 0.21 | 0.18 |
| | 1.5 | 24.1 | 1.93 | 8.0 | 0.98 | 0.59 | 0.33 | 59.5 | 0.23 | 0.18 |
| | 2.0 | 24.9 | 2.05 | 8.3 | 1.04 | 0.64 | 0.38 | 63.5 | 0.25 | 0.18 |
| | 2.5 | 25.3 | 2.16 | 8.5 | 1.11 | 0.70 | 0.44 | 67.5 | 0.26 | 0.18 |
| | 3.0 | 25.3 | 2.25 | 8.9 | 1.18 | 0.77 | 0.49 | 72.0 | 0.29 | 0.19 |
| | 3.5 | 24.5 | 2.28 | 9.3 | 1.29 | 0.86 | 0.57 | 78.5 | 0.32 | 0.21 |
| *Medium-frame bulls* | | | | | | | | | | |
| 300 | 0.5 | 7.8 | 0.76 | 9.7 | 0.88 | 0.49 | 0.24 | 53.5 | 0.31 | 0.20 |
| | 1.0 | 8.3 | 0.96 | 11.6 | 0.94 | 0.56 | 0.30 | 57.5 | 0.48 | 0.24 |
| | 1.5 | 8.6 | 1.15 | 13.4 | 1.01 | 0.62 | 0.35 | 61.5 | 0.62 | 0.28 |
| | 2.0 | 8.8 | 1.34 | 15.2 | 1.08 | 0.68 | 0.41 | 65.5 | 0.75 | 0.33 |
| | 2.5 | 8.9 | 1.52 | 17.0 | 1.15 | 0.74 | 0.47 | 70.0 | 0.92 | 0.37 |
| | 3.0 | 8.7 | 1.68 | 19.3 | 1.26 | 0.84 | 0.54 | 76.5 | 1.09 | 0.43 |
| 400 | 0.5 | 9.6 | 0.87 | 9.0 | 0.88 | 0.49 | 0.24 | 53.5 | 0.28 | 0.18 |
| | 1.0 | 10.3 | 1.07 | 10.4 | 0.94 | 0.56 | 0.30 | 57.5 | 0.39 | 0.21 |
| | 1.5 | 10.7 | 1.26 | 11.8 | 1.01 | 0.62 | 0.35 | 61.5 | 0.49 | 0.25 |
| | 2.0 | 11.0 | 1.44 | 13.1 | 1.08 | 0.68 | 0.41 | 65.5 | 0.60 | 0.28 |
| | 2.5 | 11.1 | 1.60 | 14.4 | 1.15 | 0.74 | 0.47 | 70.0 | 0.70 | 0.32 |
| | 3.0 | 10.8 | 1.74 | 16.1 | 1.26 | 0.84 | 0.54 | 76.5 | 0.84 | 0.37 |
| 500 | 0.5 | 11.4 | 0.98 | 8.6 | 0.88 | 0.49 | 0.24 | 53.5 | 0.25 | 0.17 |
| | 1.0 | 12.1 | 1.17 | 9.7 | 0.94 | 0.56 | 0.30 | 57.5 | 0.35 | 0.20 |
| | 1.5 | 12.7 | 1.35 | 10.7 | 1.01 | 0.62 | 0.35 | 61.5 | 0.42 | 0.23 |
| | 2.0 | 13.0 | 1.52 | 11.7 | 1.08 | 0.68 | 0.41 | 65.5 | 0.49 | 0.25 |
| | 2.5 | 13.1 | 1.68 | 12.8 | 1.15 | 0.74 | 0.47 | 70.0 | 0.59 | 0.27 |
| | 3.0 | 12.8 | 1.81 | 14.1 | 1.26 | 0.84 | 0.54 | 76.5 | 0.69 | 0.31 |
| 600 | 0.5 | 13.1 | 1.08 | 8.3 | 0.88 | 0.49 | 0.24 | 53.5 | 0.24 | 0.19 |
| | 1.0 | 13.9 | 1.27 | 9.2 | 0.94 | 0.56 | 0.30 | 57.5 | 0.30 | 0.19 |
| | 1.5 | 14.5 | 1.44 | 10.0 | 1.01 | 0.62 | 0.35 | 61.5 | 0.36 | 0.21 |
| | 2.0 | 14.9 | 1.61 | 10.8 | 1.08 | 0.68 | 0.41 | 65.5 | 0.43 | 0.24 |
| | 2.5 | 15.0 | 1.75 | 11.6 | 1.15 | 0.74 | 0.47 | 70.0 | 0.50 | 0.25 |
| | 3.0 | 14.7 | 1.86 | 12.7 | 1.26 | 0.84 | 0.54 | 76.5 | 0.57 | 0.29 |

TABLE 10 Nutrient Requirements for Growing and Finishing Cattle (Nutrient Concentration in Diet Dry Matter, avoirdupois system)[a,b,c]—*Continued*

| Weight (lb) | Daily Gain (lb) | Dry Matter Intake (lb) | Protein Intake (lb) | Protein (%) | ME (Mcal/lb) | $NE_m$ (Mcal/lb) | $NE_g$ (Mcal/lb) | TDN (%) | Ca (%) | P (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| 700 | 0.5 | 14.7 | 1.18 | 8.0 | 0.88 | 0.49 | 0.24 | 53.5 | 0.23 | 0.18 |
| | 1.0 | 15.6 | 1.37 | 8.8 | 0.94 | 0.56 | 0.30 | 57.5 | 0.28 | 0.20 |
| | 1.5 | 16.3 | 1.53 | 9.4 | 1.01 | 0.62 | 0.35 | 61.5 | 0.32 | 0.20 |
| | 2.0 | 16.7 | 1.69 | 10.1 | 1.08 | 0.68 | 0.41 | 65.5 | 0.38 | 0.22 |
| | 2.5 | 16.8 | 1.82 | 10.8 | 1.15 | 0.74 | 0.47 | 70.0 | 0.43 | 0.24 |
| | 3.0 | 16.5 | 1.92 | 11.7 | 1.26 | 0.84 | 0.54 | 76.5 | 0.49 | 0.25 |
| 800 | 0.5 | 16.2 | 1.27 | 7.8 | 0.88 | 0.49 | 0.24 | 53.5 | 0.22 | 0.19 |
| | 1.0 | 17.3 | 1.45 | 8.4 | 0.94 | 0.56 | 0.30 | 57.5 | 0.25 | 0.19 |
| | 1.5 | 18.0 | 1.61 | 9.0 | 1.01 | 0.62 | 0.35 | 61.5 | 0.29 | 0.20 |
| | 2.0 | 18.5 | 1.76 | 9.5 | 1.08 | 0.68 | 0.41 | 65.5 | 0.33 | 0.21 |
| | 2.5 | 18.6 | 1.89 | 10.1 | 1.15 | 0.74 | 0.47 | 70.0 | 0.38 | 0.23 |
| | 3.0 | 18.2 | 1.97 | 10.8 | 1.26 | 0.84 | 0.54 | 76.5 | 0.44 | 0.24 |
| 900 | 0.5 | 17.7 | 1.36 | 7.7 | 0.88 | 0.49 | 0.24 | 53.5 | 0.21 | 0.19 |
| | 1.0 | 18.9 | 1.54 | 8.2 | 0.94 | 0.56 | 0.30 | 57.5 | 0.25 | 0.19 |
| | 1.5 | 19.7 | 1.69 | 8.6 | 1.01 | 0.62 | 0.35 | 61.5 | 0.28 | 0.19 |
| | 2.0 | 20.2 | 1.83 | 9.1 | 1.08 | 0.68 | 0.41 | 65.5 | 0.31 | 0.21 |
| | 2.5 | 20.3 | 1.95 | 9.6 | 1.15 | 0.74 | 0.47 | 70.0 | 0.34 | 0.22 |
| | 3.0 | 19.9 | 2.02 | 10.2 | 1.26 | 0.84 | 0.54 | 76.5 | 0.39 | 0.23 |
| 1000 | 0.5 | 19.2 | 1.45 | 7.5 | 0.88 | 0.49 | 0.24 | 53.5 | 0.21 | 0.18 |
| | 1.0 | 20.4 | 1.62 | 8.0 | 0.94 | 0.56 | 0.30 | 57.5 | 0.24 | 0.18 |
| | 1.5 | 21.3 | 1.77 | 8.4 | 1.01 | 0.62 | 0.35 | 61.5 | 0.26 | 0.19 |
| | 2.0 | 21.8 | 1.90 | 8.7 | 1.08 | 0.68 | 0.41 | 65.5 | 0.28 | 0.19 |
| | 2.5 | 22.0 | 2.01 | 9.1 | 1.15 | 0.74 | 0.47 | 70.0 | 0.31 | 0.20 |
| | 3.0 | 21.5 | 2.07 | 9.6 | 1.26 | 0.84 | 0.54 | 76.5 | 0.35 | 0.22 |
| 1100 | 0.5 | 20.6 | 1.54 | 7.4 | 0.88 | 0.49 | 0.24 | 53.5 | 0.20 | 0.19 |
| | 1.0 | 21.9 | 1.70 | 7.8 | 0.94 | 0.56 | 0.30 | 57.5 | 0.22 | 0.19 |
| | 1.5 | 22.9 | 1.85 | 8.1 | 1.01 | 0.62 | 0.35 | 61.5 | 0.24 | 0.19 |
| | 2.0 | 23.4 | 1.97 | 8.4 | 1.08 | 0.68 | 0.41 | 65.5 | 0.26 | 0.19 |
| | 2.5 | 23.6 | 2.07 | 8.7 | 1.15 | 0.74 | 0.47 | 70.0 | 0.28 | 0.20 |
| | 3.0 | 23.1 | 2.11 | 9.2 | 1.26 | 0.84 | 0.54 | 76.5 | 0.32 | 0.21 |
| *Large-frame bull calves and compensating large-frame yearling steers* | | | | | | | | | | |
| 300 | 0.5 | 7.9 | 0.77 | 9.7 | 0.86 | 0.48 | 0.23 | 52.5 | 0.31 | 0.20 |
| | 1.0 | 8.4 | 0.98 | 11.7 | 0.92 | 0.54 | 0.28 | 56.0 | 0.47 | 0.24 |
| | 1.5 | 8.8 | 1.18 | 13.5 | 0.98 | 0.59 | 0.33 | 59.5 | 0.63 | 0.28 |
| | 2.0 | 9.0 | 1.38 | 15.1 | 1.03 | 0.63 | 0.37 | 62.5 | 0.76 | 0.32 |
| | 2.5 | 9.2 | 1.56 | 17.0 | 1.09 | 0.69 | 0.42 | 66.5 | 0.91 | 0.36 |
| | 3.0 | 9.2 | 1.74 | 18.8 | 1.16 | 0.75 | 0.47 | 70.5 | 1.08 | 0.43 |
| | 3.5 | 9.1 | 1.91 | 20.9 | 1.24 | 0.82 | 0.53 | 75.5 | 1.24 | 0.48 |
| | 4.0 | 8.2 | 2.04 | 24.7 | 1.41 | 0.96 | 0.66 | 86.0 | 1.53 | 0.59 |
| 400 | 0.5 | 9.8 | 0.89 | 9.0 | 0.86 | 0.48 | 0.23 | 52.5 | 0.27 | 0.18 |
| | 1.0 | 10.4 | 1.09 | 10.5 | 0.92 | 0.54 | 0.28 | 56.0 | 0.40 | 0.21 |
| | 1.5 | 10.9 | 1.29 | 11.9 | 0.98 | 0.59 | 0.33 | 59.5 | 0.51 | 0.24 |
| | 2.0 | 11.2 | 1.48 | 13.1 | 1.03 | 0.63 | 0.37 | 62.5 | 0.61 | 0.28 |
| | 2.5 | 11.4 | 1.65 | 14.5 | 1.09 | 0.69 | 0.42 | 66.5 | 0.72 | 0.31 |
| | 3.0 | 11.5 | 1.82 | 15.9 | 1.16 | 0.75 | 0.47 | 70.5 | 0.82 | 0.35 |
| | 3.5 | 11.3 | 1.98 | 17.5 | 1.24 | 0.82 | 0.53 | 75.5 | 0.96 | 0.39 |
| | 4.0 | 10.2 | 2.08 | 20.3 | 1.41 | 0.96 | 0.66 | 86.0 | 1.19 | 0.48 |
| 500 | 0.5 | 11.6 | 1.00 | 8.6 | 0.86 | 0.48 | 0.23 | 52.5 | 0.25 | 0.19 |
| | 1.0 | 12.3 | 1.20 | 9.8 | 0.92 | 0.54 | 0.28 | 56.0 | 0.36 | 0.21 |
| | 1.5 | 12.9 | 1.39 | 10.9 | 0.98 | 0.59 | 0.33 | 59.5 | 0.43 | 0.22 |
| | 2.0 | 13.2 | 1.58 | 11.8 | 1.03 | 0.63 | 0.37 | 62.5 | 0.52 | 0.25 |

TABLE 10 Nutrient Requirements for Growing and Finishing Cattle (Nutrient Concentration in Diet Dry Matter, avoirdupois system)[a,b,c]—*Continued*

| Weight (lb) | Daily Gain (lb) | Dry Matter Intake (lb) | Protein Intake (lb) | Protein (%) | ME (Mcal/lb) | $NE_m$ (Mcal/lb) | $NE_g$ (Mcal/lb) | TDN (%) | Ca (%) | P (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2.5 | 13.5 | 1.74 | 12.9 | 1.09 | 0.69 | 0.42 | 66.5 | 0.59 | 0.28 |
| | 3.0 | 13.6 | 1.90 | 14.0 | 1.16 | 0.75 | 0.47 | 70.5 | 0.68 | 0.31 |
| | 3.5 | 13.4 | 2.05 | 15.3 | 1.24 | 0.82 | 0.53 | 75.5 | 0.77 | 0.35 |
| | 4.0 | 12.0 | 2.13 | 17.5 | 1.41 | 0.96 | 0.66 | 86.0 | 0.97 | 0.40 |
| 600 | 0.5 | 13.3 | 1.10 | 8.3 | 0.86 | 0.48 | 0.23 | 52.5 | 0.23 | 0.18 |
| | 1.0 | 14.1 | 1.30 | 9.2 | 0.92 | 0.54 | 0.28 | 56.0 | 0.31 | 0.20 |
| | 1.5 | 14.8 | 1.48 | 10.1 | 0.98 | 0.59 | 0.33 | 59.5 | 0.37 | 0.21 |
| | 2.0 | 15.2 | 1.67 | 10.9 | 1.03 | 0.63 | 0.37 | 62.5 | 0.44 | 0.23 |
| | 2.5 | 15.5 | 1.82 | 11.8 | 1.09 | 0.69 | 0.42 | 66.5 | 0.51 | 0.26 |
| | 3.0 | 15.5 | 1.97 | 12.7 | 1.16 | 0.75 | 0.47 | 70.5 | 0.58 | 0.27 |
| | 3.5 | 15.3 | 2.11 | 13.7 | 1.24 | 0.82 | 0.53 | 75.5 | 0.66 | 0.30 |
| | 4.0 | 13.8 | 2.16 | 15.6 | 1.41 | 0.96 | 0.66 | 86.0 | 0.81 | 0.37 |
| 700 | 0.5 | 14.9 | 1.20 | 8.0 | 0.86 | 0.48 | 0.23 | 52.5 | 0.22 | 0.18 |
| | 1.0 | 15.9 | 1.40 | 8.8 | 0.92 | 0.54 | 0.28 | 56.0 | 0.29 | 0.19 |
| | 1.5 | 16.6 | 1.57 | 9.6 | 0.98 | 0.59 | 0.33 | 59.5 | 0.35 | 0.21 |
| | 2.0 | 17.0 | 1.75 | 10.2 | 1.03 | 0.63 | 0.37 | 62.5 | 0.39 | 0.22 |
| | 2.5 | 17.4 | 1.90 | 11.0 | 1.09 | 0.69 | 0.42 | 66.5 | 0.44 | 0.24 |
| | 3.0 | 17.5 | 2.04 | 11.7 | 1.16 | 0.75 | 0.47 | 70.5 | 0.50 | 0.25 |
| | 3.5 | 17.2 | 2.16 | 12.5 | 1.24 | 0.82 | 0.53 | 75.5 | 0.56 | 0.28 |
| | 4.0 | 15.5 | 2.20 | 14.1 | 1.41 | 0.96 | 0.66 | 86.0 | 0.70 | 0.33 |
| 800 | 0.5 | 16.5 | 1.30 | 7.9 | 0.86 | 0.48 | 0.23 | 52.5 | 0.21 | 0.19 |
| | 1.0 | 17.5 | 1.49 | 8.5 | 0.92 | 0.54 | 0.28 | 56.0 | 0.26 | 0.19 |
| | 1.5 | 18.3 | 1.66 | 9.1 | 0.98 | 0.59 | 0.33 | 59.5 | 0.31 | 0.20 |
| | 2.0 | 18.8 | 1.84 | 9.7 | 1.03 | 0.63 | 0.37 | 62.5 | 0.35 | 0.21 |
| | 2.5 | 19.2 | 1.97 | 10.3 | 1.09 | 0.69 | 0.42 | 66.5 | 0.40 | 0.23 |
| | 3.0 | 19.3 | 2.11 | 10.9 | 1.16 | 0.75 | 0.47 | 70.5 | 0.45 | 0.24 |
| | 3.5 | 19.0 | 2.22 | 11.6 | 1.24 | 0.82 | 0.53 | 75.5 | 0.50 | 0.26 |
| | 4.0 | 17.1 | 2.24 | 13.0 | 1.41 | 0.96 | 0.66 | 86.0 | 0.61 | 0.31 |
| 900 | 0.5 | 18.0 | 1.39 | 7.7 | 0.86 | 0.48 | 0.23 | 52.5 | 0.22 | 0.18 |
| | 1.0 | 19.2 | 1.58 | 8.3 | 0.92 | 0.54 | 0.28 | 56.0 | 0.25 | 0.18 |
| | 1.5 | 20.0 | 1.74 | 8.8 | 0.98 | 0.59 | 0.33 | 59.5 | 0.29 | 0.20 |
| | 2.0 | 20.6 | 1.92 | 9.2 | 1.03 | 0.63 | 0.37 | 62.5 | 0.32 | 0.20 |
| | 2.5 | 21.0 | 2.04 | 9.8 | 1.09 | 0.69 | 0.42 | 66.5 | 0.36 | 0.21 |
| | 3.0 | 21.1 | 2.17 | 10.3 | 1.16 | 0.75 | 0.47 | 70.5 | 0.40 | 0.23 |
| | 3.5 | 20.8 | 2.27 | 10.9 | 1.24 | 0.82 | 0.53 | 75.5 | 0.45 | 0.24 |
| | 4.0 | 18.7 | 2.27 | 12.1 | 1.41 | 0.96 | 0.66 | 86.0 | 0.53 | 0.28 |
| 1000 | 0.5 | 19.5 | 1.48 | 7.6 | 0.86 | 0.48 | 0.23 | 52.5 | 0.21 | 0.18 |
| | 1.0 | 20.7 | 1.66 | 8.1 | 0.92 | 0.54 | 0.28 | 56.0 | 0.25 | 0.19 |
| | 1.5 | 21.7 | 1.83 | 8.5 | 0.98 | 0.59 | 0.33 | 59.5 | 0.27 | 0.19 |
| | 2.0 | 22.3 | 1.99 | 8.9 | 1.03 | 0.63 | 0.37 | 62.5 | 0.30 | 0.20 |
| | 2.5 | 22.7 | 2.11 | 9.3 | 1.09 | 0.69 | 0.42 | 66.5 | 0.33 | 0.20 |
| | 3.0 | 22.8 | 2.23 | 9.7 | 1.16 | 0.75 | 0.47 | 70.5 | 0.36 | 0.21 |
| | 3.5 | 22.5 | 2.32 | 10.3 | 1.24 | 0.82 | 0.53 | 75.5 | 0.40 | 0.24 |
| | 4.0 | 20.2 | 2.30 | 11.3 | 1.41 | 0.96 | 0.66 | 86.0 | 0.48 | 0.27 |
| 1100 | 0.5 | 20.9 | 1.57 | 7.5 | 0.86 | 0.48 | 0.23 | 52.5 | 0.21 | 0.19 |
| | 1.0 | 22.3 | 1.75 | 7.9 | 0.92 | 0.54 | 0.28 | 56.0 | 0.23 | 0.19 |
| | 1.5 | 23.3 | 1.91 | 8.3 | 0.98 | 0.59 | 0.33 | 59.5 | 0.26 | 0.19 |
| | 2.0 | 23.9 | 2.07 | 8.6 | 1.03 | 0.63 | 0.37 | 62.5 | 0.28 | 0.19 |
| | 2.5 | 24.2 | 2.18 | 9.0 | 1.09 | 0.69 | 0.42 | 66.5 | 0.30 | 0.20 |
| | 3.0 | 24.5 | 2.29 | 9.3 | 1.16 | 0.75 | 0.47 | 70.5 | 0.32 | 0.21 |
| | 3.5 | 24.1 | 2.37 | 9.8 | 1.24 | 0.82 | 0.53 | 75.5 | 0.36 | 0.22 |
| | 4.0 | 21.7 | 2.33 | 10.7 | 1.41 | 0.96 | 0.66 | 86.0 | 0.43 | 0.25 |

TABLE 10 Nutrient Requirements for Growing and Finishing Cattle (Nutrient Concentration in Diet Dry Matter, avoirdupois system)[a,b,c]—*Continued*

| Weight (lb) | Daily Gain (lb) | Dry Matter Intake (lb) | Protein Intake (lb) | Protein (%) | ME (Mcal/lb) | $NE_m$ (Mcal/lb) | $NE_g$ (Mcal/lb) | TDN (%) | Ca (%) | P (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| *Medium-frame heifer calves* | | | | | | | | | | |
| 300 | 0.5 | 7.5 | 0.73 | 9.6 | 0.92 | 0.54 | 0.28 | 56.0 | 0.29 | 0.21 |
| | 1.0 | 8.0 | 0.91 | 11.4 | 1.02 | 0.63 | 0.36 | 62.0 | 0.44 | 0.22 |
| | 1.5 | 8.2 | 1.08 | 13.1 | 1.13 | 0.72 | 0.44 | 68.5 | 0.59 | 0.27 |
| | 2.0 | 8.0 | 1.22 | 15.1 | 1.26 | 0.84 | 0.55 | 77.0 | 0.74 | 0.33 |
| 400 | 0.5 | 9.3 | 0.84 | 8.9 | 0.92 | 0.54 | 0.28 | 56.0 | 0.26 | 0.19 |
| | 1.0 | 9.9 | 1.01 | 10.2 | 1.02 | 0.63 | 0.36 | 62.0 | 0.36 | 0.20 |
| | 1.5 | 10.2 | 1.17 | 11.4 | 1.13 | 0.72 | 0.44 | 68.5 | 0.45 | 0.24 |
| | 2.0 | 10.0 | 1.29 | 12.9 | 1.26 | 0.84 | 0.55 | 77.0 | 0.57 | 0.29 |
| 500 | 0.5 | 11.0 | 0.94 | 8.5 | 0.92 | 0.54 | 0.28 | 56.0 | 0.24 | 0.18 |
| | 1.0 | 11.8 | 1.11 | 9.4 | 1.02 | 0.63 | 0.36 | 62.0 | 0.30 | 0.21 |
| | 1.5 | 12.1 | 1.25 | 10.3 | 1.13 | 0.72 | 0.44 | 68.5 | 0.38 | 0.22 |
| | 2.0 | 11.8 | 1.35 | 11.4 | 1.26 | 0.84 | 0.55 | 77.0 | 0.45 | 0.24 |
| 600 | 0.5 | 12.6 | 1.04 | 8.1 | 0.92 | 0.54 | 0.28 | 56.0 | 0.23 | 0.18 |
| | 1.0 | 13.5 | 1.19 | 8.8 | 1.02 | 0.63 | 0.36 | 62.0 | 0.28 | 0.20 |
| | 1.5 | 13.8 | 1.32 | 9.5 | 1.13 | 0.72 | 0.44 | 68.5 | 0.32 | 0.21 |
| | 2.0 | 13.5 | 1.41 | 10.4 | 1.26 | 0.84 | 0.55 | 77.0 | 0.38 | 0.23 |
| 700 | 0.5 | 14.1 | 1.13 | 7.9 | 0.92 | 0.54 | 0.28 | 56.0 | 0.22 | 0.19 |
| | 1.0 | 15.1 | 1.28 | 8.4 | 1.02 | 0.63 | 0.36 | 62.0 | 0.25 | 0.19 |
| | 1.5 | 15.5 | 1.39 | 9.0 | 1.13 | 0.72 | 0.44 | 68.5 | 0.28 | 0.20 |
| | 2.0 | 15.2 | 1.46 | 9.6 | 1.26 | 0.84 | 0.55 | 77.0 | 0.32 | 0.22 |
| 800 | 0.5 | 15.6 | 1.22 | 7.7 | 0.92 | 0.54 | 0.28 | 56.0 | 0.21 | 0.18 |
| | 1.0 | 16.7 | 1.36 | 8.1 | 1.02 | 0.63 | 0.36 | 62.0 | 0.22 | 0.18 |
| | 1.5 | 17.2 | 1.46 | 8.5 | 1.13 | 0.72 | 0.44 | 68.5 | 0.24 | 0.19 |
| | 2.0 | 16.8 | 1.51 | 9.0 | 1.26 | 0.84 | 0.55 | 77.0 | 0.28 | 0.20 |
| 900 | 0.5 | 17.1 | 1.31 | 7.5 | 0.92 | 0.54 | 0.28 | 56.0 | 0.21 | 0.18 |
| | 1.0 | 18.3 | 1.44 | 7.8 | 1.02 | 0.63 | 0.36 | 62.0 | 0.22 | 0.18 |
| | 1.5 | 18.8 | 1.53 | 8.1 | 1.13 | 0.72 | 0.44 | 68.5 | 0.22 | 0.19 |
| | 2.0 | 18.3 | 1.56 | 8.5 | 1.26 | 0.84 | 0.55 | 77.0 | 0.25 | 0.19 |
| 1000 | 0.5 | 18.5 | 1.39 | 7.4 | 0.92 | 0.54 | 0.28 | 56.0 | 0.20 | 0.19 |
| | 1.0 | 19.8 | 1.51 | 7.6 | 1.02 | 0.63 | 0.36 | 62.0 | 0.20 | 0.18 |
| | 1.5 | 20.3 | 1.59 | 7.8 | 1.13 | 0.72 | 0.44 | 68.5 | 0.21 | 0.18 |
| | 2.0 | 19.8 | 1.61 | 8.1 | 1.26 | 0.84 | 0.55 | 77.0 | 0.22 | 0.19 |
| *Large-frame heifer calves and compensating medium-frame yearling heifers* | | | | | | | | | | |
| 300 | 0.5 | 7.8 | 0.76 | 9.5 | 0.89 | 0.50 | 0.25 | 54.0 | 0.31 | 0.20 |
| | 1.0 | 8.4 | 0.95 | 11.3 | 0.98 | 0.58 | 0.32 | 59.0 | 0.45 | 0.24 |
| | 1.5 | 8.8 | 1.13 | 13.0 | 1.05 | 0.65 | 0.39 | 64.0 | 0.58 | 0.25 |
| | 2.0 | 8.9 | 1.30 | 14.6 | 1.14 | 0.74 | 0.46 | 69.5 | 0.69 | 0.30 |
| | 2.5 | 8.7 | 1.45 | 16.7 | 1.26 | 0.84 | 0.55 | 77.0 | 0.86 | 0.35 |
| 400 | 0.5 | 9.7 | 0.87 | 8.9 | 0.89 | 0.50 | 0.25 | 54.0 | 0.27 | 0.18 |
| | 1.0 | 10.5 | 1.06 | 10.1 | 0.98 | 0.58 | 0.32 | 59.0 | 0.36 | 0.21 |
| | 1.5 | 10.9 | 1.23 | 11.3 | 1.05 | 0.65 | 0.39 | 64.0 | 0.45 | 0.22 |
| | 2.0 | 11.1 | 1.38 | 12.6 | 1.14 | 0.74 | 0.46 | 69.5 | 0.54 | 0.26 |
| | 2.5 | 10.8 | 1.51 | 14.1 | 1.26 | 0.84 | 0.55 | 77.0 | 0.65 | 0.31 |
| 500 | 0.5 | 11.5 | 0.98 | 8.4 | 0.89 | 0.50 | 0.25 | 54.0 | 0.23 | 0.17 |
| | 1.0 | 12.4 | 1.16 | 9.4 | 0.98 | 0.58 | 0.32 | 59.0 | 0.30 | 0.20 |
| | 1.5 | 12.9 | 1.32 | 10.3 | 1.05 | 0.65 | 0.39 | 64.0 | 0.38 | 0.20 |
| | 2.0 | 13.1 | 1.46 | 11.2 | 1.14 | 0.74 | 0.46 | 69.5 | 0.44 | 0.24 |
| | 2.5 | 12.8 | 1.57 | 12.4 | 1.26 | 0.84 | 0.55 | 77.0 | 0.53 | 0.26 |
| 600 | 0.5 | 13.2 | 1.08 | 8.1 | 0.89 | 0.50 | 0.25 | 54.0 | 0.22 | 0.18 |
| | 1.0 | 14.1 | 1.25 | 8.9 | 0.98 | 0.58 | 0.32 | 59.0 | 0.28 | 0.19 |

TABLE 10 Nutrient Requirements for Growing and Finishing Cattle (Nutrient Concentration in Diet Dry Matter, avoirdupois system)[a,b,c]—*Continued*

| Weight (lb) | Daily Gain (lb) | Dry Matter Intake (lb) | Protein Intake (lb) | Protein (%) | ME (Mcal/lb) | $NE_m$ (Mcal/lb) | $NE_g$ (Mcal/lb) | TDN (%) | Ca (%) | P (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1.5 | 14.8 | 1.41 | 9.6 | 1.05 | 0.65 | 0.39 | 64.0 | 0.33 | 0.19 |
| | 2.0 | 15.0 | 1.54 | 10.3 | 1.14 | 0.74 | 0.46 | 69.5 | 0.38 | 0.22 |
| | 2.5 | 14.6 | 1.63 | 11.2 | 1.26 | 0.84 | 0.55 | 77.0 | 0.44 | 0.24 |
| 700 | 0.5 | 14.8 | 1.18 | 7.9 | 0.89 | 0.50 | 0.25 | 54.0 | 0.21 | 0.18 |
| | 1.0 | 15.9 | 1.34 | 8.5 | 0.98 | 0.58 | 0.32 | 59.0 | 0.25 | 0.18 |
| | 1.5 | 16.6 | 1.49 | 9.0 | 1.05 | 0.65 | 0.39 | 64.0 | 0.29 | 0.19 |
| | 2.0 | 16.8 | 1.61 | 9.6 | 1.14 | 0.74 | 0.46 | 69.5 | 0.33 | 0.20 |
| | 2.5 | 16.4 | 1.68 | 10.3 | 1.26 | 0.84 | 0.55 | 77.0 | 0.38 | 0.22 |
| 800 | 0.5 | 16.4 | 1.27 | 7.7 | 0.89 | 0.50 | 0.25 | 54.0 | 0.20 | 0.17 |
| | 1.0 | 17.6 | 1.43 | 8.2 | 0.98 | 0.58 | 0.32 | 59.0 | 0.24 | 0.18 |
| | 1.5 | 18.3 | 1.57 | 8.6 | 1.05 | 0.65 | 0.39 | 64.0 | 0.25 | 0.18 |
| | 2.0 | 18.6 | 1.67 | 9.0 | 1.14 | 0.74 | 0.46 | 69.5 | 0.28 | 0.19 |
| | 2.5 | 18.1 | 1.74 | 9.6 | 1.26 | 0.84 | 0.55 | 77.0 | 0.33 | 0.21 |
| 900 | 0.5 | 17.8 | 1.36 | 7.5 | 0.89 | 0.50 | 0.25 | 54.0 | 0.20 | 0.18 |
| | 1.0 | 19.2 | 1.52 | 7.9 | 0.98 | 0.58 | 0.32 | 59.0 | 0.22 | 0.18 |
| | 1.5 | 20.0 | 1.64 | 8.2 | 1.05 | 0.65 | 0.39 | 64.0 | 0.23 | 0.18 |
| | 2.0 | 20.3 | 1.74 | 8.6 | 1.14 | 0.74 | 0.46 | 69.5 | 0.26 | 0.18 |
| | 2.5 | 19.8 | 1.78 | 9.0 | 1.26 | 0.84 | 0.55 | 77.0 | 0.29 | 0.20 |
| 1000 | 0.5 | 19.3 | 1.45 | 7.4 | 0.89 | 0.50 | 0.25 | 54.0 | 0.19 | 0.18 |
| | 1.0 | 20.8 | 1.60 | 7.7 | 0.98 | 0.58 | 0.32 | 59.0 | 0.21 | 0.18 |
| | 1.5 | 21.7 | 1.71 | 8.0 | 1.05 | 0.65 | 0.39 | 64.0 | 0.21 | 0.18 |
| | 2.0 | 22.0 | 1.80 | 8.2 | 1.14 | 0.74 | 0.46 | 69.5 | 0.23 | 0.18 |
| | 2.5 | 21.5 | 1.83 | 8.6 | 1.26 | 0.84 | 0.55 | 77.0 | 0.25 | 0.18 |
| 1100 | 0.5 | 20.8 | 1.54 | 7.3 | 0.89 | 0.50 | 0.25 | 54.0 | 0.19 | 0.18 |
| | 1.0 | 22.3 | 1.68 | 7.5 | 0.98 | 0.58 | 0.32 | 59.0 | 0.20 | 0.18 |
| | 1.5 | 23.3 | 1.78 | 7.7 | 1.05 | 0.65 | 0.39 | 64.0 | 0.20 | 0.18 |
| | 2.0 | 23.6 | 1.86 | 7.9 | 1.14 | 0.74 | 0.46 | 69.5 | 0.21 | 0.18 |
| | 2.5 | 23.1 | 1.88 | 8.2 | 1.26 | 0.84 | 0.55 | 77.0 | 0.22 | 0.18 |

[a]Shrunk liveweight basis, see text.

[b]Vitamin A requirements are 1000 IU per pound of diet.

[c]This table gives reasonable examples of nutrient concentrations that should be suitable to formulate diets for specific management goals. It does not imply that diets with other nutrient concentrations when consumed in sufficient amounts would be inadequate to meet nutrient requirements.

TABLE 11 Nutrient Requirements of Breeding Cattle (avoirdupois system)

| | | | Energy | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Daily | | | | In Diet DM | | | | Total Protein | | Calcium | | Phosphorus | | Vitamin A[d] |
| Weight[a] (lb) | Gain[b] (lb) | Daily DM[c] (lb) | ME (Mcal) | TDN (lb) | $NE_m$ (Mcal) | $NE_g$ (Mcal) | ME (Mcal/lb) | TDN (%) | $NE_m$ (Mcal/lb) | $NE_g$ (Mcal/lb) | Daily (lb) | In Diet DM (%) | Daily (g) | In Diet DM (%) | Daily (g) | In Diet DM (%) | Daily (1000's IU) |
| *Pregnant yearling heifers—Last third of pregnancy* | | | | | | | | | | | | | | | | | |
| 700 | 0.9 | 15.3 | 13.9 | 8.5 | 7.95 | NA[e] | 0.91 | 55.4 | 0.52 | NA[e] | 1.3 | 8.4 | 19 | 0.27 | 14 | 0.20 | 19 |
| 700 | 1.4 | 15.8 | 15.7 | 9.6 | 7.95 | 0.87 | 0.99 | 60.3 | 0.60 | 0.34 | 1.4 | 9.0 | 24 | 0.33 | 15 | 0.21 | 20 |
| 700 | 1.9 | 15.8 | 17.4 | 10.6 | 7.95 | 1.89 | 1.10 | 67.0 | 0.70 | 0.43 | 1.5 | 9.8 | 27 | 0.33 | 16 | 0.21 | 20 |
| 750 | 0.9 | 16.1 | 14.6 | 8.9 | 8.25 | NA | 0.90 | 55.1 | 0.52 | NA | 1.3 | 8.3 | 20 | 0.27 | 14 | 0.19 | 20 |
| 750 | 1.4 | 16.6 | 16.4 | 10.0 | 8.25 | 0.92 | 0.98 | 59.9 | 0.60 | 0.33 | 1.5 | 8.9 | 24 | 0.32 | 16 | 0.21 | 21 |
| 750 | 1.9 | 16.6 | 18.2 | 11.1 | 8.25 | 1.99 | 1.09 | 66.5 | 0.69 | 0.42 | 1.6 | 9.5 | 28 | 0.37 | 17 | 0.23 | 21 |
| 800 | 0.9 | 16.8 | 15.2 | 9.2 | 8.56 | NA | 0.90 | 54.8 | 0.51 | NA | 1.4 | 8.2 | 21 | 0.28 | 15 | 0.20 | 21 |
| 800 | 1.4 | 17.4 | 17.1 | 10.4 | 8.56 | 0.96 | 0.98 | 59.6 | 0.59 | 0.33 | 1.5 | 8.8 | 25 | 0.33 | 16 | 0.21 | 22 |
| 800 | 1.9 | 17.5 | 19.0 | 11.6 | 8.56 | 2.09 | 1.08 | 66.1 | 0.69 | 0.42 | 1.6 | 9.3 | 28 | 0.35 | 17 | 0.21 | 22 |
| 850 | 0.9 | 17.6 | 15.7 | 9.6 | 8.85 | NA | 0.89 | 54.5 | 0.51 | NA | 1.4 | 8.2 | 21 | 0.26 | 16 | 0.20 | 22 |
| 850 | 1.4 | 18.2 | 17.8 | 10.8 | 8.85 | 1.01 | 0.97 | 59.3 | 0.59 | 0.32 | 1.6 | 8.6 | 25 | 0.30 | 17 | 0.21 | 23 |
| 850 | 1.9 | 18.3 | 19.8 | 12.1 | 8.85 | 2.19 | 1.08 | 65.7 | 0.68 | 0.41 | 1.7 | 9.1 | 28 | 0.34 | 18 | 0.22 | 23 |
| 900 | 0.9 | 18.3 | 16.3 | 9.9 | 9.15 | NA | 0.89 | 54.3 | 0.51 | NA | 1.5 | 8.1 | 22 | 0.26 | 17 | 0.20 | 23 |
| 900 | 1.4 | 19.0 | 18.5 | 11.3 | 9.15 | 1.05 | 0.97 | 59.1 | 0.58 | 0.32 | 1.6 | 8.5 | 26 | 0.30 | 18 | 0.21 | 24 |
| 900 | 1.9 | 19.2 | 20.6 | 12.5 | 9.15 | 2.28 | 1.07 | 65.4 | 0.68 | 0.41 | 1.7 | 9.0 | 28 | 0.32 | 19 | 0.21 | 24 |
| 950 | 0.9 | 19.0 | 16.9 | 10.3 | 9.44 | NA | 0.89 | 54.1 | 0.50 | NA | 1.5 | 8.0 | 23 | 0.27 | 17 | 0.20 | 24 |
| 950 | 1.4 | 19.8 | 19.1 | 11.7 | 9.44 | 1.09 | 0.97 | 58.9 | 0.58 | 0.32 | 1.7 | 8.4 | 26 | 0.29 | 19 | 0.21 | 25 |
| 950 | 1.9 | 20.0 | 21.3 | 13.0 | 9.44 | 2.38 | 1.07 | 65.1 | 0.67 | 0.40 | 1.8 | 8.8 | 29 | 0.32 | 19 | 0.21 | 25 |
| *Dry pregnant mature cows—Middle third of pregnancy* | | | | | | | | | | | | | | | | | |
| 800 | 0.0 | 15.3 | 12.3 | 7.5 | 6.41 | NA | 0.80 | 48.8 | 0.42 | NA | 1.1 | 7.1 | 12 | 0.17 | 12 | 0.17 | 19 |
| 900 | 0.0 | 16.7 | 13.4 | 8.2 | 7.00 | NA | 0.80 | 48.8 | 0.42 | NA | 1.2 | 7.0 | 14 | 0.18 | 14 | 0.18 | 21 |
| 1000 | 0.0 | 18.1 | 14.5 | 8.8 | 7.57 | NA | 0.80 | 48.8 | 0.42 | NA | 1.3 | 7.0 | 15 | 0.18 | 15 | 0.18 | 23 |
| 1100 | 0.0 | 19.5 | 15.6 | 9.5 | 8.13 | NA | 0.80 | 48.8 | 0.42 | NA | 1.4 | 7.0 | 17 | 0.19 | 17 | 0.19 | 25 |
| 1200 | 0.0 | 20.8 | 16.6 | 10.1 | 8.68 | NA | 0.80 | 48.8 | 0.42 | NA | 1.4 | 6.9 | 18 | 0.19 | 18 | 0.19 | 26 |
| 1300 | 0.0 | 22.0 | 17.7 | 10.8 | 9.22 | NA | 0.80 | 48.8 | 0.42 | NA | 1.5 | 6.9 | 20 | 0.20 | 20 | 0.20 | 28 |
| 1400 | 0.0 | 23.3 | 18.7 | 11.4 | 9.75 | NA | 0.80 | 48.8 | 0.42 | NA | 1.6 | 6.9 | 21 | 0.20 | 21 | 0.20 | 30 |
| *Dry pregnant mature cows—Last third of pregnancy* | | | | | | | | | | | | | | | | | |
| 800 | 0.9 | 16.8 | 15.0 | 9.2 | 8.56 | NA | 0.89 | 54.5 | 0.51 | NA | 1.4 | 8.2 | 20 | 0.26 | 15 | 0.20 | 21 |
| 900 | 0.9 | 18.2 | 16.2 | 9.8 | 9.15 | NA | 0.89 | 54.0 | 0.50 | NA | 1.5 | 8.0 | 22 | 0.27 | 17 | 0.21 | 23 |
| 1000 | 0.9 | 19.6 | 17.3 | 10.5 | 9.72 | NA | 0.88 | 53.6 | 0.50 | NA | 1.6 | 7.9 | 23 | 0.26 | 18 | 0.20 | 25 |
| 1100 | 0.9 | 21.0 | 18.3 | 11.2 | 10.28 | NA | 0.87 | 53.2 | 0.49 | NA | 1.6 | 7.8 | 25 | 0.26 | 20 | 0.21 | 26 |
| 1200 | 0.9 | 22.3 | 19.4 | 11.8 | 10.83 | NA | 0.87 | 52.9 | 0.49 | NA | 1.7 | 7.8 | 26 | 0.26 | 21 | 0.21 | 28 |
| 1300 | 0.9 | 23.6 | 20.4 | 12.5 | 11.37 | NA | 0.87 | 52.7 | 0.48 | NA | 1.8 | 7.7 | 28 | 0.26 | 23 | 0.21 | 30 |
| 1400 | 0.9 | 24.9 | 21.5 | 13.1 | 11.90 | NA | 0.86 | 52.5 | 0.48 | NA | 1.9 | 7.6 | 29 | 0.26 | 24 | 0.21 | 32 |
| *Two-year-old heifers nursing calves—First 3–4 months postpartum—10 lb milk/day* | | | | | | | | | | | | | | | | | |
| 700 | 0.5 | 15.9 | 17.0 | 10.3 | 9.20[f] | 0.87 | 1.07 | 65.1 | 0.67 | 0.40 | 1.8[g] | 11.3 | 26 | 0.36 | 17 | 0.24 | 28 |
| 750 | 0.5 | 16.7 | 17.7 | 10.8 | 9.51[f] | 0.92 | 1.06 | 64.4 | 0.66 | 0.40 | 1.8[g] | 11.0 | 26 | 0.34 | 18 | 0.24 | 30 |
| 800 | 0.5 | 17.6 | 18.4 | 11.2 | 9.81[f] | 0.96 | 1.05 | 63.8 | 0.66 | 0.39 | 1.9[g] | 10.8 | 27 | 0.34 | 19 | 0.24 | 31 |
| 850 | 0.5 | 18.4 | 19.1 | 11.6 | 10.11[f] | 1.01 | 1.04 | 63.2 | 0.65 | 0.38 | 1.9[g] | 10.6 | 27 | 0.33 | 19 | 0.23 | 33 |
| 900 | 0.5 | 19.2 | 19.8 | 12.0 | 10.40[f] | 1.05 | 1.03 | 62.7 | 0.64 | 0.37 | 2.0[g] | 10.4 | 28 | 0.32 | 20 | 0.23 | 34 |
| 950 | 0.5 | 20.0 | 20.5 | 12.5 | 10.69[f] | 1.09 | 1.02 | 62.3 | 0.63 | 0.37 | 2.0[g] | 10.2 | 28 | 0.31 | 21 | 0.23 | 35 |
| 1000 | 0.5 | 20.8 | 21.1 | 12.9 | 10.98[f] | 1.14 | 1.02 | 61.9 | 0.62 | 0.36 | 2.1[g] | 10.0 | 29 | 0.31 | 22 | 0.23 | 37 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Cows nursing calves—Average milking ability—First 3-4 months postpartum—10 lb milk/day* | | | | | | | | | | | | | | | | | |
| 800 | 0.0 | 17.3 | 16.6 | 10.1 | 9.81[f] | NA | 0.96 | 58.2 | 0.57 | NA | 1.8[g] | 10.2 | 23 | 0.30 | 17 | 0.22 | 31 |
| 900 | 0.0 | 18.8 | 17.7 | 10.8 | 10.40[f] | NA | 0.94 | 57.3 | 0.55 | NA | 1.9[g] | 9.9 | 24 | 0.28 | 19 | 0.22 | 33 |
| 1000 | 0.0 | 20.2 | 18.8 | 11.5 | 10.98[f] | NA | 0.93 | 56.6 | 0.55 | NA | 2.0[g] | 9.6 | 25 | 0.28 | 20 | 0.22 | 36 |
| 1100 | 0.0 | 21.6 | 19.9 | 12.1 | 11.54[f] | NA | 0.92 | 56.0 | 0.54 | NA | 2.0[g] | 9.4 | 27 | 0.27 | 22 | 0.22 | 38 |
| 1200 | 0.0 | 23.0 | 21.0 | 12.8 | 12.09[f] | NA | 0.91 | 55.5 | 0.53 | NA | 2.1[g] | 9.3 | 28 | 0.27 | 23 | 0.22 | 41 |
| 1300 | 0.0 | 24.3 | 22.0 | 13.4 | 12.63[f] | NA | 0.90 | 55.1 | 0.52 | NA | 2.2[g] | 9.1 | 30 | 0.27 | 25 | 0.22 | 43 |
| 1400 | 0.0 | 25.6 | 23.0 | 14.0 | 13.15[f] | NA | 0.90 | 54.7 | 0.51 | NA | 2.3[g] | 9.0 | 31 | 0.27 | 26 | 0.22 | 46 |
| *Cows nursing calves—Superior milking ability—First 3-4 months postpartum—20 lb milk/day* | | | | | | | | | | | | | | | | | |
| 800 | 0.0 | 15.7 | 19.9 | 12.1 | 13.22[f] | NA | 1.27 | 77.3 | 0.85 | NA | 2.2[g] | 14.2 | 34 | 0.48 | 22 | 0.31 | 28 |
| 900 | 0.0 | 18.7 | 21.5 | 13.1 | 13.81[f] | NA | 1.15 | 69.8 | 0.74 | NA | 2.4[g] | 12.9 | 35 | 0.41 | 24 | 0.28 | 33 |
| 1000 | 0.0 | 20.6 | 22.7 | 13.8 | 14.38[f] | NA | 1.10 | 67.0 | 0.70 | NA | 2.5[g] | 12.3 | 36 | 0.39 | 25 | 0.27 | 37 |
| 1100 | 0.0 | 22.3 | 23.8 | 14.5 | 14.94[f] | NA | 1.07 | 65.2 | 0.67 | NA | 2.6[g] | 11.9 | 38 | 0.38 | 27 | 0.27 | 40 |
| 1200 | 0.0 | 23.8 | 24.9 | 15.2 | 15.49[f] | NA | 1.05 | 63.7 | 0.65 | NA | 2.7[g] | 11.5 | 39 | 0.36 | 28 | 0.26 | 42 |
| 1300 | 0.0 | 25.3 | 26.0 | 15.9 | 16.03[f] | NA | 1.03 | 62.6 | 0.64 | NA | 2.8[g] | 11.2 | 41 | 0.36 | 30 | 0.26 | 45 |
| 1400 | 0.0 | 26.7 | 27.1 | 16.5 | 16.56[f] | NA | 1.01 | 61.7 | 0.62 | NA | 2.9[g] | 11.0 | 42 | 0.35 | 31 | 0.26 | 47 |
| *Bulls, maintenance and slow rate of growth (regain body condition)* | | | | | | | | | | | | | | | | | |
| <1300 | For growth and development use requirements for bulls in Tables 1, 2, 3, and 10. | | | | | | | | | | | | | | | | |
| 1300 | 1.0 | 25.4 | 23.3 | 14.2 | 9.22 | 2.20 | 0.92 | 55.8 | 0.53 | 0.28 | 1.9 | 7.6 | 25 | 0.22 | 22 | 0.19 | 45 |
| 1300 | 1.5 | 26.1 | 25.5 | 15.6 | 9.22 | 3.43 | 0.98 | 59.7 | 0.59 | 0.33 | 2.0 | 7.9 | 28 | 0.24 | 23 | 0.19 | 46 |
| 1300 | 2.0 | 26.2 | 27.6 | 16.8 | 9.22 | 4.71 | 1.05 | 64.0 | 0.65 | 0.39 | 2.2 | 8.2 | 31 | 0.26 | 24 | 0.20 | 46 |
| 1400 | 1.0 | 26.8 | 24.6 | 15.0 | 9.75 | 2.33 | 0.92 | 55.8 | 0.53 | 0.28 | 2.0 | 7.5 | 26 | 0.21 | 23 | 0.19 | 48 |
| 1400 | 1.5 | 27.6 | 27.0 | 16.5 | 9.75 | 3.63 | 0.98 | 59.7 | 0.59 | 0.33 | 2.1 | 7.7 | 29 | 0.23 | 24 | 0.19 | 49 |
| 1400 | 2.0 | 27.7 | 29.1 | 17.8 | 9.75 | 4.98 | 1.05 | 64.0 | 0.65 | 0.39 | 2.2 | 8.0 | 31 | 0.25 | 25 | 0.20 | 49 |
| 1500 | 0.0 | 25.2 | 20.0 | 12.2 | 10.26 | NA | 0.79 | 48.4 | 0.41 | NA | 1.7 | 6.9 | 23 | 0.20 | 23 | 0.20 | 45 |
| 1500 | 1.0 | 28.3 | 25.9 | 15.8 | 10.26 | 2.45 | 0.92 | 55.8 | 0.53 | 0.28 | 2.1 | 7.4 | 27 | 0.21 | 24 | 0.19 | 50 |
| 1500 | 1.5 | 29.0 | 28.4 | 17.3 | 10.26 | 3.82 | 0.98 | 59.7 | 0.59 | 0.33 | 2.2 | 7.6 | 29 | 0.22 | 25 | 0.19 | 51 |
| 1600 | 0.0 | 26.5 | 21.0 | 12.8 | 10.77 | NA | 0.79 | 48.4 | 0.41 | NA | 1.8 | 6.9 | 23 | 0.19 | 24 | 0.20 | 47 |
| 1600 | 1.0 | 29.7 | 27.2 | 16.6 | 10.77 | 2.57 | 0.92 | 55.8 | 0.53 | 0.28 | 2.2 | 7.3 | 29 | 0.22 | 26 | 0.19 | 53 |
| 1600 | 1.5 | 30.4 | 29.8 | 18.2 | 10.77 | 4.01 | 0.98 | 59.7 | 0.59 | 0.33 | 2.3 | 7.4 | 31 | 0.22 | 27 | 0.20 | 54 |
| 1700 | 0.0 | 27.7 | 22.0 | 13.4 | 11.28 | NA | 0.79 | 48.4 | 0.41 | NA | 1.9 | 6.8 | 26 | 0.21 | 26 | 0.21 | 49 |
| 1700 | 0.5 | 29.6 | 25.3 | 15.4 | 11.28 | 1.26 | 0.85 | 52.0 | 0.47 | 0.22 | 2.1 | 7.0 | 27 | 0.20 | 26 | 0.19 | 52 |
| 1800 | 0.0 | 28.9 | 23.0 | 14.0 | 11.77 | NA | 0.79 | 48.4 | 0.41 | NA | 2.0 | 6.8 | 27 | 0.21 | 27 | 0.21 | 51 |
| 1800 | 0.5 | 30.9 | 26.4 | 16.1 | 11.77 | 1.31 | 0.85 | 52.0 | 0.47 | 0.22 | 2.2 | 7.0 | 28 | 0.20 | 28 | 0.20 | 55 |
| 1900 | 0.0 | 30.1 | 23.9 | 14.6 | 12.26 | NA | 0.79 | 48.4 | 0.41 | NA | 2.0 | 6.8 | 29 | 0.21 | 29 | 0.21 | 53 |
| 1900 | 0.5 | 32.2 | 27.5 | 16.8 | 12.26 | 1.37 | 0.85 | 52.0 | 0.47 | 0.22 | 2.2 | 6.9 | 29 | 0.20 | 29 | 0.20 | 57 |
| 2000 | 0.0 | 31.3 | 24.9 | 15.2 | 12.74 | NA | 0.79 | 48.4 | 0.41 | NA | 2.1 | 6.8 | 30 | 0.21 | 30 | 0.21 | 55 |
| 2100 | 0.0 | 32.5 | 25.8 | 15.7 | 13.21 | NA | 0.79 | 48.4 | 0.41 | NA | 2.2 | 6.8 | 32 | 0.22 | 32 | 0.22 | 58 |
| 2200 | 0.0 | 33.6 | 26.7 | 16.3 | 13.68 | NA | 0.79 | 48.4 | 0.41 | NA | 2.3 | 6.8 | 33 | 0.22 | 33 | 0.22 | 60 |

[a] Average weight for a feeding period.

[b] Approximately 0.9 ± 0.2 lb of weight gain/day over the last third of pregnancy is accounted for by the products of conception. Daily 2.15 Mcal of $NE_m$ and 0.1 lb of protein are provided for this requirement for a calf with a birth weight of 80 lb.

[c] Dry matter consumption should vary depending on the energy concentration of the diet and environmental conditions. These intakes are based on the energy concentration shown in the table and assuming a thermoneutral environment without snow or mud conditions. If the energy concentrations of the diet to be fed exceed the tabular value, limit feeding may be required.

[d] Vitamin A requirements per pound of diet are 1273 IU for pregnant heifers and cows and 1773 for lactating cows and breeding bulls.

[e] Not applicable.

[f] Includes 0.34 Mcal $NE_m$/lb of milk produced.

[g] Includes 0.03 lb protein/lb of milk produced.

# Index